Geology in the Vicinity of Fordwick, Virginia.

Lehigh University Bethlehem, Pa.

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Figure 1
PANORAMA - FORDWICK AND BROWN RIDGE

GEOLOGY IN THE VICINITY OF FORDWICK, VIRGINIA

by

Carl Andrew Warmkessel

A DISSERTATION

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of Lehigh University

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GEOLOGY IN THE VICINITY OF FORDWICK, VIRGINIA

INTRODUCTION

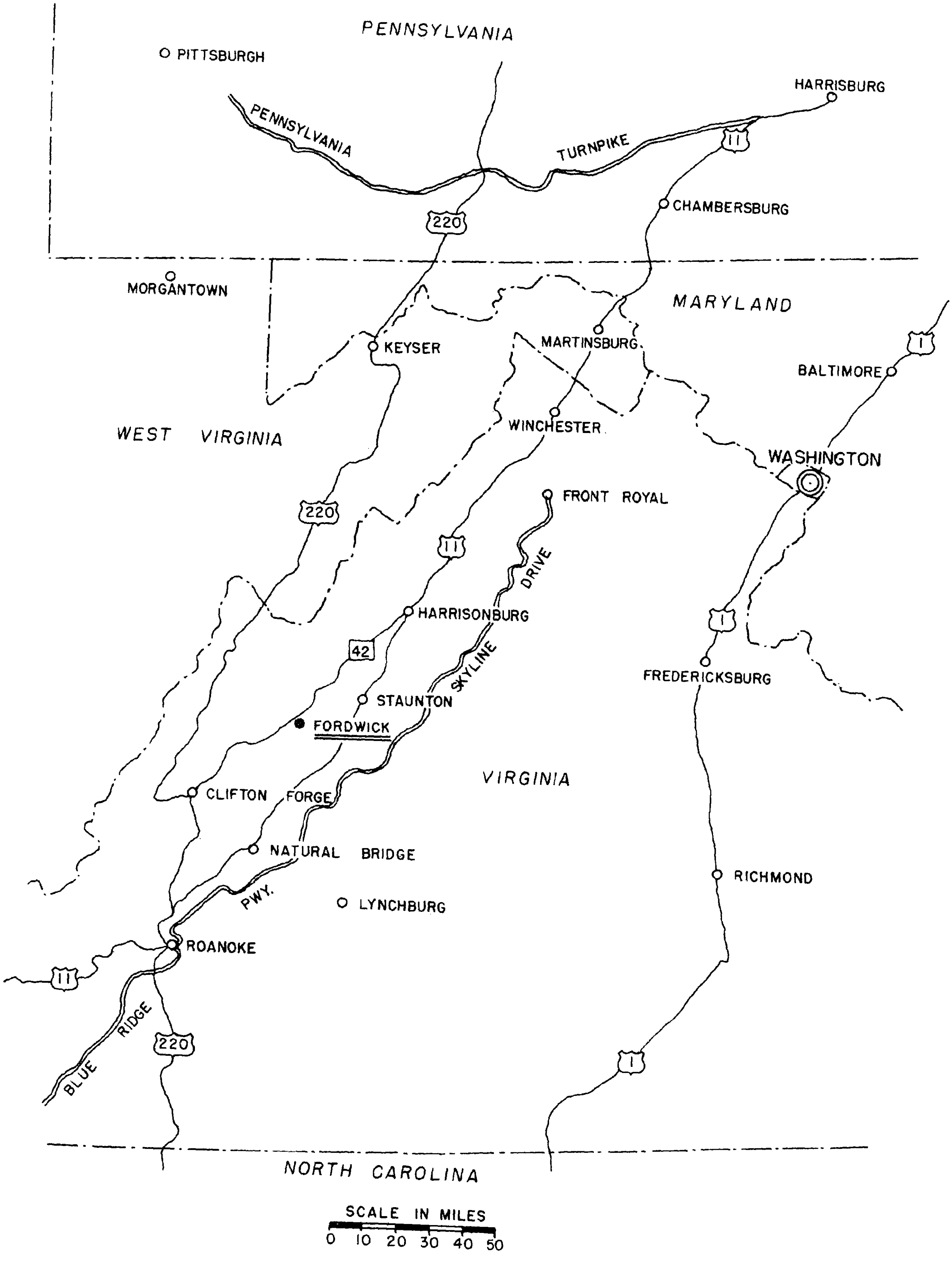
The Fordwick, Virginia, area described is located about twenty miles southwest of Staunton, Virginia, and lies between latitude 38°2' North and 38°7' North and longitudes 79°19' West and 79°26' West (see Figure 2). The area is approximately seven miles long and two and a half miles wide, most of which lies in Augusta County with a small portion extending southwestward into Rockbridge County. It is in the southern half of the Craigsville, Virginia, topographic quadrangle of the United States Geological Survey. The area covers approximately eighteen square miles of the Middle Section of the Valley and Ridge physiographic province.

The town of Craigsville is located on the northwest side of the area described. The town of Fordwick and the Lehigh Portland Cement Company's Fordwick plant are located about one mile southeast of Craigsville in the valley between Black Oak Ridge and Brown Ridge. Black Oak Ridge separates the towns of Craigsville and Fordwick.

The rocks of the Fordwick area consist of limestones, dolomites, cherty limestones, sandstones and shales of the late Silurian and Devonian ages. All have been folded and faulted.

MAP SHOWING LOCATION OF FORDWICK, VIRGINIA

Figure 2



The purpose of this paper is to present a detailed geological map of Fordwick, Virginia, and vicinity and to prove the value of chemical analyses as a means of correlation of beds and determination of geologic structure. The writer has been using chemical analyses for detailed interpretation of geologic structure in the Fordwick area for the past eleven years. The first detailed chemical correlation on the area was made in 1940 during an exploratory drilling program conducted by the Lehigh Portland Cement Company. Additional work has been done in the area intermittently from 1940 until the present time. Quarry operations have proven that the structural interpretations made in 1940 solely on the basis of chemical analyses are correct in every detail.

PHYSIOGRAPHY

Drainage

The principal stream of the Craigsville quadrangle is the Calfpasture River which flows southwestward across the quadrangle in the valley northwest of Great North Mountain. The Fordwick area is drained by the Little Calfpasture River which flows southwestward in the valley southeast of Great North Mountain. Several small streams flow approximately parallel to these two rivers. Numerous brooks flowing approximately perpendicular to the major drainage of the area form the overall, typical trellis drainage pattern. This follows the geological structure which trends northeast and southwest throughout the entire quadrangle.

The Calfpasture River is physiographically the oldest stream in the Craigsville quadrangle and is in the stage of middle to late maturity in the erosion cycle. The Little Calfpasture River, not having developed an appreciable flood plain as yet, is in early maturity.

Relief

Within the Craigsville quadrangle the elevations range from approximately 1,460 feet above sea level, at the southwest end of Estaline Valley, to 4,458 feet above sea level at Elliott Knob on Great North Mountain. This is a relief of 2,998 feet. Most of the mountain crests are about 3,100 feet above sea level, and the valley floor elevations range from about 1,500 to 1,650 feet. In the Fordwick area the elevations range from 1,460 to about 1,850 feet above sea level on Black Oak Ridge and about 2,000 feet on Brown Ridge. The maximum relief is approximately 540 feet.

The most conspicuous topographic feature of the quadrangle is Elliott Knob on Great North Mountain eight miles northeast of Fordwick. Other prominent topographic features are Great North Mountain in the center of the quadrangle, Shenandoah Mountain to the northwest and Little North Mountain to the southeast. In the Fordwick area, Black Oak Ridge and Brown Ridge are prominent. These two ridges rise from the floor of the large valley between Great North and Little North Mountains. Little Calfpasture River separates the Black Oak and Brown ridges southwestward from Fordwick.

The area is now in the mature stage of the second cycle of erosion. The first erosion cycle reduced all of the area to base level, with the exception of Elliott Knob on Great North Mountain which remained as a monadnock. Elliott Knob was a sandstone and conglomerate hill still remaining above the peneplane at the time the general uplift started the second cycle of erosion. The present relief has been etched during the second cycle.

The effect of the bedrock upon the topography is well illustrated throughout the Craigsville topographic quadrangle. In general, sandstones and conglomerates form the mountain crests; shales the shoulders of the mountains and some of the valleys; the limestones underly the valleys. The above statement, while generally applicable to the Craigsville quadrangle as a whole, does not apply to the area in the vicinity of the towns of Craigsville and Fordwick where regional structure, as well as bedrock, have controlled the topography. Brown Ridge and Black Oak Ridge are anticlinal hills separated by the synclinal valley of the Little Calfpasture River. The softer overlying shales have been removed and now the underlying sandstones have slowed the rate of erosion, so that they not only form the ridge crests but are also found in the floor of the Little Calfpasture River valley.

GENERAL GEOLOGY OF WESTERN VIRGINIA

PHYSIOGRAPHY

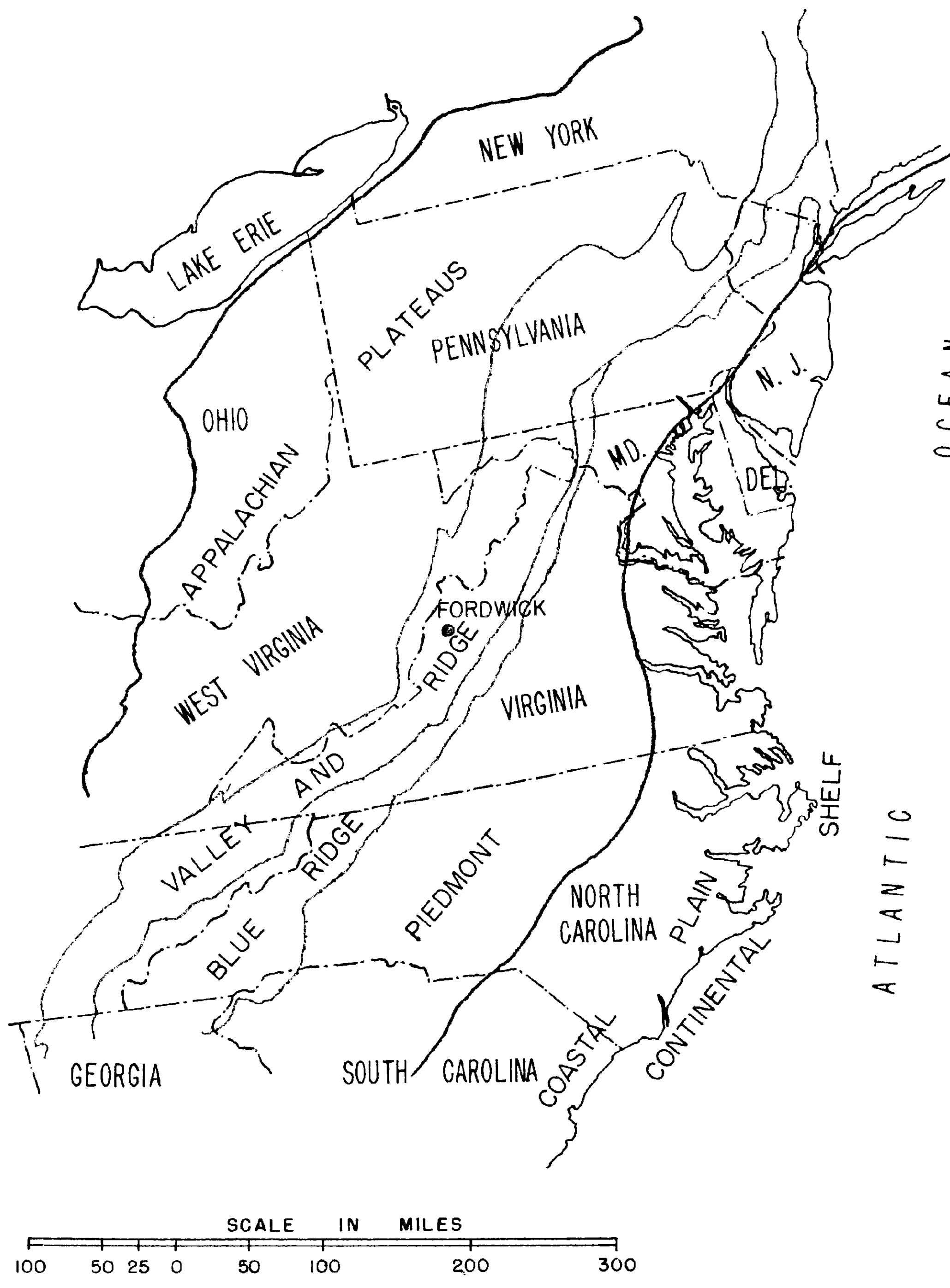
There are two major physiographic divisions in Virginia. The Atlantic Coastal Plain includes the belt of land 60 to 80 miles wide adjacent to the Atlantic Ocean and the Continental Shelf. The balance of the state lies within the Appalachian Highlands. The latter term is broadly used to include several well defined physiographic provinces. (See Figure 3.) From the southeast to the northwest these provinces are: The Piedmont Province, a dissected upland varying in width from 40 miles at the northern part of the state to about 170 miles along the southern border. The Blue Ridge Province, a relatively narrow ridge in the northern part of the state which develops into a rolling plateau 10 to 65 miles wide in the southern part of the state. The Valley and Ridge Province, a series of parallel valleys and ridges forming a northeast-southwest trending belt along the length of the state. The Appalachian Plateau Province is the westernmost physiographic province of Virginia. The plateau is 2,000 feet or more above sea level and has been dissected into a maze of deep ravines and sharp hills and ridges.

Figure 3

MAJOR PHYSIOGRAPHIC DIVISIONS OF

VIRGINIA AND ADJACENT STATES

(after N. M. Fenneman)



Valley and Ridge Province

The Valley and Ridge Province, which contains the Craigsville quadrangle, consists of a 25 to 50 mile wide belt of parallel valleys and ridges lying adjacent to the western boundary of the Blue Ridge Province. The eastern part of the province, the Shenandoah Valley, consists of a series of parallel valley-like lowlands ranging in elevation from 500 feet above sea level in the valley floors to 2,500 feet in the divides. There are no sharp or distinct ridges separating the valley-like lowlands. The western part of the province consists of nearly parallel narrow ridges and valleys. The ridges in this latter part form an even sky line at an elevation of about 3,100 feet.

The formations in the Valley and Ridge Province range in age from Cambrian through the Pennsylvanian. The rocks, because of their greatly varying resistance to erosion, have an important effect on the topography. The soluble Cambrian and Ordovician limestones and weak Ordovician shales form the lowlands of the Shenandoah Valley. In the western part of the province the resistant sandstones and quartzites form the even-crested ridges, and the shales and limestones produce the valleys. In the central portion of this belt the Clinch sandstone of Silurian age is the principal ridge maker.

The drainage is characterized by major streams cutting across the geological structure of the province. A trellis drainage pattern prevails in the province. After the land was reduced to a peneplane in post-Triassic time, it was uplifted in a broad arch with a steeper dip on the eastern slope. The major eastward flowing streams cut back their headwaters faster than the westward flowing streams and captured many of the headwaters of the latter. As a result, much of the drainage of the middle and northern parts of the province flows eastward across the Valley and Ridge, through narrow gaps in the Blue Ridge, in deep valleys across the Piedmont and across the Coastal Plain into the Atlantic Ocean. The James is an example of these eastward flowing rivers. The New River, rising in the Blue Ridge and flowing westward across the Valley and Ridge Province, is an example of one of the westward flowing streams whose original direction has not been changed. None of the rivers currently flows transverse across the entire belt of ridges in a course consequent upon the uplifted and warped peneplane surface. The present course of the major streams, including the James, was determined by the character and structure of the underlying rocks rather than the slope of the peneplane.

The first peneplanation of western Virginia, of which there is still visible record, probably occurred during Cretaceous or Jura-Cretaceous time. There are three distinct and well defined levels in the region: The Upland Peneplane, preserved on the even ridge crests of the Valley and Ridge and Blue Ridge. The elevations of this surface range from 3,200 to 4,600 feet above sea level. The Valley Peneplane, preserved on the floor of the Shenandoah Valley and its larger branches. The third level is represented by the dissection of the Valley peneplane by the rivers to depths of 400 to 500 feet. (Wright, 1925)

The three above mentioned levels have created five major elements in the topography (op. cit.). First: Monadnocks on the Upland Peneplane. These hills were all that remained above the base leveled surface. They remained either because the underlying rock was more resistant to erosion or because they were situated a greater distance from the main drainage lines. In most instances the former reason is probably correct. Second: The remnants of the Upland Peneplane as preserved on the crests of the major mountains. This surface corresponds to the highest peneplane (Kittatinny or Schooley) found in New Jersey and Pennsylvania. Third: Monadnocks of the Valley Peneplane. These are hills ranging in elevation from the level of the Valley Peneplane to slightly below the level of the Upland Peneplane. These ridges, parallel to the regional strike of the rocks, are generally associated with the chert bearing limestones in the Shenandoah Valley and the "low" ridges of sandstone and quartzite farther west. Most of these ridges are not noticed, unless one travels normal to the strike of the region. Fourth: Remnants of the Valley Peneplane. During this cycle only the limestones and shales were beveled. This surface is referred to farther north, in New Jersey and Pennsylvania, as the Harrisburg peneplane. Fifth: Trenches cut into the Valley Peneplane represent the fifth topographic element.

In the Fordwick area several of the above mentioned topographic elements are recognizable. Elliot Knob is an example of the first. The crests of Great North and Little North Mountains represent the second element. Black Oak and Brown Ridges represent the third element. The valley between Great North and Little North Mountains, underlain by shale, represents the fourth element. The fifth topographic element, trenches in the Valley Peneplane surface, is missing in the Fordwick area.

STRUCTURE

The Taconic and Acadian disturbances had little if any effect upon the structure of the region. Following the early Permian deposition, the Appalachian geosyncline was uplifted with accompanying extensive diastrophism referred to as the Appalachian revolution. The strata of the Valley and Ridge Province were strongly folded and faulted at this time. Compression came from the southeast and gave rise to the present northeast-southwest structural trend. The folds are generally unsymmetrical, the northwest limbs of the anticlines being steeper. Many of the folds are overturned, some pass into low angle thrust faults. Erosion with periodic uplift since the close of the Paleozoic has formed the Valley and Ridge topography as we know it today.

Within the Piedmont and Blue Ridge Provinces the Pre-Cambrian, Cambrian and Ordovician rocks are much distorted. West of the Blue Ridge Province, within the Valley and Ridge, the rocks are intensely folded and faulted, including overthrusting. Farther west, in the Appalachian Plateau, are the flat-lying strata.

In the Craigsville area the folds are open and unsymmetrical, the faults are all high angle and normal.

