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CONSERVATION AND DEVELOPMENT COMMISSION
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Wilbur A. Nelson, *State Geologist*

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The Geology of the Virginia Triassic

By Joseph K. Roberts

University, Virginia
1928

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STATE CONSERVATION AND DEVELOPMENT COMMISSION

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LETTER OF TRANSMITTAL

Commonwealth of Virginia
Virginia Geological Survey
University of Virginia

Charlottesville, Va., February 24, 1927.

To the State Conservation and Development Commission:

Gentlemen:

I have the honor to transmit and to recommend for publication as Bulletin 29 of the Virginia Geological Survey Series of reports a manuscript and illustrations of a report on *The Geology of the Virginia Triassic,* by Joseph K. Roberts.

The area treated in this report is of importance because of its position between the gold-quartz belt and the Blue Ridge. It lies for the most part within the Piedmont.

The natural resources described in this report include the coal of the Richmond and Farmville basins, and the sandstones, conglomerates and diabase of the entire Triassic area. The coal is of good quality and was the first coal mined in the United States. The old mines were located along the eastern edge of the Richmond basin, and have been operated from time to time. There is no detailed information in the way of drill cores from the central portion of the basin, and there are reasons to believe that the coal beds of the central portion are less faulted than on the margins.

A Triassic limestone conglomerate is quarried at Leesburg and used for agricultural lime and other purposes. This is the only important source of lime east of the Blue Ridge in Virginia and is the same as the famous "Calico" or Potomac marble quarried in Maryland. This marble should make a beautiful interior stone.

Diabase or trap is quarried at a number of points and is an excellent road metal and ballast. A large diabase quarry is operated southeast of Leesburg. This diabase forms an enormous road metal reserve in the State. These occurrences have been accurately mapped.

This report shows the structure and oil possibilities of the Triassic and will tend to protect the people from petroleum wildcatting in this section.

Respectfully submitted,

WILBUR A. NELSON,
State Geologist.

Approved for publication:
State Conservation and Development Commission,
Richmond, Virginia, February 24, 1927.
E. O. FIPPIN, *Executive Secretary.*

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By Joseph K. Roberts

INTRODUCTION

HISTORY OF THE INVESTIGATIONS

The earliest investigations of any note upon the Triassic of Virginia were made by William B. Rogers in the early part of the nineteenth century. The results of some of this work were published in 1884, sometime after his death, in *The Geology of the Virginias*. Outside of the general information on the Triassic furnished by Rogers, he contributed a great deal toward the details of the Richmond Basin, thereby blazing the trail, for his interest seemed to center more around this portion of the Triassic than any other.

The first systematic work of importance was that of William M. Fontaine, which was published in 1883 as United States Geological Survey Monograph VI. This monograph deals with the floras of the Richmond Basin. Fontaine did his field work and made his collections during one of the periods of enthusiasm for working the Triassic coals of the Richmond Basin and he was especially favored with a goodly number of freshly opened coal pits, which furnished him a far better and more typical flora of the coal beds than could have been had any time since or than can be had even at the present time.

Following Fontaine's work there was a short contribution made by H. D. Campbell and W. G. Brown. The results of their field and laboratory work were published in 1891 in the *Bulletin of the Geological Society of America*. Following these analyses there are numerous others which have added much to our knowledge of the igneous rocks of the Triassic.

Israel C. Russell compiled in United States Geological Survey Bulletin 85, published in 1892, all the known data on the Virginia Triassic, as well as that of eastern North America, and added a number of suggestions such as an interpretation on the matters of genesis and the environment of Triassic time, for about this time and just prior to it the matter of the color of the red beds had been uppermost in the minds of geologists and Russell and Crosby were the main exponents on this subject, especially as applied to the Triassic red beds of eastern North America.

In 1894 the United States Geological Survey published the results of the field work done by Arthur Keith on the Harpers Ferry quadrangle. This work, published as the Harpers Ferry Folio, deals with a small portion of the Triassic in Northern Virginia and it has been freely used by the writer in mapping.

The results of the work of N. S. Shaler and J. B. Woodworth on the Richmond Basin were published in 1899 in the 19th Annual Report, Part II, of the United States Geological Survey. This study deals with the areal and structural geology and has added a great deal to our information on the Triassic.

Lester F. Ward added valuable suggestions to our knowledge of the Mesozoic floras and his articles appeared about 1900.

The late Thomas L. Watson made a study of the distribution, character, and weathering of Triassic diabase in the region around Chatham, Pittsylvania County, and published his results about 1899.