STRATIGRAPHY

In this section dealing with the stratigraphy of western Virginia, only the Silurian and Devonian formations of the Valley and Ridge and Appalachian Plateau Provinces will be considered. The formations which are included in the stratigraphic sequence are shown in Figure 4. The detailed correlation chart of the Helderberg group and the overlying and underlying

System	Subdivision	Series	Group	Formation
Mississippian				
Devonian	Upper Devonian	Chatauquan	Catskill	
			Chemung	
		Senecan	Brallier	
				Burket
	Middle Devonian	Erian	Romney	Hamilton Marcellus
		Ulsterian		Onondaga
	Lower Devonian	Oriskanian	Oriskany	Ridgeley Shriver
		Helder-bergian	Helder-berg	Becraft New Scotland Coeymans Keyser Clifton Forge Big Mountain
Silurian	Upper Silurian	Cayugan	Cayuga	Tonoloway Wills Creek Bloomsburg McKenzie Keefer
	Middle Silurian	Niagaran	Clinton Cacapon	
	Lower Silurian	Medinan	Clinch = Tuscarora	
Ordovician				

Figure 4. Silurian-Devonian Formations of Valley and Ridge and Appalachian Plateau Provinces of Virginia.

formations is included in the Appendix.

Silurian

Lower Silurian (Upper Median)

Clinch sandstone = Tuscarora quartzite. The Clinch sandstone and the Tuscarora quartzite occupy the same stratigraphic position in the Valley and Ridge Province of Virginia. The oldest Silurian formation in the southern part of the province is the Clinch sandstone. In the central and northern portions of the province the Tuscarora quartzite is the oldest Silurian formation.

The Clinch sandstone is found in eastern Tennessee, southwestern Virginia and southern West Virginia and is named for exposures on Clinch Mountain, Hancock and Hawkins Counties, Tennessee, and Scott County, Virginia. In 1856, J. M. Safford (Geol. Reconn. Tenn. 1st Rept., p. 157) described the Clinch Mountain sandstone as a "light gray, generally thick-bedded sandstone, at many points abounding in fucoids; sometimes contains layers of conglomerate with pebbles the size of small peas". (Wilmarth, page 464) In 1869, Safford included 400 feet of red sandstones and shales overlying his 1856 Clinch Mountain sandstone in the formation and called these red beds the Clinch red shale. In 1895 and 1896, Arthur Keith (U.S.G.S. Knoxville folio, No. 16; Loudon folio, No. 25; and Morristown folio, No. 27) restricted the Clinch sandstone to the upper white sandstone described by Safford as the Clinch Mountain sandstone and applied the term Bays sandstone to the underlying shales and sandstones. Later geologists found Keith to be in error in his 1895 and 1896 reports, because his so-called Bays sandstone was actually older than the red sandstones underlying the Clinch. The formations underlying the Clinch sandstone are now called the Juniata formation in the eastern belt and the Sequatchie formation in the western belt. They are assigned to the Upper Ordovician (Richmond). The formation overlying the Clinch is of Clinton age. (Wilmarth, 1938)

Where exposed in Virginia, Charles Butts (Butts, 1938) describes the Clinch sandstone as a medium to thick-bedded, massive, hard, gray sandstone or quartzite that often contains a quartz conglomerate at the base. The Clinch ranges from 50 to 200 feet in thickness. The fauna of the Clinch includes *Arthrophycus* and *Hughmilleria*.

The Tuscarora quartzite is exposed in central, southern and eastern Pennsylvania, western Maryland, western Virginia and eastern West Virginia. The Tuscarora quartzite was named by W. B. Clark in 1897 for exposures in Tuscarora Mountain, Pennsylvania. In 1896, N. H. Darton (U.S.G.S. Piedmont folio, No. 28, and Franklin folio, No. 32) described the Tuscarora quartzite (in Virginia) as a white and gray massive quartzite 250 to 480 feet thick that underlies the red Cacapon sandstone and overlies the red

Juniata formation. He ascribed it to part of the Medina of earlier reports of the same areas. In 1907, C. A. Hartnagel (N. Y. State Mus. Bull. 107, pp. 34-35) reported Arthrophycus as the only fossil from the Tuscarora sandstone, which is regarded as perhaps nearly identical with the "White Medina" of the Second Pennsylvania and New York Surveys. (Wilmarth, 1938) Bevan (Bevan, 1932) reported the Tuscarora as ranging up to 400 feet in thickness and equivalent to the upper Medina of New York State.

In southwestern Virginia, the Clinch overlies the Sequatchie formation which is a red and green shale containing interbedded fossiliferous, impure limestone beds. In central and northern Virginia the Juniata formation, which is equivalent to the Sequatchie, underlies the Tuscarora. The Juniata formation is a red shale interbedded with fine-grained, thick-bedded, reddish-brown sandstone.

The Clinch and Tuscarora formations are the principal ridge makers of the Valley and Ridge Province in Virginia. Tuscarora Mountain in Pennsylvania, North Mountain in northern Virginia and Clinch Mountain in southern Virginia are examples of the mountains made by these formations.

Middle Silurian (Niagaran)

Clinton formation. The Clinton formation is exposed from New York to northeastern Tennessee and also in Michigan. In 1842, Lardner Vanuxem (Geol. N. Y., pt. 3) defined the Clinton "as consisting of green and black-blue shale, greenish and gray sandstone, red sandstone often laminated, calcareous sandstone, encrinal sandstone, and red fossiliferous iron ore beds, the most prominent member being shale, the next most prominent member the greenish sandstone, and the third persistent member the iron ore beds." He stated that characteristic masses of these rocks occur around Clinton, Oneida County, New York; that the overlying formation is Niagara group = Lockport group; and that underlying the formation is Oneida or Shawangunk conglomerate. (Wilmarth, page 465)

The Clinton formation in Virginia can be separated into three divisions. The lowest member is the Cacapon sandstone, which ranges from 50 to 300 feet in thickness. It consists of interbedded strata of hard, dense, red, ferruginous sandstone and shale. Butts (Butts, 1933) reported large thicknesses of green shale and green sandstone within the Cacapon. In southwestern Virginia (Craigsville quadrangle and southward) the lower beds of the Clinton, which probably correspond to the Cacapon, contain workable deposits of fossiliferous hematite. The iron ore deposits at Estaline Furnace on Little North Mountain are part of these beds.

The middle member of the Clinton formation includes green shales, thin-bedded, green sandstones and thick-bedded, gray sandstone . The gray sandstone, a continuation of the Keefer sandstone of Pennsylvania, ranges up to 200 feet in thickness. _Mastigobolbina_ and _Bonnemaia_ are found in this member.

The upper member of the Clinton consists of thin limestone layers and 20 feet of soft shale, which is correlated with the Rochester shale of New York State. The upper member does not exceed 50 feet in thickness. _Dalmanites limulurus_ occurs in this member.

The Clinton formation attains its maximum thickness of 550 feet between Clifton Forge and Monterey. At the south end of Walker Mountain, near Marion, the Clinch-Clinton has thinned to 18 feet thick and is underlain by the Juniata and overlain by limestone and chert of Onondagan age. (Bevan, 1932)

Upper Silurian (Cayugan)

Cayuga group. The Cayuga group is exposed in New York, Pennsylvania, western Maryland and Virginia. In 1899, J. M. Clarke and Charles Schuchert (Science, n.s., vol. 10, pp. 874-878) included in the Cayugan group the Manlius limestone, the Rondout water lime and Salina beds. They applied the term to the rocks exposed about the north end of Cayuga Lake, New York. Charles Schuchert introduced the name Cobbleskill limestone for the lower Rondout beds. (Wilmarth, page 379) In 1908, G. H. Chadwick (Science, n.s., vol. 28) excluded the Salina beds from the Cayuga group. At present, United States Geological Survey includes in the Cayuga group (ascending) the McKenzie formation, the Wills Creek shale and the Tonoloway limestone. The Virginia Survey considers considers the Cayuga group to include (ascending) the McKenzie, the Bloomsburg, the Wills Creek and Tonoloway.

McKenzie formation. The McKenzie formation is exposed from central Pennsylvania southward through western Maryland into northeastern West Virginia and northern Virginia. The type section of the McKenzie formation is at McKenzie Station, Allegany County, Maryland. In 1912, G. W. Stose (U.S.G.S. Pawpaw-Hancock folio, No. 179) described the McKenzie as the basal formation of the Cayuga group overlying the Clinton shale and underlying the Bloomsburg member of the Wills Creek shale. He described the McKenzie as 170 to 300 feet of thin beds of gray crystalline limestone in gray shale with 40 feet of hard, white sandstone (Keefer sandstone member) at the base. In 1911, E. O. Ulrich (Geol. Soc. Am. Bull., vol. 22) described the Keefer sandstone as a local basal member or facies of the McKenzie (*op. cit.* pages 1253-1254).

The McKenzie shale is found only in the northern half of Virginia. It consists of 75± feet of blue clay shale, which turns yellow upon weathering, and thin beds of fossiliferous limestone. Ostracods, such as *Kloedenia*, are abundant in the formation and are characteristic. Probably the best exposures of the McKenzie in Virginia are those of Highland County. (Butts, 1933)

Bloomsburg formation. The Bloomsburg formation is exposed from southeastern New York through central northern New Jersey and across Pennsylvania and western Maryland into northern West Virginia and western Virginia. I. C. White in 1883 (2nd Penna. Geol. Survey Report G7) applied the name to 440 feet of beds visible along the east bank of Fishing Creek at the north line of the town of Bloomsburg, Columbia County, Penna. In 1931, C. K. and F. M. Swartz (Geol. Soc. Am. Bull., vol. 42, no. 4) described the Bloomsburg formation as representing a "lithological phase--not a geological age. It accumulated on the continental margin to the east while different marine deposits were formed to the west". (Wilmarth, page 214) In the same paper they reported tracing "the Bloomsburg red beds southward into Maryland and eastward through central and eastern Pennsylvania to Delaware Water Gap, where it was called Clinton by Chance and High Falls by Stose. It is continuous with Medina-Longwood sandstone of New Jersey and High Falls red beds of Hartnagel in southeastern New York. It is manifest it is the same formation throughout this entire area and should have one name to avoid confusion. The term Bloomsburg has priority" (op. cit. page 214).

In Virginia the Bloomsburg formation is a red shale with thick-bedded, red and green sandstone strata interbedded. In Powell Mountain near Woodstock it is about 200 feet thick. It thins northward and in Great North Mountain near Winchester it is only 100 feet thick. There are very few fossils in the formation and it is probably of non-marine origin. In the Massanutten Mountain area and south from Winchester, the Bloomsburg generally rests on the Tuscarora quartzite, except in local areas where it overlies thin beds of the McKenzie. Probably the best exposures of the Bloomsburg in Virginia are in Great North Mountain in Shenandoah County.

Wills Creek formation. The Wills Creek formation is exposed from central Pennsylvania southward through western Maryland into western Virginia. It was named for conspicuous exposures along Wills Creek at Cumberland, Maryland. In 1905, P. R. Uhler (Md. Acad. Sci. Trans., vol. 2) described the Wills Creek as 150± feet of "yellow shales (black when fresh), argillaceous and calcareous, with a few thin layers of dark-purple sandstone and two feet of coarse dark-purple unfossiliferous sandstone at the base." (Op. cit., page 2344) He reported the formation as underlying "Lower Helderberg" and overlying the "water lime". In 1911, E. O. Ulrich (Geol. Soc. Am. Bull., vol. 22) reported the Wills Creek as overlying the Bloomsburg sandstone and underlying the Tonoloway limestone.

In Virginia the Wills Creek consists of greenish-gray, friable, calcareous sandstone and shale. Near Monterey, the Wills Creek formation includes 30 feet of shale. (Bevan, 1932) Northward the sandstone increases in thickness and reaches 50 feet north of Winchester. In Highland County the Wills Creek is underlain by McKenzie (Bloomsburg is missing) and overlain by Tonoloway. In Clinch Mountain, Tazewell County, it lies between the Clinton and Onondaga. (Butts, 1933) The formation contains abundant *Leperditia elongata willsensis*. Butts (*op. cit.*) suggests the Wills Creek continues southwestward into Tennessee where it is represented in the Sneedville limestone. The Wills Creek is well exposed in Highland County.

Tonoloway formation. The Tonoloway formation is exposed from central Pennsylvania southward to western Virginia. The type section of the formation is on the lower slopes of Tonoloway Ridge, Washington County, Maryland. In 1911, E. O. Ulrich (Geol. Soc. Am. Bull., vol. 22) described the Tonoloway as underlying the Bossardsville limestone and overlying the Wills Creek shale in the Pennsylvania, Maryland-Virginia region. In 1912, G. W. Stose (U.S.G.S. Pawpaw-Hancock folio, No. 179) described the Tonoloway as the top formation of the Cayuga group and consisting of 400 feet of limestone with some shale. In the same paper Stose said the Tonoloway overlies the Wills Creek shale and underlies the Helderberg limestone. (Wilmarth, page 2164)

C. K. Swartz stated "Recent studies of the writer tend to show that the Tonoloway is probably the same as the Bossardsville of Pennsylvania and New Jersey." (Swartz, C.G., 1913, page 105)

In Virginia the Tonoloway is a thin-bedded or laminated, dark gray limestone. In northern Augusta County it is 25 feet thick. Westward in Highland County it reaches 300 feet in thickness. In the Clifton Forge area to the south it is 200 feet thick. In northern Virginia it thickens to 400 feet. The ostracod Leperditia alta generally characterizes the Tonoloway limestone. There are good exposures of the formation in Highland County.

Devonian

Lower Devonian

Helderberg group. The Helderberg group is exposed from New York southward through New Jersey, eastern Pennsylvania and western Maryland into northern West Virginia and Virginia. The type section of the Helderberg group forms the basal part of the Helderberg Mountains in Albany County, New York. A chart included in the Appendix shows the historical development of the term Helderberg. The correlation chart in the Appendix traces the Helderberg formations from New York southward through Virginia to Alabama.

<u>Keyser formation</u>. The Keyser formation is exposed from Pennsylvania through western Maryland into northern West Virginia and western Virginia. The type locality of the Keyser limestone is Keyser, West Virginia. E. O. Ulrich in 1911 (Geol. Soc. Am. Bull., vol. 22) first described the Keyser as the "basal formation of Helderberg of New York, Pennsylvania, Maryland, Virginia and West Virginia." (Wilmarth, page 1090) In 1913, C. K. Swartz (Md. Geol. Surv. Lower Devonian vol.) described the Keyser as 270 to 290 feet of "limestone, massive and very nodular in the lower part and more shaly and thin-bedded above. Rich coral and brachiopod fauna." (<u>Op</u>. <u>cit</u>., page 1090) C. K. Swartz considered the Keyser as the basal member of the Helderberg formation, underlying the Coeymans member, probably unconformably, and overlying the Tonoloway formation. He further stated the Keyser to be clearly transitional between the Silurian and Devonian. The Keyser contains some Helderberg faunal elements, so on the principal that the age of the formation is that of its youngest fauna the Keyser was placed in the Helderberg even though the majority of its species are distinctly Silurian. (<u>Op</u>. <u>cit</u>.)

In Virginia the Keyser formation includes the Big Mountain shale and Clifton Forge sandstone members. These two members are described below. In the type locality at Keyser, West Virginia, and in the northern part of

Virginia the Keyser formation consists of 270 to 280 feet of limestone. The upper portion of the beds are thin to medium-bedded, dark-blue, shaly limestone. The middle portion of the formation is more massive and less silicious than the upper beds. The lower portion of the formation is thin-bedded, blue, nodular limestone. From north-central Virginia southwestward the Big Mountain shale displaces the middle portion of the Keyser. The shale increases in thickness southwestward and reaches a maximum thickness of 45 feet and displaces the upper beds of the lower portion as well as all of the center portion of the Keyser. In the vicinity of Bolar, Virginia, the Big Mountain shale member is intertongued with and gradually displaced by the Clifton Forge sandstone member. The Clifton Forge sandstone increases to a maximum of 90 feet in thickness southward from Bolar. The upper limestone portion and the basal limestone beds remain as part of the Keyser throughout most of its extent in Virginia. In the Clifton Forge area and southward the limestone facies of the Keyser becomes more and more arenaceous and the formation thins to extinction.

The Keyser as a formation, including the Big Mountain shale and Clifton Forge sandstone members, thins southward and eastward from Keyser, West Virginia. Southward from Clifton Forge the Keyser thins rapidly and is not seen south of Gala, Virginia, and is absent in the Saltville and Big Stone Gap areas where the Tonoloway is in contact with sandstones of apparent Coeymans age. (Swartz, F. M., 1929, page 29) The Shenandoah River from the Potomac River southward to Staunton generally marks the eastern limits of the Keyser. The following fossils are usually abundant in the Keyser formation: Chonetes jerseyensis, Whitfieldella minuta, Favosites helderbergiae var. praecedens, Uncinnulus convexorus, Merista typa, Stropheodonta bipartita, Spirifer modestus, Camarotoechia altiplicata, Rensselaeria mutabilis, and Cladopora rectilineata.

Big Mountain shale. The Big Mountain shale is exposed in northern West Virginia and western Virginia. The type section of these beds is in Big Mountain near the village of Upper Tract, Pendleton County, West Virginia. In 1929, F. M. Swartz (U.S.G.S. Prof. Paper 158) described the Big Mountain as 30 to 61 feet of greenish to yellow calcareous shale with some impure limestone beds. The Big Mountain shale separates the upper Keyser limestone member from the lower limestone member. The shale thins northward and southward from the type locality. Southward from Bolar, Virginia, the Big Mountain shale is replaced by the Clifton Forge sandstone with which it intertongues. (Wilmarth, 1938) Included in the fauna of this member are: Chonetes jerseyensis and Cladopora rectilineata.

Clifton Forge sandstone. The Clifton Forge sandstone is exposed in central western Virginia. In 1929, F. M. Swartz (U.S.G.S. Prof. Paper 158) applied the term to the sandstone beds of the Keyser in the vicinity of Clifton Forge, Virginia. The Clifton Forge is a calcareous to shaly sandstone with some arenaceous shale. It ranges from 66 to 102 feet in thickness and intertongues with and displaces the Big Mountain shale and the lower beds of the upper Keyser limestone south of Bolar, Virginia.

Coeymans formation. The Coeymans formation is exposed in eastern New York, New Jersey, Pennsylvania, western Maryland, northern West Virginia and western Virginia. The term Coeymans was first applied to exposures at Coeymans, Albany County, New York, in 1899 by J. M. Clarke and Charles Schuchert (Sci., n.s., vol. 10) to the Lower Pentamerus (Helderberg and Petamerus limestones) of former New York geologists. New York State reports describe the Coeymans as a vertically jointed, hard, massive, bluish-gray limestone. (Op. cit., page 481) In New York State the Coeymans is the basal member of the Helderberg group and overlies the Manlius (Silurian) and underlies the Kalkberg (which in turn underlies the New Scotland).

In central and northern Virginia the Coeymans is a massive, thick-bedded, crystalline, highly crinoidal limestone. In south central Virginia the formation gradually becomes sandy and south of New River is a coarse, calcareous sandstone. In the northern part of the state the Coeymans is 20 to 25 feet thick. It increases in thickness southwestward and in the central part of the state is up to 60 feet thick. South of Bolar it again decreases in thickness.

The contact with the underlying Keyser is readily identifiable since, especially in the southern part of the state, the basal Coeymans is usually arenaceous. The contact with the overlying New Scotland, where the latter is sandy or cherty, can easily be identified on the lithologic as well as faunal basis. In areas such as Fordwick and Bells Valley, however, the New Scotland and Coeymans have almost identical lithologies and the contact can be drawn only on the basis of the presence of *Eospirifer macropleurus*, indicating New Scotland, and if present, the *Meristella arcuata* zone found near the top of the Coeymans.

The diagnostic *Gypidula coeymanensis* is common in the Coeymans in the northern part of the state. This key fossil becomes scarce to the southwest and has not been found in the Fordwick-Clifton Forge area.

New Scotland formation. The New Scotland formation is exposed from eastern New York southward to northern West Virginia and western Virginia. The type section of the formation is at the town of New Scotland, Albany

County, New York. In 1899, J. M. Clarke and Charles Schuchert (Sci., n.s., vol. 10) first applied the name New Scotland to the Catskill or Delthyruis shaly limestone of former New York geologists. In New York the 50 to 127 feet of New Scotland beds overlie the Kalkberg (which overlies the Coeymans) limestone and underlie the Becraft limestone. Southward from Pennsylvania the Kalkberg is missing and the New Scotland rests on the Coeymans and underlies the Becraft limestone. (Op. cit., page 1493)

The New Scotland from Keyser, West Virginia, southward to Monterey, Virginia, is a cherty limestone maintaining a constant thickness of 25 to 35 feet. South of Monterey the cherty limestone is displaced by calcareous sandstone. F. M. Swartz (Swartz, F.M., 1929, page 41) has applied the name Healing-Springs sandstone to this facies of the New Scotland. He reported this sandstone facies as "quite unfossiliferous at Clifton Forge and Gala". It contains fragments of Eospirifer macropleurus.

At Fawcetts Gap near Winchester and in the Fordwick-Bells Valley area, the New Scotland is present as a massive, thick-bedded, crystalline limestone similar to the underlying Coeymans. F. M. Swartz (op. cit., 1929) reported the New Scotland as cherty at Fulks Run about midway between Fawcette Gap and Fordwick and nearly on the strike between these two localities. He further reported the New Scotland as cherty at Craigsville about 4 miles north of Bells Valley. The present writer has found Eospirifer macropleurus in non-cherty, crystalline Bells Valley type New Scotland one and a half miles southeast and one mile east of Craigsville, and one mile south of Augusta Springs. In these localities the overlying cherty material is Becraft. No outcrops were available to limit the extent of the cherty facies of the New Scotland closer than given above.

Becraft formation. The Becraft formation is exposed from eastern New York southward through Pennsylvania and western Maryland into northern West Virginia and western Virginia. The term Becraft was applied by James Hall to exposures on Becraft Mountain, Columbia County, New York. In 1893, Hall (N. Y. State Geol. 12th Ann. Rept.) applied the name Becraft to the Upper Pentamerus limestone or Scutella limestone of former New York geologists. N. H. Darton, in 1894, (N. Y. State Mus. 47th Ann. Rept.) reported the Becraft limestone as a pure, semi-crystalline, massive, very fossiliferous limestone up to 60 feet thick underlying the Upper Shaly (Port Ewen) limestone and overlying the Lower Shaly (New Scotland) limestone. (Wilmarth, page 142) In New York there are two younger Helderberg formations recognized, the Port Ewen and Alsen limestones. In central Pennsylvania and southward the Becraft is the top formation of the Helderberg group and underlies the

Oriskany and overlies the New Scotland.

In Virginia the Becraft is restricted to the eastern half of the Valley and Ridge Province occupying the New Scotland-Oriskany (Ridgeley) interval with the Shriver absent. In the western half of the province the New Scotland-Ridgeley interval is occupied by the Shriver and the Becraft is missing.

The Becraft, in the central and northern part of the outcrop belt, is a medium-bedded, dark-gray to black, cherty limestone below grading upward into a chert-free, medium-bedded, dark gray limestone. In the southern part of the Becraft belt, from New River southward, it apparently has changed to a coarse sandstone. South of New River the sandy Becraft is apparently the only representative of the Helderberg group present. (Schuchert, 1943, page 260) The fauna of the Becraft include _Spirifer concinnus_, _Rhipidomella assimilis_, _Streptelasma strictum_, _Uncinulus abruptus_, _Schuchertella woolworthana_, and _Eatonia peculiaris_.

Oriskany group. The Oriskany group is exposed from New York southward through Pennsylvania and western Maryland into eastern West Virginia and western Virginia. The term Oriskany sandstone was applied by Lardner Vanuxem in 1839 (N. Y. Geol. Surv., 3rd Rept.) to 30 feet of white sandstone at Oriskany Falls, New York. The United States Geological Survey uses the term _Oriskany_ group to include the Esopus grit at the top, Oriskany sandstone and Port Ewen at the base. Where the deposits of Oriskanian age are not differentiated the term Oriskany sandstone is applied. The New York State Survey considers the Port Ewen to be part of the Helderberg group. (Wilmarth, 1938) In New Jersey and Pennsylvania the Esopus is grouped as Onondagan (Ulsterian).

In central Pennsylvania, Maryland and northern Virginia the Oriskany group includes the Shriver chert below and the Ridgeley sandstone above. In central Virginia the relationship of the Oriskany to the underlying Helderberg is not clearly differentiated. F. M. Swartz (Swartz, F. M., 1929) places the Shriver in the same apparent stratigraphic position as the Becraft, that is, underlying the Ridgeley and overlying the New Scotland, but it is not its equal. No sections have been described where both the Shriver and Becraft formations are present together. Sections 20 miles apart will show them in the same stratigraphic position.

Shriver chert. The Shriver chert is exposed from central Pennsylvania through western Maryland to eastern West Virginia and central western Virginia. The type locality of the Shriver chert is Shriver Ridge at Cumberland, Maryland. C. K. Swartz first described the Shriver in 1912 (Md. Geol. Surv. Lower Devonian vol.) "as a dark siliceous shale with much black impure chert in nodules or layers of nodules. Thickness 0 to 100 feet. Basal member of Oriskany formation. It underlies Ridgeley sandstone and overlies Becraft member of Helderberg formation. Meager fauna." (Wilmarth, page 1991)

The Shriver in Virginia is a dark gray siliceous shale with much interbedded black chert. It is overlain by the Ridgeley sandstone containing the characteristic Costispirifer arenosus. Throughout the western half of the central part of the Valley and Ridge Province of Virginia the interval between the New Scotland and Ridgeley sandstone is occupied by the typical Shriver cherty shale. In the eastern half of the area the New Scotland-Ridgeley interval is occupied by typical Becraft limestone. Throughout the Shriver area of Virginia it is 100 to 110 feet thick. In the Fordwick area the interval between the New Scotland limestone and the Ridgeley (Oriskany) sandstone is occupied by typical Becraft cherty limestone.

Ridgeley sandstone. The Ridgeley sandstone is exposed from eastern Pennsylvania to eastern West Virginia and central western Virginia. The type locality of the Ridgeley is at Ridgely, West Virginia (note difference in spelling). In 1913, C. K. Swartz (Md. Geol. Surv., Lower Dev. vol.) described the Ridgeley sandstone member as "calcareous sandstone, which passes into an arenaceous limestone. Top member of Oriskany formation. Thickness

50 to 250 feet. Closely resembles Oriskany of New York in lithology and fauna. Overlies Shriver chert member and underlies Romney formation which contains Onondaga fauna in basal beds." (*Op. cit.*, pages 1812-1813)

In Virginia the Ridgeley is a thick-bedded calcareous sandstone which upon weathering becomes friable and pitted with numerous molds of large fossil shells. *Costispirifer arenosus* and *Rensselaeria "ovoides"* are the common and characteristic fossils of the Ridgeley. In northern Virginia the formation is 150 feet thick. It thins southward and is 35 feet thick at Fordwick. It has not been recognized south of the Clifton Forge-Covington area of Alleghany County where it is present as sandstone lenses up to five feet in thickness.

In this paper, since the only Oriskanian present in the Fordwick area is the Ridgeley member, the sandstone occupying the Becraft-Romney interval is referred to as the Oriskany sandstone.

Middle Devonian

Onondaga formation. The Onondaga formation is exposed from New York southward through Pennsylvania and western Maryland into northern West Virginia and western Virginia. The type section of the Onondaga limestone is in Onondaga County, New York. Throughout most of Virginia, West Virginia and western Maryland the Onondaga is included in the Romney shale as the Onondaga shale member.

However, in southwestern Virginia the Onondaga is a limestone and is considered as a separate formation, as it is in New York, and is treated here as such. In 1839, James Hall first mentioned the "gray crinoidal or Onondaga limestone" as underlying the Seneca limestone and overlying the Oriskany sandstone. He described the Onondaga as a gray of grayish-blue, compact limestone. In 1905, J. M. Clarke and D. D. Luther applied the name Onondaga to the 65 to 70 feet of limestone overlying the Oriskany quartzite and underlying the Marcellus shale. (Op. cit., 1938)

In Virginia the Onondaga has two distinct lithological facies. In the southwestern part of the state it is a dense, medium-bedded, bluish-gray cherty limestone. Near the base of the formation, sandy shale strata or thin layers of argillaceous limestone frequently are present. This facies of the Onondaga is 75 to 100 feet thick and is treated as a distinct formation. The best exposures of the limestone facies of the Onondaga are found in the Clinch Mountain in Smyth County. In Rockbridge County the limestone facies is represented by a foot of cherty limestone in Panther Gap (about 16 miles southwest of Craigsville).

From south-central Virginia northward, the Onondaga at the base of the Romney is represented by 50 to 60 feet of brown to greenish shale, which turns yellow upon weathering. In northern Virginia and Maryland the

Onondaga shale is dark brown to black when unweathered. This portion of the Romney contains the typical Onondaga fauna as found in the limestone facies farther south, such as Schuchertella pandora, Chonetes acutiradiatus, Anoplia nucleata, Leptocoelia acutiplicata, Bollia ungula, and Octonaria stigmata. (Schuchert, 1943, page 261)

The Onondaga overlies the Oriskany sandstone. Where present as a limestone facies, the Onondaga underlies shales of Marcellus age which are mapped as the lower part of the Romney shale. In the Onondaga shale areas, the formation underlies shales which are mapped as the Romney.

Middle and Upper Devonian

Romney shale. The Romney shale or its correlative is exposed in southern Pennsylvania, western Maryland, eastern West Virginia, and central and northern Virginia. The formation received its name for exposures at Romney, Hampshire County, West Virginia. In 1892, N. H. Darton (Am. Geol., vol. 10) first applied the name Romney to "the 500 to 900 feet of the basal series of Devonian sediments in central Appalachian Virginia". (Wilmarth, page 1840) He described the beds as fissile shales, in greater part black or dark brown, containing occasional thin beds of sandstone and limestone. The shales, according to Darton, unconformably overlie the Monterey sandstone and underlie the Jennings formation and contains Hamilton fossils. C. W. Stose in 1909 (U.S.G.S. Mercersburg-Chambersburg, Pa., folio, No. 170), and others more recently, considered the Romney shale to include beds equal to the Onondaga, Marcellus and Hamilton formations of New York. The overlying Jennings formation includes the Genessee (Burket), Portage and Chemung. Charles Butts in 1932 (Va. Geol. Surv., Bull. 34) designated the Romney shale to include Onondaga, Marcellus, and Hamilton members. He did not report the presence of definite Genesee (Burket) beds. Butts applied the name Brallier shale to the beds of Portage age that overlie the Romney shale. (Op. cit., pages 1840-1841)

In Virginia the term Romney shale is applied to the entire thickness, 500 to 1,000 feet of yellow, green or black, fissile shale lying between the Oriskany sandstone (or Onondaga limestone) below and the Brallier shale above. The Romney includes, in ascending order, shales of Onondaga, Marcellus, Hamilton, and Genesee (Burket) ages.

As mentioned, above in southwestern Virginia the Onondaga is limestone and not included in the Romney shale. The Marcellus member of the Romney is a black, fissile shale with poorly defined limits containing Buchiola retrostriata and Leiorhynclius nysius (Kindle, page 44), and is believed to be present throughout the entire extent of the Romney. The Hamilton member of the Romney is represented by a dark green, fossiliferous shale with some interbedded sandstone layers. The Hamilton member has not been recognized in the Romney farther south than Shenandoah County. The beds of Genesee ? and Naples age are dark colored, fissile shales.

In southwestern Virginia where the Marcellus and Hamilton members are missing, the black shale lying between the Onondaga limestone and Brallier shale is referred to as either Romney or "black shale of Devonian age". (Wilmarth, 1938)

Brallier shale. The Brallier shale is exposed from central Pennsylvania southward into northern Virginia. The type section is named for a railway station six miles northeast of Everett, Bedford County, Pennsylvania. In 1918, Charles Butts (Am. Jour. Sci., 4th series, vol. 46) described the Brallier as consisting of 1,350 to 1,800 feet of "fine-grained, siliceous shale, in thick, even layers, revealing fissility on weathering; largely wavy or dimpled laminae; some even and slaty; a few thin fine-grained sandstone layers". (Op. cit., page 250) He reported the Brallier as the upper formation of the Portage group and overlying the Harrell shale and underlying the Chemung formation. (Op. cit.) Fossils are rare in the shale but the sandstone lenses, in Pennsylvania, carry "Ithaca" fossils.

In Virginia the Brallier formation consists mainly of shales with some interbedded sandstone. The shaly strata range from siliceous or micaceous, dark-gray, fissile shale to soft, laminated, argillaceous rock. The material weathers to a yellow color with black manganese stains common. The sandstone is greenish-brown on the fresh surface and weathers to a rusty-brown. The sandy strata range from a few inches to a foot or more in thickness and the beds characteristically maintain their thickness within any one exposure. (Butts, 1933)

In northern Virginia the Brallier is 3,000 to 4,000 feet thick and forms the lower part of the Kimberling shale of the Pocahontas folio. (Campbell, 1896) Southwestward the formation thins and in Smyth County, in southwestern Virginia, is 1,000 feet thick. The Brallier shale is well exposed near Millboro, Bath County, and near Jennings Gap, Augusta County. Fossils are scarce but occasionally the pelecypods Buchiola and Pterochaenia are found. (Butts, 1933, page 34)

Upper Devonian (Upper Senecan, Chatauquan)

Chemung formation. The Chemung formation is exposed throughout western and central New York, central and northern Pennsylvania, western Maryland and western Virginia. The name was first applied to the beds occurring in the valley of the Chemung River and in the town of Chemung, Chemung County, New York, in 1839 by James Hall (N. Y. Geol. Surv. 3rd Rept.). In 1840, (N. Y. Geol. Surv. 4th Rept.) he stated the Chemung group underlies red sandstone, which is equivalent to the Old Red Sandstone of Europe, and overlies the Portage group. Hall described the Chemung as consisting of (descending): (1) "Green shales with thin beds of sandstone; (2) dark, nearly black, sandy, highly micaceous shale with septaria, iron pyrites, and thin interstratified masses of gray sandstone containing Chemung fossils; (3) greenish-olive sandy shale or very shaly sandstone, very slaty." (Wilmarth, page 411) In 1846, Ebenezer Emmons (Agric. N. Y. vol. 1) described the formation as underlying the Catskill group and overlying the Portage group. (Op. cit.) Since 1846 the New York Geological Survey has not changed the upper or lower limits of the Chemung formation. Many changes, however, have been made in the correlation and designation of the members of the formation.

The term Chemung formation is applied, in Pennsylvania, Maryland and northern Virginia, to a series of marine sandstones and green, gray and brown shales of late Devonian age which are older in part and in part grade laterally into the continental red beds known as the Catskill facies. The Chemung formation, as so designated, overlies sandstones and shales containing Portage fauna and designated as the Portage formation. In western New York and north-western Pennsylvania, the Chemung is overlain by younger marine Devonian beds variously named but absent in Virginia. (Op. cit., page 413)

The exact boundary between the Chemung and the underlying Brallier shale is difficult to determine, since the contact is gradational between these two formations. The Chemung contact is drawn where Cyrtospirifer disjunctus first appears. This is generally the only criterion available for drawing the Chemung-Brallier contact, since there is rarely any lithologic change. (Willard, 1939, page 248) "Chadwick (Geol. Soc. Am., Bull., vol. 46, pages 305-342, 1935) characterizes the Chemung fauna by the presence of: Strophonella coelata, Douvillina mucronata (cayuta auct.), Leptostrophia nervosa, Dalmanella corinata, Atrypa aspersa (spinosa), Pterinea chemungensis, Pterinea reversa, Byssopteria radiata, Goniophora chemungensis" and others. (Op. cit., page 248) The shale beds of the Chemung are green colored when fresh, weathering to yellow, lumpy and less fissile than the Brallier shale beds. The sandstone beds are coarser grained, thicker, and form a larger proportion of the formation than in the Brallier shale. (Butts, 1933) "In some areas, beds of red shale are present, as in the Elliott Knob-Crawford Mountain ridge northwest of Buffalo Gap, Augusta County, and on the west slope of Price Mountain in the east angle of Craig County. In other areas, as on Mason Creek north of Salem, Roanoke County, thick-bedded, medium-grained, compact hard reddish or purplish sandstone is a conspicuous constituent." (Wilmarth, page 34)

In northern Virginia the Chemung is estimated to be 2,000 feet thick. It thins somewhat to the southwest and is reported by J. H. Swartz as 1,800 feet thick in Smyth County and in passing to the south loses entirely its typical character and changes into beds of pure Portage lithofacies; greenish-gray shales weathering to a cream color. (Schuchert, 1941)

Catskill facies. The Catskill facies is found in New York, New Jersey, Pennsylvania, Maryland and western Virginia. The type section is in the Catskill Mountains, Greene County, New York. The definition of the Catskill has been under almost constant revision ever since 1840 when W. W. Mather (N. Y. Geol. Surv. 4th Rept.) defined Catskill Mountains series as "white, gray and red conglomerates; with gray, red, olive, and black grits, slates and shales. Overlies Helderberg (Onondaga) limestone series and underlies the coal-bearing rocks of Carbondale, Penna." (Wilmarth, page 373) "In 1936, Bradford Willard (Geol. Soc. Am. Bull., vol. 47, no. 4) used the term Catskill as a phase or facies term to include all the continental Devonian beds. G. H. Chadwick, in 1936, (N. Y. State Mus., Bull. 307) proposed to restrict

Catskill to the beds exactly correlating with 'what we now understand as the Senecan series of the Upper Devonian' and to exclude beds of Hamilton age."