The most recent work done is that on the mineralogy and petrology of the Belmont Stock of diabase in Loudoun County by Earl V. Shannon of the United States National Museum. This study adds much to the needed data on the Triassic intrusives and is a very monumental piece of work, such as it is hoped will be done for the other bodies of diabase rock in the various areas.

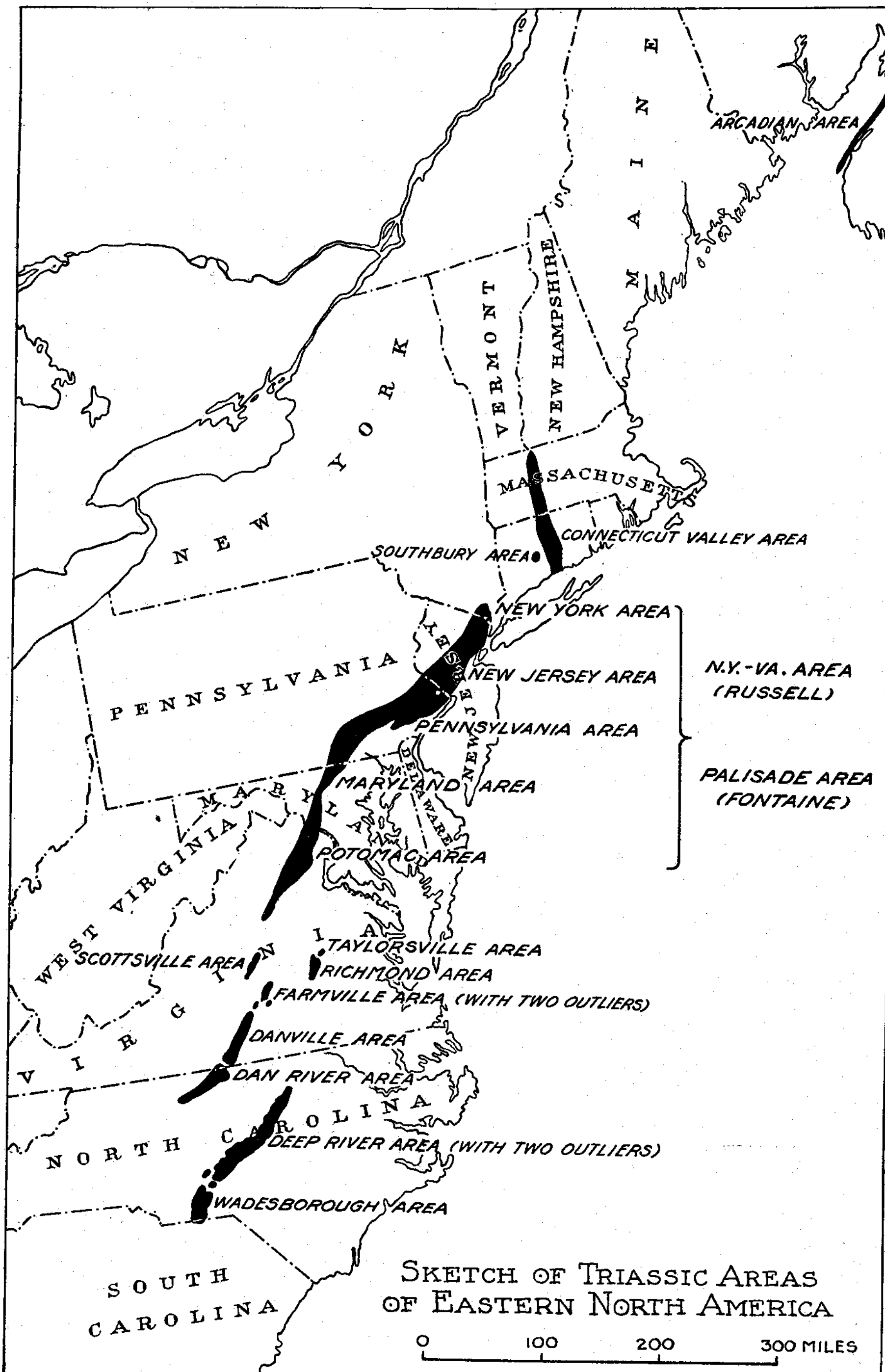
The early contributions of Rogers, Lyell and others are now more or less historical. Those of Fontaine and Ward paved the way for detailed studies on the Triassic. Much work of this nature has been done in New England, New Jersey and Pennsylvania, which in a measure has served as a basis for the work in Virginia. There are many references to be found dealing with the Triassic of Virginia and the more important ones are given in the bibliography. Most of the literature deals with the Richmond Basin because of the fact that it is coal-bearing and has such a well preserved flora.