"The United States Geological Survey applies the name Catskill formation to the nonmarine red sediments contemporaneous and intertonguing with marine sediments ranging in age from Hamilton to Chemung, both inclusive, and in part later than the Chemung, extending from New York to western Virginia." (*Op. cit.*, page 375)

In Virginia the Catskill formation is composed mainly of red shale with a few strata of red sandstone. Locally there are beds of brown or gray shale or sandstone. The contact with the Chemung is gradational as mentioned above. It may be seen in the Elliott Knob area of Augusta County. The Catskill reaches a maximum thickness of 2,000 feet in northern Virginia. It thins southward, and its southern limit is in the Elliott Knob area of Augusta County. (Butts, 1933)

The Silurian-Devonian Boundary

The stratigraphic position of the Silurian-Devonian boundary in eastern United States, especially in the central Appalachian area, has long been a question of debate. In Virginia and Maryland the age of the Keyser is directly related to this discussion, since it lies immediately below the Coeymans, which is a recognized member of the Helderberg group of the Lower Devonian, and above the Tonoloway which is of unquestioned late Silurian age. The Keyser has been classed in the past both as Silurian and Devonian. Although there is still some controversy, the United States Geological Survey and the Virginia Geological Survey, at the present time, regard the Keyser formation as the basal member of the Helderberg group.

The principal difficulty in solving the problem of the Silurian-Devonian boundary is that the best Upper Silurian-Lower Devonian sequence of rocks, in the writer's opinion, was not worked in detail until after the "poorer" sections with greater gaps in depositional history had been established as standard sections. Murchison, Sedgewick, Lonsdale and others in England, and D'Halloy, Dumont, deVerneuil and others, together with Murchison and Sedgewick established the Silurian-Devonian boundary in the Rhineland area of Germany. In New York, Hall, Vanuxem, Clarke, Schuchert, etc. drew the Silurian-Devonian boundary and roughly correlated it with the accepted European section. Ulrich, C. K. Swartz, Butts, Schuchert, F. M. Swartz and others, working in Maryland and Virginia attempted to correlate their area to those of New York and Europe. Their problems and offered solutions started a series of discussions that have lasted for almost forty years.

The entire discussion of the Silurian-Devonian boundary usually revolves around the question of the age of the Keyser formation in the central Appalachian area because it lies between accepted Silurian and Devonian units. The Keyser is older than the Coeymans and younger than the Bertie of the accepted New York State "standard" sections.

The writer has noted a chemical relationship at the Silurian-Devonian boundary as defined for western New York State by Clarke and Schuchert in 1899, which may, when applied in Virginia, present an additional argument for placing the Keyser in the Devonian system and the Silurian-Devonian boundary between the Keyser and the Tonoloway. At Gunnville, New York, about eighteen miles east of Buffalo, the silica content of the Onondaga limestone increases toward its base. The silica is in the form of chert. The Silurian Bertie water lime, which there underlies the Onondaga limestone, New York area, is a high-magnesia limestone. Thus, descending, the silica content drops abruptly at the base of the Onondaga and there is an immediate increase in the magnesia content below the hiatus representing the Silurian-Devonian boundary. The Helderberg group in this area is missing in the Bertie-Onondaga hiatus.

In the eastern part of the State, at Alsen where the Helderberg group is present, a similar chemical change as mentioned was noted between the Coeymans and Manlius formations. In this area the Silurian-Devonian boundary is placed at the Manlius-Coeymans contact. The Coeymans silica content is higher than that of the Manlius. The magnesium carbonate content of the Manlius is higher than that of the Coeymans. The calcium carbonate content of the two formations is approximately the same.

There are no reliable chemical analyses of known stratigraphic horizons available to the writer, up to the time of this writing, between Alsen, New York, and Fordwick, Virginia. To be sure, there are published chemical analyses of the formations being discussed, between Alsen and Fordwick, but the manner in which the formations were sampled is not known. The writer is reluctant to use any published analysis, unless it is known to be truly representative of the formation. Many of the published analyses were made from a single rock specimen which represented just one bed rather than the entire formation. Several vaguely correlated diamond drill core analyses from the Saylorsburg, Pennsylvania, area seem to confirm the silica-magnesia relationship of the Silurian-Devonian boundary. In this area the Keyser is a high-silica, low-magnesia limestone and the underlying Bossardsville, which is unquestioned as the correlative of the Tonoloway in Maryland and Virginia, is a low-silica, high-magnesia limestone.

In the Fordwick area there is a chemical distinction between the Keyser and Tonoloway similar to the Onondaga-Bertie differences at Gunnville, New York; the Coeymans-Manlius differences at Alsen, New York, and the Keyser-Bossardsville differences at Saylorsburg, Pennsylvania. The silica content is high (30-50%) in most of the Keyser at Fordwick. The Tonoloway does not crop out, but,where penetrated by diamond drill holes, is a dolomitic limestone. The closest surface outcrop of the Tonoloway is at Bells Valley. Samples from there are chemically similar to the Tonoloway from the drill cores.

The chemical distinction at the Silurian-Devonian contacts above listed is not present between the Coeymans and Keyser in the Fordwick area. The Coeymans is a high-lime, low-silica, low-magnesia limestone with no chemical properties resembling the basal Devonian bed at the recognized Silurian-Devonian boundaries in New York and eastern Pennsylvania. The Keyser, having a high-silica, low-magnesia content, in no way chemically resembles the uppermost Silurian bed in New York and eastern Pennsylvania. The chemical similarity of the Keyser-Tonoloway relationship to the Silurian-Devonian relationship in New York and eastern Pennsylvania, in the writer's opinion, supports his thesis for placing the Keyser in the Helderberg group.

C. K. and F. M. Swartz (Swartz, C. K., 1941, Pl. 1) correlated the Keyser in Virginia, Maryland and Pennsylvania, with the Manlius, Rondout and Decker formations in northern New Jersey and southeastern New York, Their interpretation was based on the presence of Chonetes jerseyensis in the lower Keyser beds and in the Decker and Cobleskill formations.

The Keyser is disconformably overlain by the Coeymans throughout much of its extent and is, therefore, older than typical Helderberg. Hence, the question is not the relation of the Keyser to the Manlius of southeastern New York but to the Manlius of central New York. Perhaps the southeastern New York Manlius is the correlative of the central New York Manlius. (Op. cit.) Ulrich was not in agreement with this correlation, for in 1912 (Md. Geol. Surv., Lower Devonian) he reported Cobleskill faunas in the Tonoloway of Maryland and the Keyser-Decker beds as represented in the top of the Manlius at Manlius, New York.

The late Silurian age of the Manlius in New York is not based on assured evidence. The central New York Manlius was deposited in a restricted sea with a restricted fauna, whereas the unquestioned Helderberg was deposited in an open sea with abundant life. The faunal dissimilarity between the Helderberg and Manlius is an expression of their ecology and not a reliable time indication. (Swartz, C. K., 1941)

The correlation of the Tonoloway-Coeymans sequence, on paleontologic and stratigraphic evidence, from Virginia and Maryland to New York is questionable. There is doubt as to the equivalence of the Keyser of Virginia, Maryland and central Pennsylvania with the entire Manlius-Rondout-Decker sequence of northern New Jersey and southeastern New York.

Figure 5 shows the silica-magnesia relationship at the four localities mentioned above. It will be noted that the Alsen sequence is not in paleontologic agreement with the Saylorsburg and Fordwick sequences as currently interpreted by the Pennsylvania, New Jersey and New York Geological Surveys. If Ulrich's opinion, as mentioned above, is used (also based on paleontologic evidence), the Keyser must be considered in part at least as younger than the Manlius. The chemical evidence is in agreement with Ulrich's paleontologic data. The present writer suggests there may have been two basins of deposition, one in New York and northern New Jersey and a second in Pennsylvania, Maryland and Virginia with perhaps a shallow water, interbasin connection. The New York Manlius, under such conditions may be considered a reversion to high magnesia type deposition in a separate basin; or the upper Keyser, in the Pennsylvania-Maryland-Virginia basin may be considered as correlative to a Manlius-Coeymans hiatus in the New York-New Jersey basin.

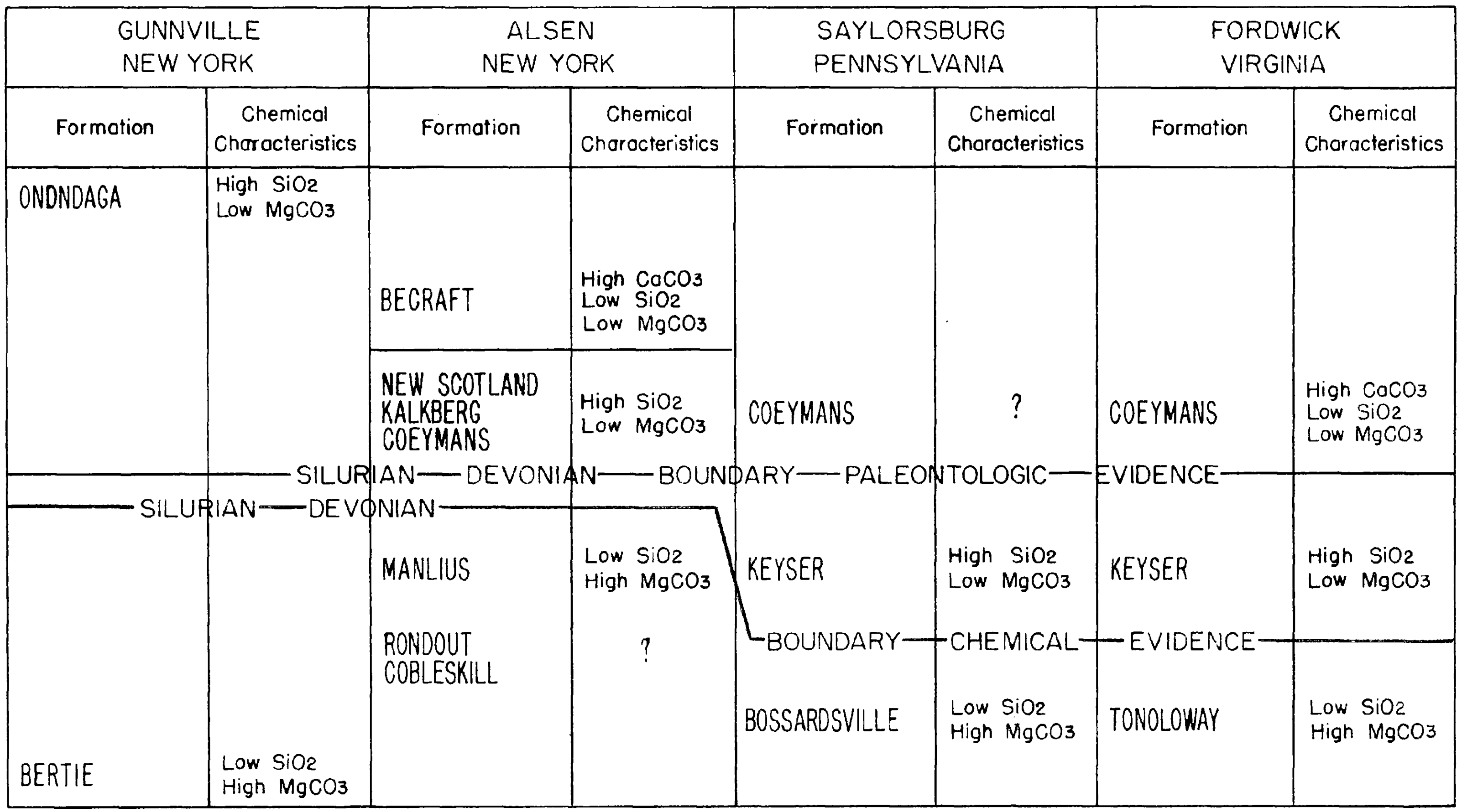


Figure 5
SILICA – MAGNESIA RELATIONSHIP AT
SILURIAN – DEVONIAN BOUNDARY

Upon the reasons given here, the writer is of the opinion that the Keyser rightly belongs in the Devonian and that it is an early or basal Helderberg formation not found in the "standard" New York section. This chemical interpretation of the Silurian-Devonian boundary, in the writer's opinion, presents a new approach to the problem. In summary, the following facts are offered:

Reasons Cited for Placing the Keyser in the Silurian:

1. "The Keyser is not equivalent in age to the beds included in the Helderberg group of the Helderberg Mountain area, since the term was revised in 1899" (by Clarke and Schuchert). It is instead the correlate of beds below the Helderberg group as so defined. (Swartz, C. K., 1941, page 1188)
2. "The Keyser limestone is separated from the Coeymans limestone of the Helderberg group by a widespread disconfirmity." (*Op. cit.*, page 49)
3. "The present weight of evidence favors the view that the Keyser is essentially equivalent to the Cobleskill-Manlius beds of central New York. The Silurian age of the latter beds has never directly been questioned. However, the importance of this argument is reduced by the imperfections of the faunas of the New York formations." (*Op. cit.*, page 49)

4. "The Keyser fauna contains significant species derived from underlying Silurian beds. These include *Stenochisma lamellata*, *Spirifer vanuxemi* and *Calymene camerata* from the Tonoloway, *Halysites catenulatus* from older formations." (*Op. cit.*, page 49)

5. "The Keyser fauna contains only a few of the species which have been cited in support of the Devonian age of the Helderberg group." (*Op. cit.*, page 49)

6. "The occurrence of linking species in both the Keyser and Helderberg faunas is not conclusive evidence of the Devonian age of both. They do show that the hiatus between the Keyser and Coeymans was not very long continued." (*Op. cit.*, page 49)

7. "It [Keyser] has water lime beds like those of the late Silurian." (Schuchert, 1941, page 223)

Reasons Cited for Placing the Keyser in the Devonian:

1. The Keyser introduced a time of extensive invasions of normal marine waters into the Appalachian trough in Virginia and Maryland following a period of abnormal conditions that prevailed during Tonoloway time. The Keyser inaugurated a period of extensive marine submergence that characterized the Lower

Devonian as compared to the Upper Silurian of the Appalachian area. (Swartz, F. M. in Willard, 1939, page 48)

2. The Keyser contains many species closely related to the Coeymans and New Scotland forms as well as early species of several important Devonian genera. These forms are abundant in Maryland and Virginia but rare in the New York equivalents of these formations. (Ex.: Chonetes jerseyensis) The age of the Keyser should be determined on the full fauna of the Maryland-Virginia area and not on the impoverished New York fauna. (*Op. cit.*, page 49)
3. Following the principle that the age of a formation is the same as the age of the youngest fauna present, the Keyser, which contains Helderberg elements, should be considered Helderbergian. (Swartz, C. K., 1913)
4. The widespread submergence and favorable conditions of marine life during Keyser time was more in keeping with the conditions during Helderberg and early Devonian time than with conditions which prevailed during Tonoloway (late Silurian) time. (*Op. cit.*)

5. The chemical relationship of the Keyser and Tonoloway, as described above, suggests the Silurian-Devonian boundary should be placed at the base of the Keyser rather than at the base of the Coeymans.
6. "The Keyser sea is transgressive from south to north, as if heralding Lower Devonian time. (Earlier seas are also southern)." (Wilmarth, p. 223)

GENERAL GEOLOGY OF THE FORDWICK AREA

STRATIGRAPHY

Figure 8, Geologic Map of the Fordwick Area, shows the distribution of the various formations and their structural relations.

Silurian

In this paper the Tonoloway is considered the youngest Silurian formation present in south-central Virginia. The Keyser, currently assigned by F. M. Swartz to the Silurian, is included with the Devonian system (see Silurian-Devonian boundary discussion). The nearest outcrop of the Tonoloway formation to the area covered is at Bells Valley about five miles southwest of Fordwick, where it is a blue, thin-bedded, dolomitic, nodular limestone.

Lower Devonian

Helderberg group. In the Fordwick area, following the current correlation by the United States Geological Survey, the Helderberg group includes (ascending order) the Keyser, Coeymans, New Scotland and Becraft formations. The Keyser includes the Clifton Forge sandstone member. (See Figure 6)

Keyser limestone. The Keyser limestone, in the Fordwick area, is best exposed in Possum Hollow a quarter mile northeast of Fordwick and northeastward from the

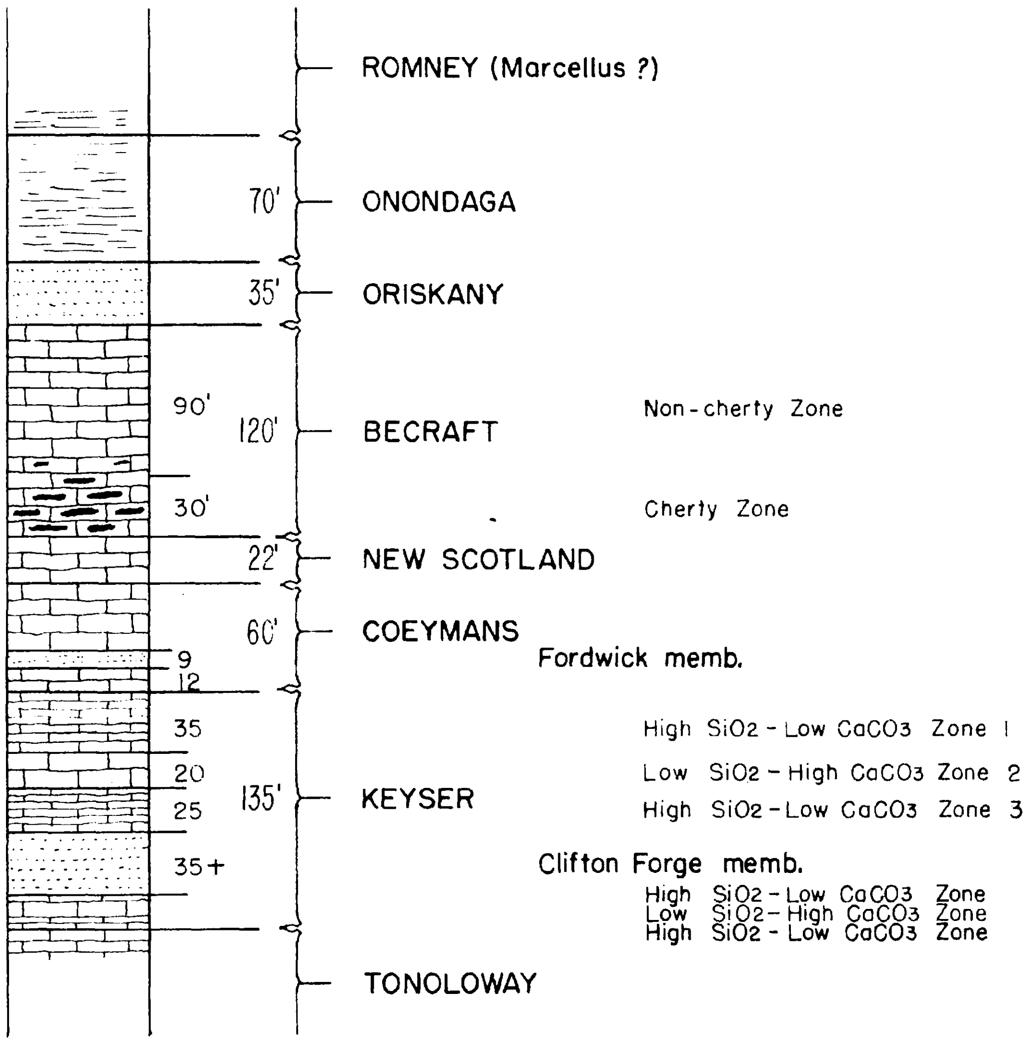
Hollow along the northwest side of Brown Ridge. The Keyser is also exposed in an abandoned quarry on the southeast side of Black Oak Ridge one and one-half miles south of the Chesapeake and Ohio Railroad cut through the ridge. The upper half of the Keyser and the contact with the overlying Coeymans can best be seen in the cut. Several diamond drill holes in McCutcheon Ridge, near the Augusta-Rockbridge County line, penetrated the Keyser through the Clifton Forge sandstone member, although there are no local exposures of the Keyser. The total thickness of the Keyser, reconstructed from diamond drilling, is 135 feet comparable with 134 feet at Bells Valley (Swartz, F. M., 1929).