AREA INVOLVED IN THE TRIASSIC

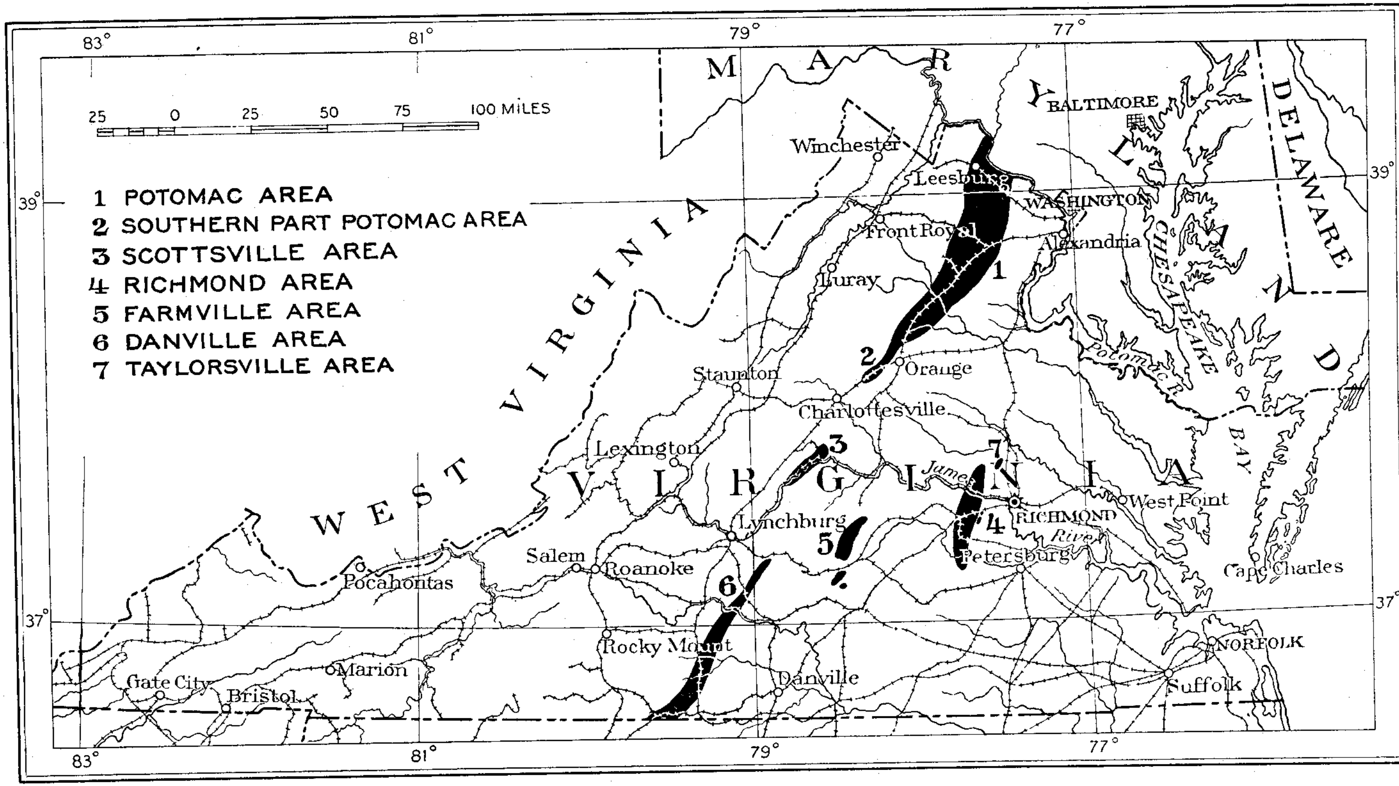
The Triassic belt, entering Virginia from Maryland and Pennsylvania, is not continuous through the state but occurs in isolated areas which are widely separated in the majority of cases. Fairly accurate data are available on the sizes of most of these individual areas. Topographic maps were used in mapping, except for the region around Danville in which the State map was used.

The Triassic areas, on the basis of their origin, are of two distinct types, namely, those of a swamp or mesophytic origin—such as the Richmond and Farmville basins—and those of a continental or residual origin, including all the areas except those named under the first heading. Of the latter type the areas from north to south are: Potomac, Scottsville, and Danville.