The Keyser limestone can be clearly separated into several lithological zones each of which bears distinct physical and chemical characteristics. Within the area studied these zones are consistent and uniform.

The upper thirty-five feet of the Keyser (Zone 1, Figure 6) is dark-gray, thin- to medium-bedded, siliceous limestone. The calcium carbonate content is low, the silica high. (See Table III) When struck with a hammer, small chips spall off, possibly due to the high-silica content. Fossils are scarce in most of the outcrops of this zone. The most fossiliferous site is in an abandoned quarry on the southeast side of Black Oak Ridge two miles southeast of Fordwick.

Figure 6

GEOLOGIC COLUMN
FORDWICK, VIRGINIA AREA



The zone is the best source of water. All except one of the springs in the Fordwick area are located in it. Hence, a spring implies proximity to the Keyser-Coeymans contact, because the springs are usually in the top fifteen feet of the high-silica zone. The one exception is a spring in the Becraft on the northwest side of Black Oak Ridge near the Craigsville plant of the Stillwater Woolen Mills.

Immediately under the low-calcium carbonate - high-silica beds is a high-calcium carbonate zone twenty to twenty-two feet thick of coarsely crystalline, light bluish-gray, thick-bedded limestone (Zone 2, Figure 6). Lithologically it is similar to the Coeymans limestone, except that the Coeymans contains crinoid stems, is more coarsely crystalline, includes pink calcite crystals and has a slightly lower silica content.

A second high silica bed of the Keyser (Zone 3, Figure 6) underlies the high lime bed. It is a black, thin-bedded, fine-grained, hard, siliceous limestone, closely resembling the upper siliceous zone. It is far easier to distinguish these siliceous beds chemically than lithologically. (See Table III.) Fossils are not abundant. The thickness of this zone is hard to establish, since the Tonoloway is not exposed. The few diamond drill holes which did enter the Tonoloway indicate the thickness of the zone to be about seventy-five feet.

The Clifton Forge sandstone member of the Keyser is present in the lower third of the formation. In the Fordwick area it is in the lower siliceous zone. The Big Mountain shale member is not exposed. Where the Clifton Forge sandstone crops out on the sides and crest of Brown Ridge northeastward from Fordwick, it is a medium-grained, thick-bedded, light-gray rock which weathers dark-brown. Fossils are few and poorly preserved. Stratigraphically the Clifton Forge is the oldest rock exposed in the Fordwick area. Approximately thirty feet of the sandstone is exposed, but everywhere the base is hidden.

The Frontispiece illustrates the influence of the Clifton Forge sandstone on the terrain. In the picture, Brown Ridge slopes to the right (south). The crest, which rises sharply south of the Lehigh Portland Cement Company plant stack, marks the contact of the Clifton Forge sandstone with the overlying Keyser limestone. (See Section CC, Figure 13.)

Coeymans limestone. The Coeymans in the Fordwick area crops out on both sides of Black Oak Ridge south of the Chesapeake and Ohio Railroad cut; on the southwest side of Brown Ridge at Fordwick; in a narrow band along the southeast side of Brown Ridge; and on McCutcheon Ridge. The present workings of the Lehigh Portland Cement Company have uncovered it on the southwest end of Brown Ridge. Previous workings of the Company exposed the formation on McCutcheon Ridge at the Rockbridge-Augusta County line and on the southeast side of Black Oak Ridge south of Fordwick.

The Coeymans is massive, coarsely crystalline, thick-bedded, crinoidal limestone, pale-gray, often contains numerous pink calcite crystals. The calcium carbonate content ranges between 94 and 98 per cent. The surface of the limestone beneath the soil is karst. In the Possum Hollow area there is a ten-foot shaly zone about forty feet above the base. In McCutcheon Ridge a four-foot shale zone, about forty-two feet above the base, was not seen on the surface but was penetrated by several diamond drill holes. A lenticular sandstone, up to nine feet thick lies twelve feet above the base of the Coeymans. This bed will be described as the Fordwick member of the Coeymans formation.

The Coeymans normally is fifty-eight to sixty feet thick in the Fordwick area. These figures check exactly with those reported at Bells Valley five miles south of Fordwick. (Swartz, F. M., 1929) There are two exceptions to the above figures. Diamond drill holes in the northwest side of McCutcheon Ridge and northwest side of Brown Ridge, in the vicinity of Fordwick, penetrated 95+ feet of Coeymans-like, coarsely crystalline, thick-bedded, crinoidal limestone. Because the overlying Becraft has been eroded, the exact thickness of the Coeymans limestone cannot be determined at these two localities. Eospirifer macropleurus was not found in the Brown Ridge cores. The McCutcheon quarry cores were destroyed. Hence, no exact determination of the thickness of the Coeymans or the New Scotland, which the writer believes is present as a non-cherty limestone in both areas, can be made. The normal, combined thickness of the Coeymans-New Scotland in the Fordwick area and Bells Valley is 78 to 80 feet. The areas of thickening of the Coeymans-New Scotland are on the northwest limb of the Brown Ridge anticline and its southwestward extension on McCutcheon Ridge where no evidence has been found of faulting. The only known reason for this change is the shaly zone found only in the two localities where the Coeymans-New Scotland interval has thickened. Since this shaly zone occurs forty to forty-two feet above the base of the Coeymans, the writer believes the Coeymans, rather than the New Scotland, thickened. No faunal or chemical evidence has been found bearing upon this statement.

The contact between the Coeymans and Keyser is well exposed in the Chesapeake and Ohio Railroad cut through the north end of Black Oak Ridge and in the Gay quarry of Lehigh Portland Cement Company. It is visible in other localities of the Fordwick area but none shows the contact as well. The contact may be considered disconformable in that the coarsely crystalline, pure Coeymans limestone overlies the fine-grained, siliceous Keyser limestone.

There is no angular discordance nor evidence of erosion of the top of the Keyser. The same type of silica occurs in both formations, i.e. single or double terminated quartz, chert, and other siliceous compounds. The writer believes that the Keyser-Coeymans hiatus must have been short.

The Fordwick sandstone member. Locally the Coeymans has a seven- to nine-foot sandstone stratum about twelve feet above the base. This bed the writer here names the Fordwick sandstone member of the Coeymans. It is lenticular and is exposed on the northwest side of Brown Ridge, across the crest of the ridge southward from Fordwick and northeastward along the southeast side of the ridge; on both sides and across the crest of Black Oak Ridge about two miles south of the Chesapeake and Ohio Railroad cut; and in McCutcheon Ridge. It is not present in the Gay Quarry of the Lehigh Portland Cement Company at the southeast end of Brown Ridge nor in the railroad cut. The Fordwick member is a medium- to coarse-grained, thin-bedded, unfossiliferous, light-gray sandstone which weathers light chocolate-brown and pitted.

The Fordwick sandstone shows an extensive ripple-marked surface in the brook flowing southeastward off Black Oak Ridge and entering the Little Calfpasture River about three hundred yards south of the abandoned No. 3 quarry of Lehigh Portland Cement Company. The sandstone forms the bed of the brook for a distance of about one hundred yards. The ripple marks strike N.5°E. This is the only place where these marks have been found in the Fordwick sandstone.

The Fordwick sandstone influences the topography of Brown Ridge. (See Frontispiece.) The crest rises abruptly to the right of the Lehigh Portland Cement Company stack and slopes gently southward for a picture distance of about three inches. The Fordwick sandstone crops out on the crest.

New Scotland. In the Fordwick area the New Scotland is exposed in both flanks of Black Oak Ridge; across Brown Ridge about one mile southeast of Fordwick and northeastward along the southeast flank of the ridge; and on the northwest flank of McCutcheon Ridge. Throughout the Fordwick area, in both the cherty and the non-cherty phases, the New Scotland ranges between twenty-two and twenty-five feet thick, as based on the stratigraphic range of *Eospirifer macropleurus* not lithology or chemical analyses.

The New Scotland in the Fordwick area exhibits two distinct lithologies, both of which are easily confused with the adjacent formations, were it not that the New Scotland is distinguishable paleontologically. In Black Oak Ridge, in the vicinity of Craigsville, the cherty New Scotland limestone closely resembles the overlying

Becraft cherty limestone. A mile and a half southwestward along the southeast flank of Black Oak Ridge where the New Scotland is well exposed in an abandoned quarry, as in all of Brown Ridge and McCutcheon Ridge, it is a non-cherty, coarsely crystalline limestone nearly identical to the underlying Coeymans. F. M. Swartz (op. cit.) found this same New Scotland-Coeymans similarity at Bells Valley. The chemical similarities parallel the lithologies. The only sure way to identify the New Scotland is the presence of Eospirifer macropleurus, usually present, though not plentiful in the area.

The cherty phase of the New Scotland is a dark, fine- to medium-grained, medium-bedded limestone containing a large amount of interbedded, black chert. The old "marble" quarry and an abandoned limestone quarry in Black Oak Ridge northeast of the Chesapeake and Ohio Railroad reveal cherty New Scotland and overlying Becraft. The chert in both formations, when freshly exposed, is black. Upon long-continued weathering, the chert in the Becraft turns light-gray to almost white, while that in the New Scotland remains darker-gray. Chemically the New Scotland and Becraft cover identical ranges in all constituents. If ten or twelve random samples of each formation are analyzed and the average results for each formation compared, the silica of the New Scotland will very likely be a per cent or so higher and the calcium oxide correspondingly lower than these constituents of the Becraft. The per cent of chert in the New Scotland insoluble residue on the average is slightly higher (up to 5%) than in the Becraft.

The non-cherty phase of the New Scotland is similar to the Coeymans. Chemically they are identical. Even on the basis of the calculated tricalcium silicate, (see page 81 for formula) which would emphasize any differences in silica and calcium oxide especially, there is no difference noticeable. In the insoluble residue studies no authigenic feldspar was found in the New Scotland but it was found in the Coeymans.

Since the New Scotland is concealed by surface cover between the cherty phase at Craigsville and the non-cherty phase where it is exposed on the southeast flank of Black Oak Ridge a mile and a half to the southwest, the writer was unable to determine if the change in lithology is abrupt or gradual. No intermediate phase was found cropping out anywhere in the Fordwick area.

Becraft. The Becraft is well exposed in the Chesapeake and Ohio Railroad cut; along the northwest side of Black Oak Ridge; on the southeast side of Black Oak Ridge two miles southeast of the railroad cut; across Brown Ridge one and a half miles southwest of Fordwick; on the southeast flank of Brown Ridge and on the northwest side of McCutcheon Ridge.

The Becraft formation, the youngest member of the Helderberg group in central Virginia, can be separated into two lithologic zones in the Fordwick area. The lower is twenty-five to thirty feet thick and contains a large quantity of chert, the upper, about ninety feet thick, contains no chert. There is no sharp contact between the two zones, but the cherty limestone is transitional with the non-cherty limestone within five feet. There is no faunal difference. Chemically there is a marked difference shown in Table III, Chemical Analyses.

The cherty zone of the Becraft is a medium- to fine-grained, dark-gray, thin- to medium-bedded, dense, siliceous limestone with interbedded layers of black chert nodules. These layers usually range from one to four inches thick. The rock in the non-cherty zone is fine- to medium-grained, dark-gray, medium-bedded, dense limestone.

The Becraft, especially the non-cherty zone, decomposes rapidly when exposed to solvent action of water. The subsoil surface is always karst wherever the overlying Oriskany sandstone has been removed, and the Becraft subjected to the full effect of the water. The ease of solution of the Becraft has resulted in numerous sink holes wherever the formation comes to the surface. This characteristic of the Becraft is of great aid in areal mapping in the Fordwick area, since none of the other formations exhibit this property.

The Becraft is not a common source of water even though it does contain many sink holes. Only one spring has been found in the formation. It is located on the northwest side of Black Oak Ridge. This spring maintains a constant year-round flow and supplied Craigsville with water before the town developed its present water supply on Little North Mountain.

In the Fordwick area the contact of the Becraft with the overlying Oriskany sandstone is generally marked by a one- to four-foot zone of sandy, reddish-brown clay wherever ground water has circulated. This type is exposed at the southern end of Brown Ridge and the northeast end of Black Oak Ridge. On the southern part of Black Oak Ridge, where the Becraft-Oriskany contact has not been affected by solution weathering, the clay seam is absent.

Oriskany sandstone. In northern and western Virginia and Maryland the Oriskany is divided into the Shriver chert below and the Ridgeley sandstone above. In the Fordwick area the Shriver is missing. Since only the sandstone is present, the term Oriskany sandstone is applied.

The Oriskany sandstone is exposed in the Chesapeake and Ohio Railroad cut and northward along the northeast flank of Black Oak Ridge and on the western side of the Little Calfpasture River valley; on the crest and northeast side of Black Oak Ridge southward from the railroad cut; on the southeast flank of Black Oak Ridge about three miles south of the railroad cut; in the Little Calfpasture River valley about two miles south of Fordwick and on the crest of the southern part of Brown Ridge.

The Oriskany, youngest of the three sandstones found in the Fordwick area, attains a maximum thickness of thirty-five feet. It overlies the Becraft limestone and underlies the Onondaga shale member of the Romney formation. It is a medium-grained, medium- to massive-bedded, light-gray, weathering to a medium- to dark-brown, friable sandstone containing many molds of fossils. Costispirifer arenosus, common throughout most of the exposures, is a diagnostic fossil.

The Oriskany influences the topography. Referring again to the Frontispiece, note that the crest of Brown Ridge, above the southern edge of Fordwick, rises abruptly, then slopes gently southward. This slope marks the Oriskany outcrop.

Middle Devonian

Onondaga formation. The Onondaga formation in central and northern Virginia has usually been mapped as the basal member of the Romney shale. In the Fordwick area the Onondaga is distinguishable from the balance of the Romney shale. It overlies the Oriskany sandstone and underlies the black, fissile Marcellus shale member of the Romney formation. The Onondaga is a greenish-brown to yellow green shale which turns yellow upon weathering. The argillaceous zones weather weakly fissile, the arenaceous friable or fracture into small blocky pieces roughly a quarter- to half-inch thick and about an inch square.

In the Fordwick area, the Onondaga shale is exposed on Black Oak Ridge northward from the Chesapeake and Ohio Railroad cut; in the valley northwest of Black Oak Ridge; in the valley southeast of Brown Ridge and in the valley between Black Oak Ridge and Brown-McCutcheon Ridges south of the junction of Smith Creek with Little Calfpasture River. In all the Onondaga exposures, except the shale quarry of Lehigh Portland Cement Company, the material is so deeply weathered that almost all the fossils are unrecognizable except *Phacops rana*. Only fragments of this trilobite were found. After the weathered shale at the shale quarry had been removed, brachiopods, ostracods and gastropods have been found in the exposed "fresh" material (see Paleontology). The Onondaga is the youngest rock formation exposed in the area being described.

CORRELATIONS

Insoluble Residues

Sample Preparation

All samples for insoluble residue studies were furnished by the Lehigh Portland Cement Company. Each sample, approximately thirty-five grams as received, was a representative portion of five to ten feet of crushed drill core and was taken from the bulk sample remaining after the representative portion desired by the Company for chemical analysis had been removed. Standard sampling procedure was followed. The samples were then quartered, crushed, sieved and digested in acid as outlined in the flow sheet (Figure 7). Residues were prepared from a 10 gram ± .1 gram samples. For the first 25 samples both the -100 +200 mesh and -200 mesh portions were prepared and digested in acid. Because the residues for these two size fractions differed only in particle sizo, the use of the -200 mesh sieve was discontinued. Residues were prepared for 467 samples.

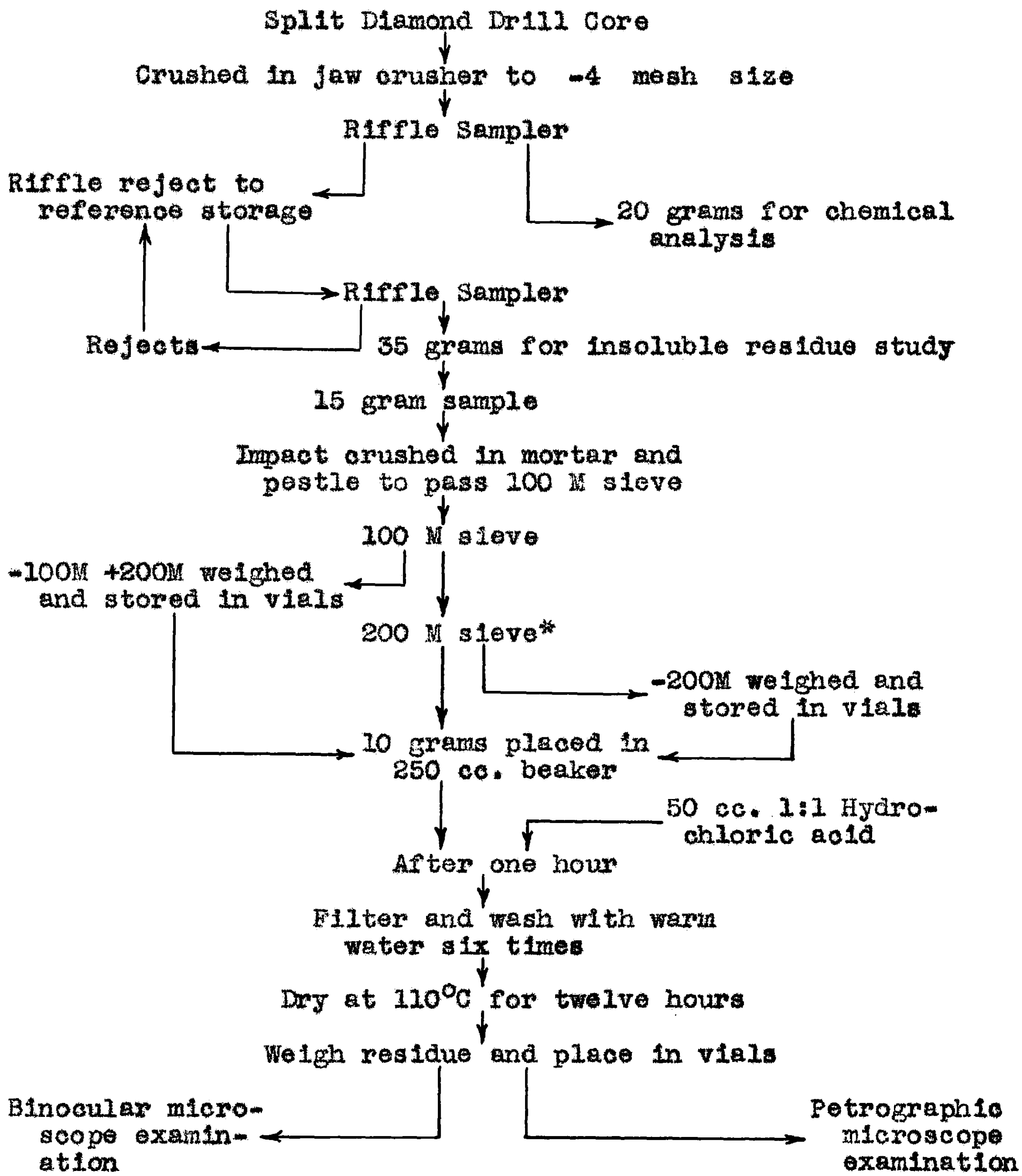
During the sample preparation a relationship of the silica to grindability was noted. As the silica increased the grindability decreased. The high-calcium oxide (CaO), low-magnesium oxide (MgO), low silica (SiO_2) beds of the Keyser, Coeymans and New Scotland formations tend to powder under impact. The high silica beds are tougher and break into small fragments rather than mashing directly to a powder.

The insoluble residue was examined under a binocular microscope with both transmitted and reflected light. All mineral identifications were made by the oil immersion method with a polarizing microscope.

Figure 7

Insoluble Residue Sample Preparation

Flow Sheet



*Discontinued after the twenty-fifth sample was run.

Results

The weight per cent of insoluble residue was approximately equivalent to the weight per cent of SiO_2 plus R_2O_3 reported in the chemical analyses. Where the SiO_2 content was very low, as in the Coeymans, New Scotland and parts of the Keyser, it was necessary to digest 20 grams to obtain sufficient residue for further study. A summary of the weight per cent of residue and $CaCO_3$ is given in Table I.

The minerals identified and their occurrence are given in Table II. Authigenic feldspars were found only in the Coeymans formation, but were not restricted to any one zone or zones. They are rare and many residues showed none. No other minerals were of correlative value because they were scattered throughout the formations. Chert is present in all residues but predominates only in residues from the cherty phases of the New Scotland and Becraft. There is less chert in the New Scotland than in the Becraft.

TABLE I. PERCENTAGE OF INSOLUBLE RESIDUE IN THE FORMATION AT FORDWICK, VIRGINIA

Formation	No. of Samples	Avg. Wgt. Per Cent	Range of Weight Per Cent: Normal		Range of Weight Per Cent: Extreme		Samples in Extreme Range		Normal $CaCO_3$ Range	
			From	To	From	To	No.	Per Cent	From	To
Becraft	69	15.0	6.0	25.0	4.0	43.0	6	8.0	86	95
New Scotland (cherty)	26	12.0	4.0	20.0	3.0	36.0	2	8.0	79	90
New Scotland (non-cherty)	71	2.4	0.3	4.5	-	-	0	0.0	90	94
Coeymans	119	2.0	0.1	4.0	-	-	0	0.0	93	99
Keyser (Upper siliceous)	64	21.0	10.0	32.0	8.0	40.0	4	6.3	50	75
Keyser (Upper lime)	59	2.8	0.5	5.0	0.3	7.5	3	5.1	88	94
Keyser (Lower siliceous)	28	22.5	10.0	35.0	7.0	49.0	2	7.2	50	70
Keyser (Lower lime)	31	9.9	4.5	15.0	3.0	21.0	3	9.7	80	92

TABLE II. OCCURRENCE OF INSOLUBLE RESIDUE MINERALS

Minerals	Keyser				Coeymans			New Scot- land		Becraft	
	Lower Lime Zone	Lower Silica Zone	Upper Lime Zone	Upper Silica Zone	Below Shaly Zone	Shaly Zone	Above Shaly Zone	Cherty Facies	Non-cherty Facies	Cherty Zone	Non-cherty Zone
Albite	x	x	x		x					x	x
Apatite		x				x					
Augite	x										x
Chalcedony--small, radial	x			x						x	x
Chert	x	x	x	x	x	x	x	x	x	x	x
Chlorite			x	x							
Feldspar--authi- genic (microcline center)					x		x				
Garnet			x				x				x
Glauconite*		x*									
Gypsum					x		x				
Hematite	x	x		x				x	x	x	
Hornblende	x										
Leucoxene*		x*									
Microcline	x				x						x
Muscovite				x							x
Pyrite	x									x	
Quartz--crystalline	x	x	x	x	x	x	x	x	x	x	x
Quartz--double terminated		x	x		x		x	x	x		
Quartz--single terminated				x					x		
Sphalerite			x							x	x
Tourmaline--large, rounded, brown	x		x					x	x		x
Tourmaline--olive green		x						x	x	x	
Tourmaline--angular, brown		x		x	x					x	x

TABLE II. OCCURRENCE OF INSOLUBLE RESIDUE MINERALS (Continued)

Minerals	Keyser				Coeymans			New Scot-land		Becraft	
	Lower Lime Zone	Lower Silica Zone	Upper Lime Zone	Upper Silica Zone	Below Shaly Zone	Shaly Zone	Above Shaly Zone	Cherty Facies	Non-cherty Facies	Cherty Zone	Non-cherty Zone
Zircon--small, rounded	x		x	x		x		x			
Zircon--broken							x		x		x
Zircon--elongated				x		x				x	
Zircon--small, prismatic*					x*						
Zircon--prismatic, clear*									x*		

*One grain

Chemical Correlation

The writer had access to all of the Lehigh Portland Cement Company analyses for the area. Chemical composition is important in the manufacture of cement and for that reason it is necessary to know in detail the composition of the formations used in the cement raw mix. Continuous sections from drill cores are analyzed at relatively close intervals, so that results can be grouped together to construct chemical sections of the formations. In the Fordwick area, the percentages of all constituents of each lithologic unit characteristically fall within certain definite limits (see Table III). Experience has shown that in this area and others $CaCO_3$ and $MgCO_3$ are most useful in correlation. In some instances SiO_2 is useful.

Geologic sections using chemical composition as the basis for correlation were constructed by matching zones of similar composition which occupy the same relative position with respect to zones of different composition. Subsequent quarry operations have proven that such matching or correlation is valid. Practically all of the chemical correlation done in the Fordwick area was based on results obtained from diamond drill core samples. The samples obtained from outcrops in the area check chemically with the diamond drill cores from the same horizons. Drill cores are more reliable than outcrop samples where correlation is based on composition, because they give a continuous section of unweathered rock.

Chemical analyses of outcrop samples can be very misleading if the sample is not taken properly. It is extremely important to collect samples in the unweathered zone of the rock, especially when used in conjunction with results obtained from diamond drill cores. The sample should be taken no closer than three inches to an exposed surface or clay seam, particularly where dolomites and dolomitic limestones are being examined. A sample taken from the weathered surface may contain only two or three per cent $MgCO_3$, whereas a sample taken three or more inches in from the surface will have 20 per cent $MgCO_3$. The advantage of diamond drill cores, in addition to providing a continuous section, to obtain chemically true, unweathered samples is readily apparent.

It is not proposed to use chemical analyses as a sole means of correlation, but rather that they be used as an additional tool for the study of correlation and structural problems. The author has been fortunate in having a great quantity of chemical analyses to work with. When using chemical analyses for correlation the validity of the interpretations is directly proportional to the number of analyses available.

One distinct advantage of chemical correlation over paleontological correlation, when using diamond drill cores or well cuttings, is that each foot drilled will always give some data. Every rock has a chemical composition but not all rocks have fossils. Many drill cores of fossiliferous rocks fail to yield diagnostic fossils.

When using chemical analyses of drill cores for correlations, the spacing of the prospect holes is dependent on the uniformity of the beds and the complexity of structure. In the Fordwick area almost perfect correlation can be obtained with holes spaced at thousand-foot intervals along the strike if $CaCO_3$ and $MgCO_3$ determinations are made on every ten-foot composite of the core. The spacing of the holes across the strike is governed by the intensity of folding and faulting. Drill holes should not be spaced more than 300 feet apart normal to the strike. From the writer's experience in the Jacksonburg cement rock belt of the Lehigh Valley, where the beds have a wide chemical range and the structure is far more complex than in the Fordwick area, the holes should not be located more than three or four hundred feet apart parallel to the strike nor more than two hundred feet apart normal to the strike. In some cases correlation is impossible even with holes drilled on hundred-foot centers. In general, for most of the cement rock belt, holes spaced at two hundred-foot intervals, along the strike with carbonate analyses made on every ten-foot composite of core, are suitable for chemical correlation.

Where correlations cannot be made using $CaCO_3$ and $MgCO_3$, other chemical components of the stone may prove useful. Several examples will illustrate this principle:

1. The two low $CaCO_3$ beds of the Keyser formation in the Fordwick area are separable only on the basis of their silica content. The topmost zone of the Keyser (Zone 1, high SiO_2 - low $MgCO_3$) contains much more silica (40 to 55 per cent SiO_2) than the Zone 3 (high SiO_2 - low $MgCO_3$), (15 to 30 per cent SiO_2), (see Table III).
2. The lowest one hundred feet of the Jacksonburg cement rock member in the vicinity of Fogelsville, Pennsylvania, is a uniform lithologic unit. The $CaCO_3$ and $MgCO_3$ content of this zone is uniform throughout the area. However, the bottom 25 to 30 feet contain 28-30 per cent SiO_2, whereas the upper 70 feet contain 20-22 per cent SiO_2. This zone can be recognized in almost all drill cores cutting it.
3. Correlation using Al_2O_3 alone or the Al_2O_3/SiO_2 ratio is not possible at Fordwick. At Alsen, New York; in the Lehigh Valley cement rock belt, and in the bauxite deposits at Warm Springs, Georgia, the SiO_2/Al_2O_3 ratio is distinctive for each lithologic unit.

4. The tricalcium silicate value (C_3S) has been used successfully in several areas, including the Fordwick area. C_3S is one of the compounds formed in cement clinker. The potential C_3S value is commonly used in calculating the final mix control or kiln feed in the cement industry. It is determined from the oxide analysis of the drill core or quarry rock. The formula used is:

$$(C_3S) = 4.07\ CaO - 7.6\ SiO_2 - 1.43\ Fe_2O_3 - 6.72\ Al_2O_3.$$

Minus values are possible with this formula. Low-grade limestones, sandstones and shales give minus C_3S values. High-grade limestones may show plus values of 300 or more C_3S.

Table III lists the chemical composition of the various geologic units of the Fordwick area.

TABLE III. CHEMICAL ANALYSES OF FORMATIONS IN THE FORDWICK, VIRGINIA, AREA

Formation	Thickness	Location	SiO_2	Fe_2O_3	Al_2O_3	CaO	MgO	$CaCO_3$
Becraft--upper zone, non-cherty	90	4	6.9	1.0	1.5	88.8	1.8	
Becraft--upper zone, non-cherty	90	2	6.3	1.2	1.4	89.6	1.3	
Becraft--lower zone, cherty	25	4	23.1	1.6	2.5	70.9	1.9	
Becraft--lower zone, cherty	30	2	16.4	1.8	2.5	76.8	1.7	
New Scotland--cherty	20	5	22.7	1.9	2.6	70.2	1.8	
New Scotland--non-cherty	20	2	2.4	0.6	0.5	95.2	1.3	
New Scotland--non-cherty	20	3	2.9	0.7	1.1	93.7	1.6	
New Scotland--non-cherty	20	4	2.9	0.7	0.9	90.9	4.1	
Coeymans--above shaly zone	60	1	2.8	0.7	1.3	93.5	2.7	
Coeymans--shaly zone	10	1	19.9	2.0	6.0	62.4	9.7	
Coeymans--below shaly zone	40	1	5.2	0.9	1.4	88.7	3.8	
Coeymans--composite	60	2	1.4	1.2	1.7	93.9	1.7	
Coeymans--composite	90	3	2.6	0.6	0.9	94.1	1.8	
Coeymans--composite	60	4	2.4	0.8	0.8	91.8	3.8	
Keyser--upper silica zone No. 1	35	1	50.0	1.3	7.5	38.9	2.3	
Keyser--upper silica zone No. 1	35	2	18.8	1.9	4.0	67.4	7.5	
Keyser--upper silica zone No. 1	35	4	54.4	1.3	8.1	32.7	2.4	
Keyser--upper lime zone No. 2	20	1	8.0	0.9	1.6	86.7	2.8	
Keyser--upper lime zone No. 2	20	2	14.1	1.5	2.0	79.9	2.5	
Keyser--upper lime zone No. 2	20	4	5.7	0.8	1.2	89.5	2.7	
Keyser--lower silica zone No. 3	30	1	27.0	1.7	5.8	60.2	5.3	
Keyser--lower silica zone No. 3	30	4	28.0	2.4	8.6	48.7	5.5	
Keyser--lower lime zone	30	4	1.4	0.8	1.7	-	1.5	96.3

1. Brown Ridge--near Fordwick
2. Brown Ridge--near southwest end
3. McCutcheon Ridge
4. Black Oak Ridge--southwest of Fordwick
5. Black Oak Ridge--near Craigsville

Paleontology

Paleontology has been used only to establish, by conventional standards, the validity of the formations being worked. The fossils identified by the writer in the Fordwick area are listed in the following table:

TABLE IV. FAUNAL LIST

Formation	Keyser	Coeymans	New Scotland	Becraft	Oriskany	Onondaga
Coelenterata						
Cladopora	x					
Favosites helderbergiae Hall		x	x	x		
F. helderbergiae var. *praecedens* Schuchert	x					
Streptelasma strictum Hall			x	x		
Striatopora bella Swartz	x					
Stromatoporoidea undetermined	x					
Echinodermata						
Edriocrinus pocilliformis Hall	x					
Bryozoa						
Present but not determined	x	x	x	x		
Brachiopoda						
Actinopteria sp.						x
Anoplia nucleata Hall						x
Anoplotheca acutiplicata (Conrad)						x
Atrypa reticularis (Linné)	x	x				x
Camarotoechia altiplicata (Hall)	x	x	x			
C. gigantea Maynard	x					

TABLE IV. FAUNAL LIST (Cont'd.)

Formation	Keyser	Coeymans	New Scotland	Becraft	Oriskany	Onondaga
Brachiopoda (cont'd.)						
C. litchfieldensis (Schuchert)	x					
Crispella vanuxemi var. prognosticus Schuchert	x					
Chonetes jerseyensis Weller	x					
Costispirifer arenosus (Conrad)					x	
Dalmanella concinna (Hall)	x					
D. perelegans (Hall)			x			
Delthyris perlamellosus Hall		x	x			
Eatonia medialis (Vanuxem)			x			
E. peculiaris (Conrad)				x		
Eospirifer macropleurus (Conrad)			x			
Leptaena rhomboidalis (Wilckens)	x	x	x	x		
Meristella arcuata (Hall)		x	x			
M. praenuntia Schuchert	x					
Merista typa (Hall)	x					
Nucleospira concinna (Hall)						x
N. swartzi Maynard	x					
Orbiculoidea lodiensis (Hall)						x
Rensselaeria mutabilis (Hall)	x					

TABLE IV. FAUNAL LIST (Cont'd.)

Formation	Keyser	Coeymans	New Scotland	Becraft	Oriskany	Onondaga
Brachiopoda (cont'd.)						
R. ovoides (Clarke)					x	
Rhipidomella assimilis (Hall)				x		
R. emarginata (Hall)	x					
R. oblata (Hall)		x				
Schuchertella prolifica Schuchert	x					
S. sinuata (Hall and Clarke)	x					
S. woolworthana (Hall)		x	x	x		
Spirifer concinnus Hall				x		
S. cyclopterus Hall		x	x	x		
S. modestus Hall	x					
Stenochisma deckerensis (Weller)	x					
Stropheodonta bipartita (Hall)		x	x	x		
Uncinulus convexorus Maynard	x					
U. nucleolatus (Hall)	x					
Whitfieldella minuta Maynard	x					
Cephalopoda						
Bactrites sp.						x
"Orthoceras" sp.	x					

TABLE IV. FAUNAL LIST (Cont'd.)

Formation	Keyser	Coeymans	New Scotland	Becraft	Oriskany	Onondaga
Gastropoda						
Platyceras gebhardi Conrad			x			
P. multiplicatum F. M. Swartz		x				
Tentaculites gyracanthus (Eaton)	x					
Ostracoda						
Bollia obesa Ulrich						x
B. ungala Jones						x
Ostracods not determined	x					
Trilobita						
Calymene camerata Conrad	x					
Dalmanites sp.				x		
Phacops logani Hall				x		
P. rana (Green)						x
Proteus sp.	x					

STRUCTURE

In general, geologic structures of the Fordwick area are typical of the western half of the Valley and Ridge Province. They consist of a series of parallel anticlines and synclines striking generally northeast-southwest coinciding with the ridges and valleys of the area. The folds are mainly all simple and open, neither overturned nor thrust faulted. A normal fault is present along the southeast side of Brown Ridge.

Folds

As shown on the geological cross sections, there are two anticlines, whose axes coincide with the axes of Brown Ridge and Black Oak Ridge, separated by the synclinal valley of the Little Calfpasture River. The valley northwest of Black Oak Ridge is a syncline adjacent to the anticline of Great North Mountain. The rocks of Estaline Valley are not sufficiently exposed to allow accurate description of their aspect other than that they connect with the Little North Mountain anticline.

The axis of the Black Oak Ridge anticline strikes approximately N.45°E. and plunges northeastward about four degrees. As shown on section C-C (Figure 13), the southeast limb of the Black Oak Ridge anticline is steeper than the northwest. A secondary anticline developed east of the major crest is shown on section C-C by the flattening of the beds on the eastern side of the ridge. The secondary anticline merges with the major anticline of the ridge to the northeast. In section B-B (Figure 12), which crosses the northeast end of Black Oak Ridge near the Chesapeake and Ohio Railroad cut through the ridge, the secondary crest is absent.

The axis of the Brown Ridge anticline strikes approximately N.50°E. and plunges five degrees southwestward. The southeast limb is steeper than the northwest. The crest coincides with the crest of Brown Ridge except for the southwesternmost mile and a half where, near the junction of Smiths Creek with the Little Calfpasture River, the two axes are about four hundred feet apart. A small, closely folded syncline in the southeast section of Brown Ridge, and well exposed in the northeast wall of the Gay quarry of the Lehigh Portland Cement Company, is faulted out in the northeast section of Brown Ridge, section B-B.