The Potomac area extends from the Potomac River south to the Rapidan River, an average length of approximately 86 miles and with a width of from less than half a mile to 15.10 miles. This area includes parts of Loudoun, Fairfax, Prince William, Fauquier, Culpeper, Orange, and Madison counties. The area by counties is as follows:



Sketch map of Triassic areas of eastern North America.



Sketch map of Triassic areas in Virginia.

	Square miles
Loudoun	260.6
Fairfax	63.0
Prince William	169.0
Fauquier	156.9
Culpeper	132.4
Orange	13.7+
Madison	.4
	796.0+

The area covered by the Potomac River is more than half the size of the State of Rhode Island and almost one-third the size of Delaware.

The Barboursville area, formerly regarded as a separate area and now known to be an extension of the Potomac area, lies mostly within Orange County with its southernmost extension a little over the Orange-Albemarle County line. The maximum width is 3 miles and it extends about 20.5 miles south of the limits of the old New York-Virginia area.

The Scottsville area is approximately 25 miles southwest of the old Potomac area with its major axis in the same general direction as the area above mentioned. This area is about 20 miles long and has a maximum width of 3½ miles. It lies partly in three counties with a square mileage as follows:

	Square miles
Albemarle	21.2
Buckingham	4.9
Nelson	4.6
	30.7

The major portion of this area lies on the north side of James River.

The Danville area involves a length of approximately 60 miles with a much narrower width than the Potomac, which never exceeds 9 miles and most of the area is far less than this figure. The average width is around 4½ miles. This area includes parts of Campbell, Appomattox and Pittsylvania counties, covering approximately 300 square miles and comprising all of the Triassic from Campbell County to the Virginia-North Carolina line.

The Farmville area, the smaller of the two basins to the east of those mentioned, is approximately 20 miles long and its maximum width just north of Farmville is not over 4 miles. About 12 miles north of Farmville, near Ca Ira, the area takes a somewhat slight turn to the northeast for a distance of 6 miles and terminates. This area lies approximately 25 miles southeast of the Scottsville area, 25 miles northeast of the Danville area, and about 32 miles west of the Richmond area. It involves parts of Prince Edward, Buckingham, and Cumberland counties. The area comprises about 25 square miles, not counting two small outliers of the main area. One of these outliers is in Prince Edward County and the other in Charlotte County and both cover an area of less than 3 square miles.

The Richmond area which was the first of all the Triassic areas of Virginia to be investigated has been discussed in the literature for about 150 years. It is by no means a large area, its length north and south being approximately 33 miles and its widest portion measuring about 9 miles. The area is more or less boat shaped and determination of its boundary limits is very difficult. About one-fifth of the area lies to the north of James River and involves parts of Henrico and Goochland counties; the portion south of James River includes parts of Powhatan, Chesterfield, and Amelia counties. The area computed is about 189 square miles, exclusive of outliers. This area is the most difficult of all to trace, hence the number of square miles can be only approximate. The map prepared by Shaler and Woodworth is reproduced, though the writer has used the formational names of the other Virginia areas for the Richmond area.

ACKNOWLEDGMENTS

The Triassic problem was suggested in June, 1920, by the late Thomas L. Watson, State Geologist of Virginia. The field work was begun in 1920 and extended over four consecutive summers. After the death of Thomas L. Watson, the manuscript was returned by Albert W. Giles, Acting State Geologist, and a discussion of the igneous rocks was added. This latter subject was to have been reported by Doctor Watson.

At the time the field work was done, topographic maps of the United States Geological Survey on the scale of 2 inches to the mile were available for all of the Triassic except the southern portion of the Danville area, and this had to be done on a base map of a scale of 1:500,000.

The writer wishes to express his gratitude for much assistance from Thomas L. Watson during the field work, especially on the stratigraphy and economic geology. Many helpful suggestions and criticisms were made by Edward B. Mathews on the field work, by Edward W. Berry on the paleontology and stratigraphy, Harry Fielding Reid on the structure, Joseph T. Singewald on the economic geology, and by Marcus I. Goldman on the sedimentary studies. Through the kindness of Edward B. Mathews the laboratory work was begun at Johns Hopkins University. L. C. Glenn granted the privilege of completion of the work in the Vanderbilt University laboratory. The present State Geologist of Virginia, Wilbur A. Nelson, has given his co-operation in many ways and has made possible the publication of the report. Anna I. Jonas in her studies of the Piedmont of Virginia has traced a number of faults into the Triassic and these have been added to the geologic map. Finally, appreciation is due many of the citizens whose services have been of assistance in the field work; especially Robert B. Ely of Leesburg, and the late Charles L. Cline of Culpeper.

PHYSIOGRAPHY

All of the Triassic areas lie west of the Fall line[1] within the physiographic province termed the Piedmont Plateau. The Potomac, Scottsville and Danville areas occupy basins far to the west or close to the Blue Ridge region and here the Triassic sediments accumulated in depressions along the eastern foothills of the Appalachian Mountains. The Farmville and Richmond areas, with their small outliers, lie in the central portion and on the eastern edge of the Piedmont Plateau, respectively, occupying depressions of the old eroded land surfaces whose rocks are of pre-Cambrian age.

Watson summed up the general characteristic marks of the Piedmont area as follows:[2]

> ...... In general, the surface of the (Piedmont referred to) Plateau has a gentle southeastward slope from an average altitude of 1,000 feet along its western margin to from 200 to 400 feet on the east, where the plateau rocks pass beneath the Coastal Plain sediments. The western border of the region is an irregular one marking the change to the steeper slopes of the Blue Ridge and its outliers. The topography of the plateau is much older and more varied, and its geology more complex than that of the Coastal Plain. Its topography is that of a more or less smooth, broadly rolling or undulating upland of moderate elevation, into which the streams have rather deeply sunk their channels. Scattering hills and ridges—partially reduced masses—rise in some case several hundred feet above the general level of the upland surface of the Plateau. Below the upland surface, deep and narrow gorges have been carved out by the streams.

The Triassic belt in the northern part of the state lies less than 20 miles east of the Blue Ridge, but on the Virginia-Carolina border it is more than 60 miles. There are two general types of elevations common to the western Triassic area; one type consists of the high elevations which vary from 150 to 400 feet above the general level of the surrounding country, some examples of which are Mt. Pony, southeast of Culpeper, Buzzard Mountain (Twin Peaks of some of the older writers) northeast of Rapidan Station, Cedar Mountain southwest of Culpeper and White Oak Mountain, which extends approximately two-thirds of the length of the Danville area; the other type consists of small elevations ranging upwards to 150 feet above the general level of the country, examples of which are the hills around Belmont Park, Ashburn, Manassas, Remington, Calverton, Howardsville, Gladys and Chatham. All of the elevations in the Farmville and Richmond areas are of the lower type and the hills not only are low but they are broad and flat as opposed to the low and sharp hills of the western areas. The lowlands range from 250 to 500 feet above sea level in the Potomac area, around 500 in the Scottsville area and 450 to 650 feet in the Danville area. The average elevation

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[1] Watson, Thomas L., Annual report on the mineral production of Virginia during the calendar year 1908; Virginia Geol. Survey Bull. 1-A, p. 7, 1909.
[2] Idem, p. 10.

of the lowlands in the Farmville and Richmond areas ranges from 200 to 250 feet above sea level.

Red shale usually forms the lowlands in all the areas, sandstones, conglomerates and diabase the lower elevations, and conglomerates and diabase the higher elevations, such as Cedar Mountain formed of the Border Conglomerate and Mt. Pony and Buzzard Mountain formed of diabase. The western border of the areas is always more hilly than the eastern except in two cases, Mt. Pony and White Oak Mountain.

The Triassic sediments are well peneplained and highly weathered. Since the accumulation and down-faulting the Triassic section has been subjected to an unusual amount of erosion which has left only a few of the very resistive portions remaining. The Farmville and Richmond areas are peneplained to a far more advanced stage than the western areas and the matter of tracing outcrops in these two areas is a much more difficult matter than in any of the others. Though this peneplanation has progressed to an advanced stage and much of this has been achieved by the action of streams, yet there are very few cliffs left by the streams where good exposures may be studied. The only two good bluffs left by river action are the bluffs of red shale and intercalated red sandstone on the Potomac River and conglomerate on the Banister River.