Faults

The only important fault present is a normal fault along the southeast side of Brown Ridge. On the down throw side, the Onondaga is dropped against the Keyser, a vertical displacement of three hundred feet or more. The fault surface strikes approximately N.50°E. and dips approximately 82°S.E. at the extreme northeast end of the Gay quarry of the Lehigh Portland Cement Company, the only place where it is exposed. Drag folds are absent.

Slickensides indicate the relative direction of movement. The fault cuts across the syncline on the southeastern side of Brown Ridge. In the Gay quarry area the fault is in the southeast limb of the syncline. Five miles northeastward it cuts the southeast limb of the Brown Ridge anticline. It crosses the axis of the syncline approximately two miles east-southeast of the town of Fordwick.

GEOLOGIC HISTORY

Any discussion of the geologic history of western Virginia will deal primarily with the Paleozoic era, since the great majority of the material was deposited during that time. That of the Fordwick area will deal primarily with the Silurian and Devonian periods.

Early Paleozoic

The beginning of the Paleozoic era in eastern United States was marked by a gradual encroachment of the seas from the Gulf of Mexico and the Gaspe region of Canada into the Appalachian geosyncline bordering the west side of Appalachia. Virginia was flooded in early Cambrian time and remained submerged throughout much of the early and middle Paleozoic with occasional intervals of withdrawal and return of the sea.

Silurian

At the beginning of the Silurian period, Appalachia was still large. Erosion reduced the landmass throughout the period to low hills. The eroded sediments were spread westward in the geosynclines. Toward the close of Cayugan time, the seas cleared and limy deposition succeeded the earlier ferruginous materials as the Tonoloway dolomitic limestone was formed.

Devonian

The Silurian and Devonian in Virginia represents a time of almost continuous deposition from Upper Silurian

(Tonoloway) through controversial Lower Devonian (Keyser) into typical Helderberg. A short hiatus occurred between the Tonoloway and Keyser deposition. In the central portion of the Appalachian trough, comprising western Virginia, eastern West Virginia and western Maryland, submergence was most nearly continuous. Elsewhere in eastern United States the Silurian-Devonian hiatus represents a gap in depositional history that in some cases extends from Niagaran (Middle Silurian) to Ulsterian (Middle Devonian) time. The hiatus increases in magnitude southward and northward from the central Appalachian area.

The turbid sea environment prevailing throughout the central Appalachians during pre-Tonoloway time was probably caused by debris being carried into the Appalachian trough from the low hills which were the remnants of the early Silurian, mountainous Appalachia. By Keyser time the seas had cleared and, except for a period of turbidity in middle Keyser, remained clear until the close of the Helderbergian. A local uplift in south-central Appalachia in the middle of Keyser time rejuvenated the streams sufficiently to carry sands and silt into the sea and deposit the Clifton Forge sandstone in the southern portion of the central Appalachians and its facies counterpart, the Big Mountain shale, farther north and westward. By the close of Keyser time, lime depositing conditions returned and prevailed in the Appalachian trough, except for localized facies changes, throughout the balance of Helderbergian time.

The trough was generally submerged from New York to Virginia by the start of Coeymans time. The Manlius-Rondout-Cobleskill sequence in eastern New York may be represented in Virginia by the Keyser.

The orogeny started in late Helderbergian time. The writer believes this activity started south of Clifton Forge where sandstones were deposited during Becraft time. The rejuvenated streams carried sands into the Becraft sea. Today the Becraft southward from Fordwick to Clifton Forge changes from cherty limestone to sandstones. By Oriskany time Appalachia was so uplifted that streams carried sand into the sea to form the Oriskany sandstone. The lower Oriskany deposits in northern and western Virginia are cherty limestones, while contemporary deposits in Pennsylvania and New York, which were closer to the center of the main Acadian orogenic activity, are sandstones.

The advent of the Middle Devonian (Ulsterian) was marked by the deposition of the Onondaga shale in central Virginia (Fordwick area). To the south and north the shales grade into argillaceous or cherty limestones. By Erian and Senecan time mud was being deposited throughout all of the Virginian Appalachian trough. Mud, silt and sand continued to be deposited in the synclinal sea in

Chatauquan (Upper Devonian) time. During this latter epoch the Catskill continental facies started to displace the marine shales westward.

Post Devonian

During the Mississippian period streams carried vast amounts of sediments from Appalachia and deposited them in the continually subsiding Appalachian trough. During the lower third of the Mississippian, except in the extreme southwest part of the State, the Appalachian trough subsidence was about in balance with the rate of deposition and the land surface almost coincided with sea level. The shore line fluctuated greatly. During the middle Mississippian in Virginia, the Appalachian trough remained flooded and thick limestones originated. The latter third of Mississippian time saw a return deposition of a great thickness of continental mud and sands.

The Pennsylvanian period in Virginia represents a time of almost continuous non-marine deposition. A vast piedmont plain extended westward from Appalachia. The low, swampy land was covered with a dense growth of vegetation which was to give rise to our present-day coal. Occasionally brief marine floodings occurred. Because of the flatness of the land, they were widespread and the thin beds of marine limestone produced now form important horizon markers in studies of the Pennsylvanian series. Little Permian was formed in Virginia.

The Appalachian Revolution

The Paleozoic era closed with an earth movement which permanently changed the physical appearance of eastern United States, the Appalachian revolution. Those minor disturbances during the Paleozoic era which particularly effected the New England and Maritime Provinces had little effect on Virginia.

During the Appalachian revolution compressive forces were exerted from the southeast. The sediments of the Appalachian geosyncline were so folded and faulted as to be reduced about half their original width. The distortion decreased in intensity westward, so that the Pennsylvanian and Permian beds of West Virginia were only slightly disturbed. Since the Appalachian revolution, the ancient landmass of Appalachia had disappeared, the Appalachian Mountains have been carved from the rocks formed in the Appalachian geosynclinal seas, and eastern North America has assumed the physical appearance we know today.

ECONOMIC GEOLOGY

Limestones

The limestones of the Fordwick area have been quarried commercially for the past hundred years. During the latter half of the last century a small "marble" quarry was worked in the Coeymans formation in Black Oak Ridge. The quarry is located on the northwest side of the ridge, adjacent to the town of Craigsville. Many of the old tombstones in the cemeteries of the area are made from this Coeymans "marble". The stone is coarsely crystalline and contains numerous fossils and fossil fragments, especially crinoid stem segments. It takes a fine polish and has a pleasing pink color but does not hold up well on exposure to weathering. The operation of the quarry was abandoned about the turn of the century because other stones became available which was more suited for ornamental work.

In 1902, the Virginia Portland Cement Company built a cement plant at Fordwick. The Helderberg limestones and Onondaga shale were quarried to supply the necessary raw mix components for producing the cement clinker. In 1915, the Lehigh Portland Cement Company purchased the plant and property from the former company. The plant is situated on the northwest side of Brown Ridge about two miles southeast of Craigsville. When purchased from Virginia Portland Cement Company, the plant was capable of producing up to 460,000 barrels of cement per year. The plant has been modernized and improved and the present capacity is 1,700,000 barrels per year.

The limestones and shales of the Fordwick area are well suited for the manufacture of all types of portland cement as well as several specialized types of cement with proper blending. The American Society of Testing Materials in the Standard Specifications defines portland cement as:

> The product obtained by pulverizing clinker consisting essentially of hydraulic calcium silicates, to which no additions have been made subsequent to calcination other than water and/or untreated calcium sulfate, except that not to exceed 1.0 per cent of other materials may be interground with the clinker at the option of the manufacturer, provided such materials in the amounts indicated have been shown to be not harmful by tests carried out or reviewed by Committee C-1 on cement. (of the Society)

There are five types of portland cement recognized in the United States.

Type I "For use in general concrete construction where the special properties specified for types II, III, IV and V are not required."

Type II or Moderate Heat of Hardening Cement, "for use in general concrete construction exposed to moderate sulfate action, or where moderate heat of hydration is required."

Type III or High Early-Strength Cement, "for use when high early strength is required."

Type IV or Low-Heat Cement, "for use when a low heat of hydration is required."

Type V or Sulfate-Resisting Cement, "for use when high sulfate resistance is required."

The chemical requirements for the five standard types of cement are listed in Table V. One specialty cement made here is mortar cement, which is essentially equal parts of Type I cement (see Table V) clinker and raw limestone ground together with a water repellent agent.

The Coeymans and the New Scotland formations contain a very high percentage of CaO. This is the principal constituent of the cement raw mix. The cherty Becraft formation is used as a source of silica and requires blending with limestone and shale because of the high SiO_2. The non-cherty Becraft requires only the addition of limestone because of the higher R_2O_3 content. The Onondaga shale is used as the source of Al_2O_3 for the raw mix. In the event it is needed, the Oriskany sandstone is available to supply additional silica. These formations are chemically sufficient to meet the raw mix demands for any of the regular standard cements. Clinton iron ore is available within trucking distance of the area to supply any necessary additional iron for making Type II

TABLE V. CHEMICAL REQUIREMENTS OF THE STANDARD TYPE CEMENTS*

	Type I	Type II	Type III	Type IV	Type V
Magnesium oxide (MgO), max., per cent	5.0	5.0	5.0	5.0	4.0
Sulfur trioxide (SO_3), max., per cent	2.0[a]	2.0	2.5[a]	2.0	2.0
Loss on ignition, max., per cent	3.0	3.0	3.0	2.3	3.0
Insoluble residue, max., per cent	0.75	0.75	0.75	0.75	0.75
Silica (SiO_2), min., per cent	-	21.0	-	-	24.0
Alumina (Al_2O_3), max., per cent	-	6.0	-	-	4.0
Iron oxide (Fe_2O_3), max., per cent	-	6.0	-	6.5	4.0
Ratio of Al_2O_3 to Fe_2O_3	-	0.7 to 2.0	-	-	0.7 to 2.0
Tricalcium silicate ($3\ CaO.SiO_2$), max., per cent (b)	-	50	-	35	-
Dicalcium silicate ($2\ CaO.SiO_2$), min., per cent (b)	-	-	-	40	-
Tricalcium aluminate ($3\ CaO.Al_2O_3$), max., per cent (b)	-	8	15	7	5

(a) The maximum limit for SO_3 content for Type I cement shall be 2.5 per cent when the tricalcium aluminate content is over 8 per cent; for Type III cement it shall be 3 per cent when the tricalcium aluminate content is over 8 per cent.

(b) The tricalcium silicate, dicalcium silicate and tricalcium aluminate are calculated from the chemical analysis as follows:

Tricalcium silicate = (4.07 x per cent CaO) - (7.60 x per cent SiO_2) - (6.72 x per cent Al_2O_3) - (1.43 x per cent Fe_2O_3) - (2.85 x per cent SO_3)

Dicalcium silicate = (2.87 x per cent SiO_2) - (0.754 x per cent $3\ CaO.SiO_2$)

Tricalcium aluminate = (2.65 x per cent Al_2O_3) - (1.69 x per cent Fe_2O_3)

* American Society for Testing Materials Specifications C 150-46 (1946).

The typical compositions of the various types of cement are listed on the following table:

TABLE VI. AVERAGE ANALYSES OF THE STANDARD TYPES OF CEMENT*

	Type I	Type II	Type III	Type IV	Type V
Silica (SiO_2), per cent	21.3	22.3	20.4	24.3	25.0
Alumina (Al_2O_3), per cent	6.0	4.7	5.9	4.3	3.4
Iron Oxide (Fe_2O_3), per cent	2.7	4.3	3.1	4.1	2.8
Calcium Oxide (CaO), per cent	63.2	63.1	64.3	62.2	64.1
Magnesia (MgO), per cent	2.9	2.5	2.0	1.8	1.9
Sulfur Trioxide (SO_3), per cent	1.8	1.7	2.3	1.9	1.6
Loss, per cent	1.3	0.8	1.2	0.9	0.9
Insoluble	0.2	0.1	0.2	0.2	0.2

*Research Reports, Portland Cement Association, April, 1941.

cement.

The Keyser formation is not being used at the present time as a raw mix component, but it has been used in the past in place of the Becraft. The Keyser can be used as a raw mix component, but because of its higher $MgCO_3$ content it is not as desirable.

The limestones of the Fordwick area would not be as economically important as they are if it were not for the factor of available transportation. The Chesapeake and Ohio connects Fordwick with both eastern and midwestern United States. The coal for fuel in burning the cement clinker, and gypsum, for a retardant, are shipped in and the finished cement is shipped to the markets by railroad. If the railroad were not present, the limestones of Fordwick would probably remain as unexploited high-grade limestones.

Iron Ore

At the present time the iron ore deposits in the general Fordwick area have little economic importance. A small quantity of the iron ore is being used as a raw mix component by the Lehigh Portland Cement Company plant for special cements. Previous to the opening of the large iron ore deposits of the Minnesota area there were numerous small active iron furnaces near Fordwick. During the war between the states the Estaline Furnace was very active. The ore was taken from the high-grade pockets of the Clinton iron ore formation on Little North Mountain southeast of the Fordwick area. Another large furnace, using the same ore, was located at Goshen about nine miles southwest of Craigsville.

Water Resources

Surface Water. The Little Calfpasture River is the only stream in the Fordwick area which is commercially significant. The Lehigh Portland Cement Company has dammed the river at Fordwick to provide a reservoir for boiler and condensor water. The stream is fed principally by small spring fed brooks flowing off the southeast slope of Great North Mountain.

There are no figures available on the amount of water normally flowing in the river. The average rate of flow does not fluctuate very greatly from winter to summer. At no time in the past fifty years has the stream gone dry; however, there have been a few occasions, during extremely long droughts, when the water reserve in the company reservoir became dangerously low from the standpoint of plant requirements. The river reacts rapidly to the rainfall resulting from thunderstorms during the summer. All of the water falling on the southeastern slope of Great North Mountain between the Augusta County-Rockbridge County line and Elliott Knob is drained by the Little Calfpasture River past the town of Fordwick. The stream channel is not always able to carry the huge volume of water being fed into it during heavy thunderstorms and flash floods occur. The stream will usually return to normal flow again within twelve to twenty-four hours.

Subsurface Water. Springs are numerous within the Fordwick area. Many of the "hollows" in both Black Oak Ridge and Brown Ridge contain springs which flow continuously winter and summer. Many of the farms depend solely upon these springs for their water supply. The towns of Craigsville and Fordwick and the Lehigh Portland Cement Company plant, prior to the development of the spring fed water supply on Little North Mountain, were dependent on the springs of these two ridges to supply their water. Due to an increase in water requirements in excess of that capable of being furnished by the local springs, the town of Craigsville developed their present water supply on the northwest side of Little North Mountain. Fordwick and the Lehigh Portland Cement Company now tap into the pipe line going to Craigsville.

With one exception, all of the springs are found only in the top thirty-foot zone of the Keyser formation. The single exception is a spring on the northwest side of Black Oak Ridge and about five hundred feet northeast of the Craigsville Grade School building. This spring is located in the upper part of the Becraft formation. This information is useful when studying the geology of the area. Whenever a spring is found on either of the two ridges it is strong evidence that the Keyser is present and the Keyser-Coeymans contact is in the vicinity. There are approximately sixteen good year round springs present in the southwestern half of Brown Ridge. The upper thirty feet of the Keyser formation is present in this part of the ridge. There is not a single known spring in the northeastern half of the ridge and the upper Keyser is not present in this portion of the ridge.

The fact that the upper thirty feet of the Keyser is the best water bearing zone of the area is further proven by the wells that have been drilled by private individuals. Wells which do not enter this zone are inconsistent producers and are seldom able to supply enough water year round to meet the normal needs of a single family. Wells into the Keyser zone, however, always supply all the water required for even the largest families.

There are some "winter springs" in the Onondaga shale in the northern part of the Fordwick area. These springs generally dry up by May or June and remain dry until the following fall when rains again fill the ground with water. Wells drilled in this area must generally go to a depth of a hundred and fifty to two hundred feet to assure an adequate year round water supply for a family.

SUMMARY

The rocks of the Fordwick, Virginia, area are folded and faulted limestones, dolomites, cherty limestones, sandstones and shales belonging to highest Silurian (Tonoloway) and the Keyser limestone, the Helderberg group, Oriskany and Onondaga formations of the Devonian. In this paper the Keyser is assigned as basal Devonian. The Onondaga shale is distinguishable from the balance of the Rommey shale and is treated as a separate formation instead of a member of the Rommey group.

The prime purpose of the paper has been to apply chemical correlation. It is not suggested that chemical correlation be used exclusively, but rather as an additional means of correlation. Where it is in disagreement with other means, the best evidence must be accepted. The writer, using chemical analyses for correlation, in many instances has been able to construct more accurate geological sections, proven by subsequent quarry operations, than could be constructed using only faunal and lithologic data. The Helderberg group of the Fordwick area, because of the narrow range of chemical characteristics of its members, has proven to be ideally suited for chemical correlation. Many analyses are required before all the chemical characteristics of a formation are known and thoroughly reliable correlations can be made. Because hundreds of analyses of the

formations in the Fordwick area have been studied by the writer, it is possible in practically all instances to identify the formations solely on the basis of the standard loss free oxide analysis used by the Lehigh Portland Cement Company.

A chemical relationship of the formations at the Silurian-Devonian boundary in western New York (Gunnville), eastern New York (Alsen), eastern Pennsylvania (Saylorsburg) and Fordwick has been described. In all cases the silica content increases downward through the Devonian to the Silurian. Immediately below the Silurian-Devonian boundary as accepted the silica decreases, but the magnesia increases.

Since this silica-magnesia change is noted between the Keyser and Tonoloway but not between the Coeymans and Keyser in the Fordwick area, the writer places the Keyser in the basal Devonian, in Virginia.

Insoluble residues proved of little value to the writer as a means of correlation. No new mineral constancies were found in the insoluble residues which were not already known, either from the chemical analysis of the sample, or its appearance before preparation for obtaining the insoluble residue.

A new member of the Coeymans has been named Fordwick sandstone. It is a nine-foot bed located twelve feet above the base of the Coeymans. The sandstone is lenticular and local.

From the standpoint of economic geology, the Helderberg, Oriskany and Onondaga sequence of the Fordwick area is ideally suited for supplying many raw materials required for a cement plant. Coal and gypsum must be brought into the area. Because of the chemical uniformity of the various formations of the sequence, all types of portland cement, except white cement, are produced at the Fordwick plant of the Lehigh Portland Cement Company.

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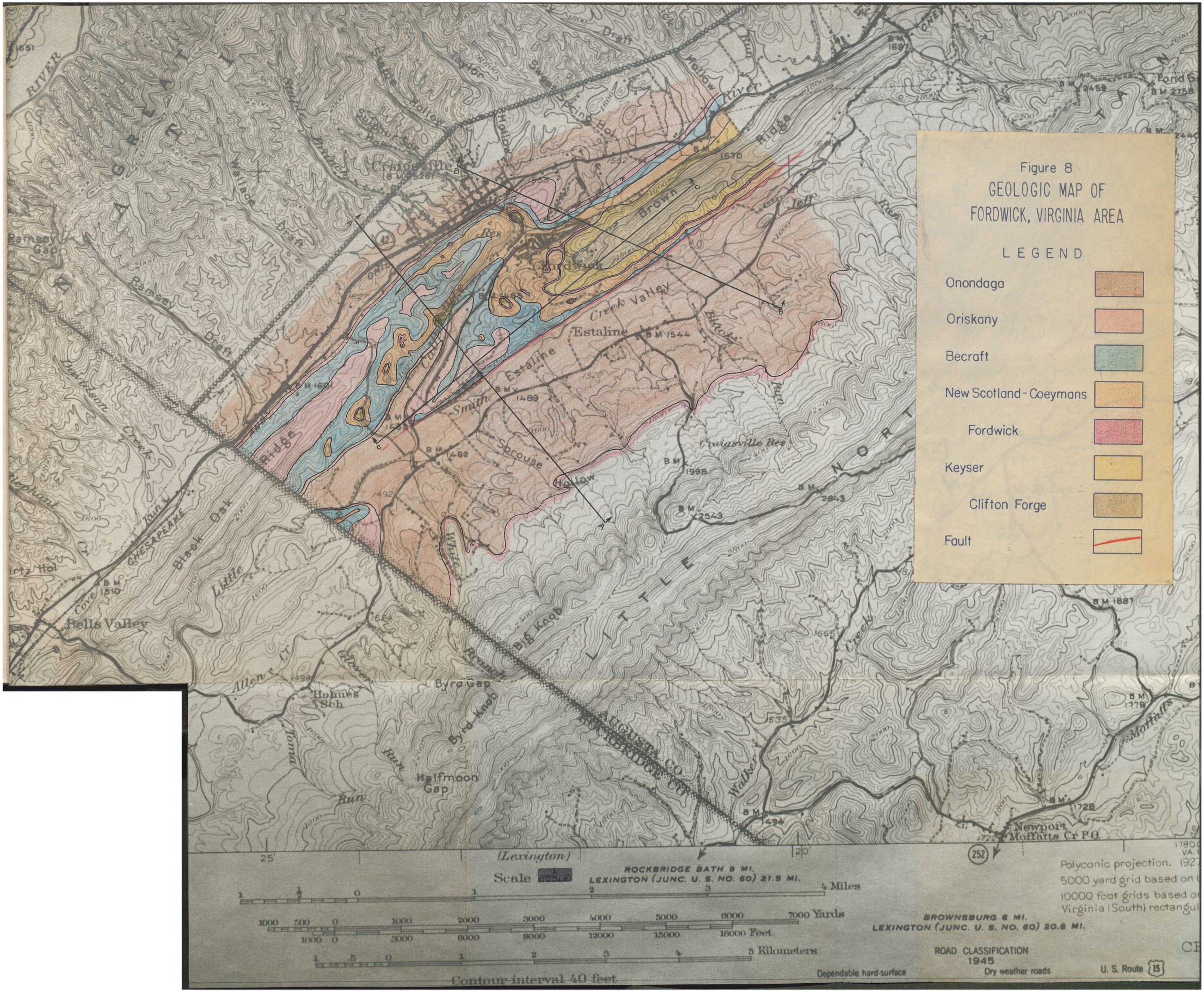


Figure 8
GEOLOGIC MAP OF
FORDWICK, VIRGINIA AREA
LEGEND
Onondaga
Oriskany
Becraft
New Scotland - Coeymans
Fordwick
Keyser
Clifton Forge
Fault
Craigsville
Estaline
Bells Valley
Halfmoon Gap
Byrd Gap
Holmes Sch
Newport
AUGUSTA CO
ROCKBRIDGE CO
(Lexington)
ROCKBRIDGE BATH 9 MI.
LEXINGTON (JUNC. U. S. NO. 60) 21.5 MI.
BROWNSBURG 6 MI.
LEXINGTON (JUNC. U. S. NO. 60) 20.8 MI.
Scale
Miles
Yards
Feet
Kilometers
Contour interval 40 feet
ROAD CLASSIFICATION
1945
Dependable hard-surface
Dry weather roads
U. S. Route
Polyconic projection.
5000 yard grid based on
10000 foot grids based on
Virginia (South) rectangul

FIGURE 9 - HISTORICAL CHART

Figure 9

CHART SHOWING HELDERBERG HISTORY IN NEW YORK STATE

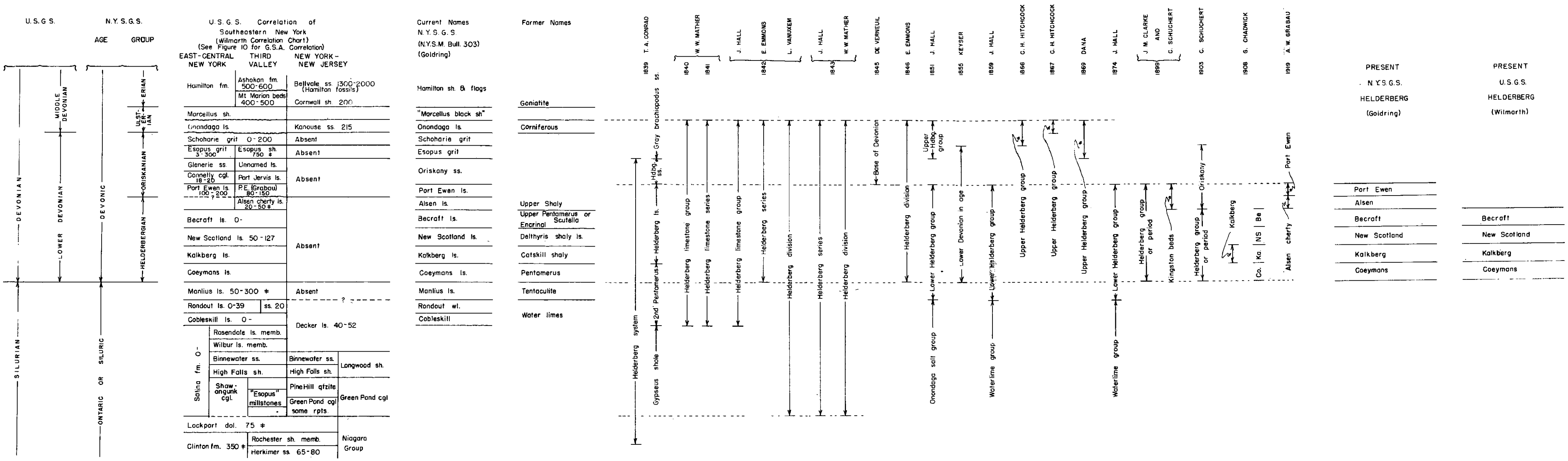


FIGURE 10 – CORRELATION CHART

Figure 10

HELDERBERG CORRELATION CHART

DRAWN FROM CORRELATION CHART OF
DEVONIAN SUBCOMMITTEE OF GEOLOGICAL SOCIETY OF AMERICA
(G. S. A. BULL., VOL. 53, PL. I, 1942)

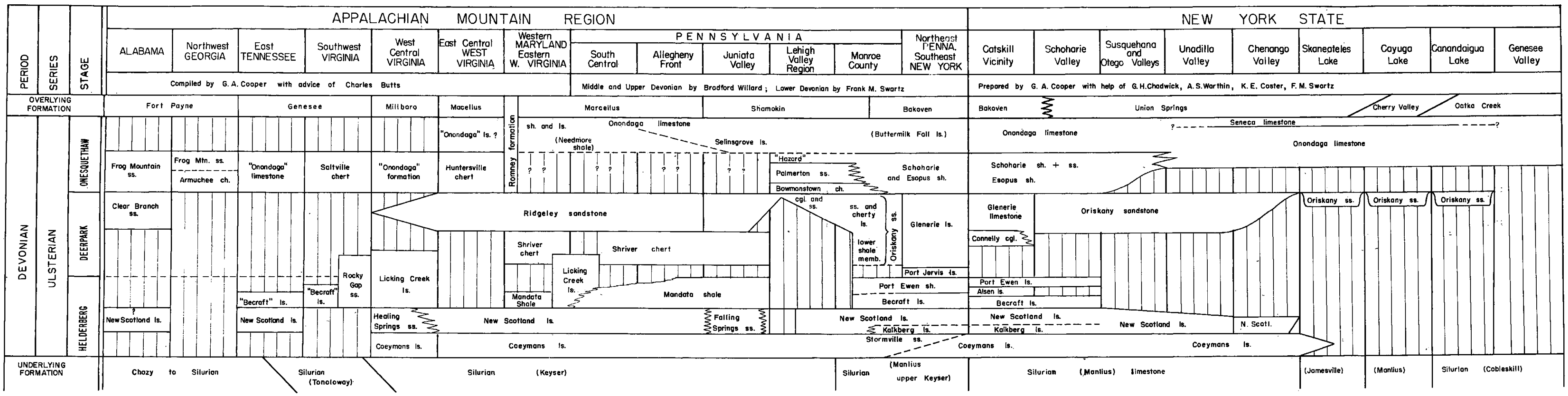


FIGURE II - SECTION A-A

TRANVERSE SECTION ACROSS SOUTHWEST END OF BROWN RIDGE

SECTION A-A

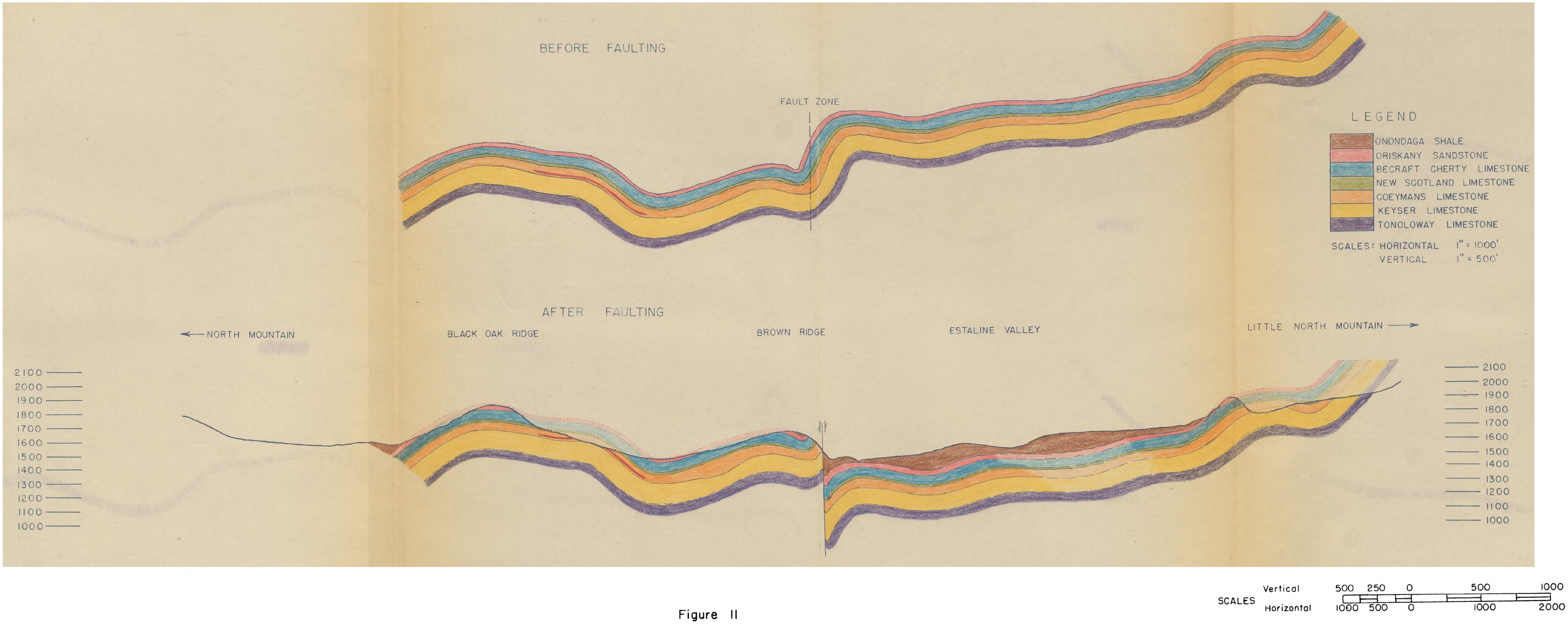


Figure 11

FIGURE 12 - SECTION B-B

TRANSVERSE SECTION OF BROWN RIDGE

SECTION B - B

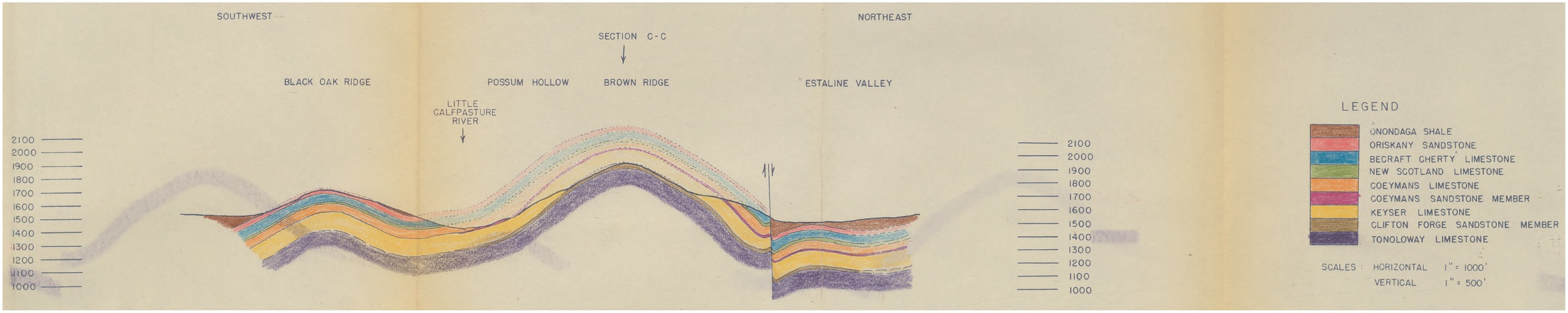


Figure 12

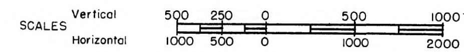


FIGURE 13 - SECTION C-C

LONGITUDINAL SECTION OF BROWN RIDGE

SECTION C-C

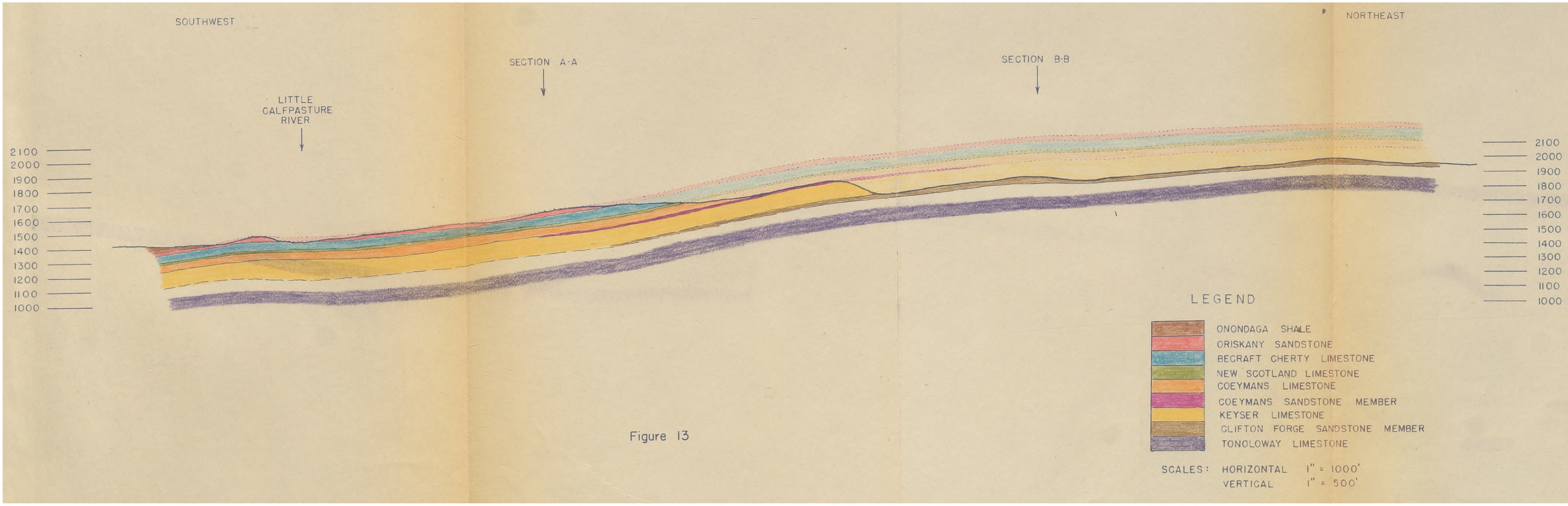
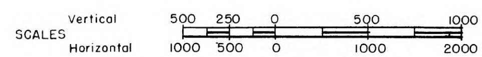


Figure 13



VITA

Carl Andrew Warmkessel was born in Allentown, Pennsylvania, on June 15, 1913, the only son of Horace O. and Nancy (nee Jenkins) Warmkessel. After attending the public schools, he graduated from Allentown High School in June, 1931. He entered the Engineering College of Lehigh University in September, 1931. At the end of the Freshman year he transferred to the College of Arts and Science, majoring in Geology. He received his Bachelor of Arts degree from Lehigh University in June, 1936, and started work on his Master of Arts degree. In May, 1937, he became Geologist for Lehigh Portland Cement Company and is still in their employ. He received his Master of Arts degree from Lehigh University in June, 1941, and thereupon became a candidate for the degree of Doctor of Philosophy at Lehigh. He served as Captain in the United States Army Air Force, bearing the titles of Wing Photo Officer, Third Air Force Staging Wing and Wing Postal Officer, from October, 1942, until March, 1946.

The nature of his work with Lehigh Portland Cement Company is such that seldom can publication of his findings be made without being detrimental to the best interests of the Company. While an undergraduate at Lehigh University, he presented a paper, "Burden of Lehigh River During the Flood of August, 1933", to the Pennsylvania Academy of Science (Penna. Acad. Sci., Proc., vol. 8, 1934, pp. 94-96) and prepared jointly with Doctor B. L. Miller the chapter on "Ground Water Resources" in the Northampton County Report, Bulletin C-48, for the Pennsylvania Topographic and Geologic Survey (Penna. Geol. Surv., 4th ser., 1939, pp. 409-428).

He is a member of the Geological Society of America, the Paleontological Society, and the Society of the Sigma Xi, Lehigh Chapter.