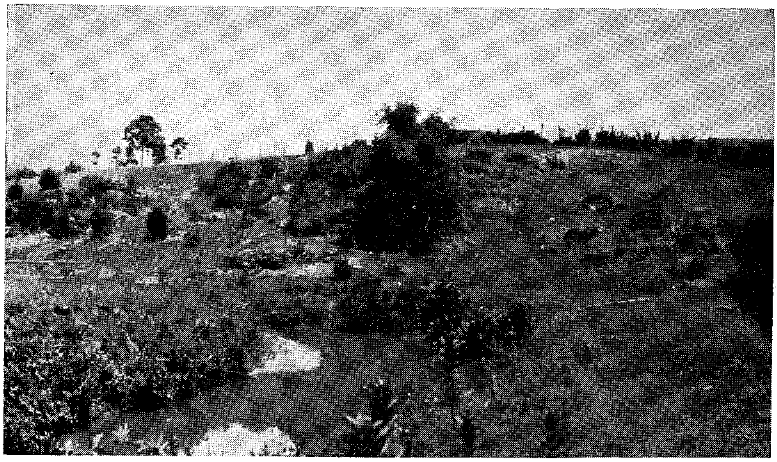
DRAINAGE

The drainage of the various Triassic areas is rather simple. One of the most significant facts is that none of the larger streams have their source within the Triassic belt but rise well to the west. The streams on a basis of size may be divided into three classes, namely, the large streams, such as the Potomac, James and Dan rivers; the intermediate streams, such as the Rappahannock, Rapidan, Roanoke and Appomattox rivers; and the small streams, such as Goose Creek, Bull Run, Mountain Run, Rockfish River, Banister River, Willis River, and the like.

All of the areas are well watered and the water table is comparatively shallow, the wells averaging in depth around 50 feet. The wells in the towns such as Manassas are deeper. There are very few springs throughout the Triassic and the supply of domestic water comes from wells and the streams. The one famous spring within the area is that known as the Huguenot Springs in Powhatan County, once a popular summer resort for its sulphur water.

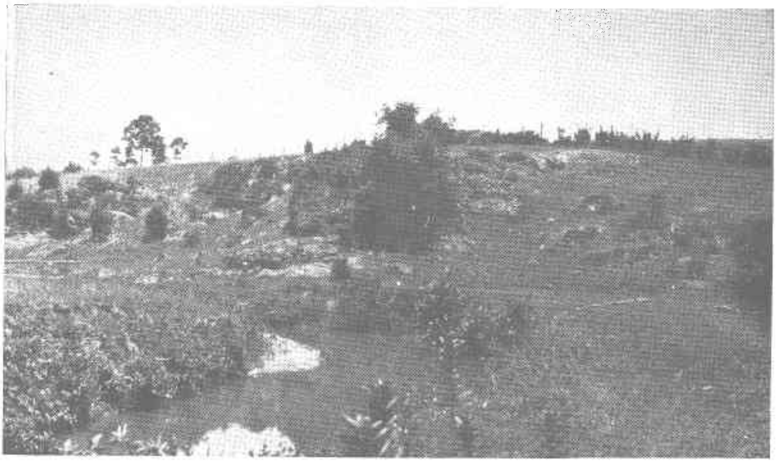
Many of the intermediate size streams get into the low water stage in prolonged droughts but none of them go dry. The smaller streams are the first ones to show the effects of the dry seasons and some of those become dry for a short time.

The Potomac River cuts across the Triassic and is the Virginia-Maryland boundary and drains the northern portion of the Potomac area, from which stream the area takes its name. The middle and southern portions



A. Typical exposure and topography of Border Conglomerate (trap phase) 2 miles northeast of Liberty Mills, Orange County.

B. Typical Border Conglomerate topography surrounding the town of Howardsville, Albemarle County.



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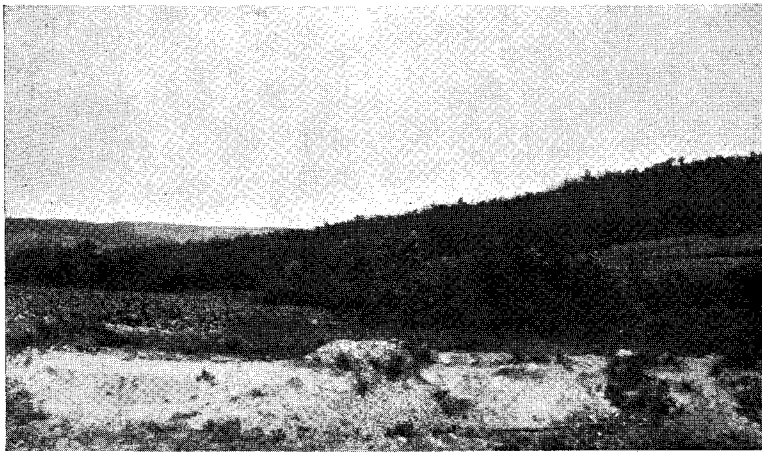
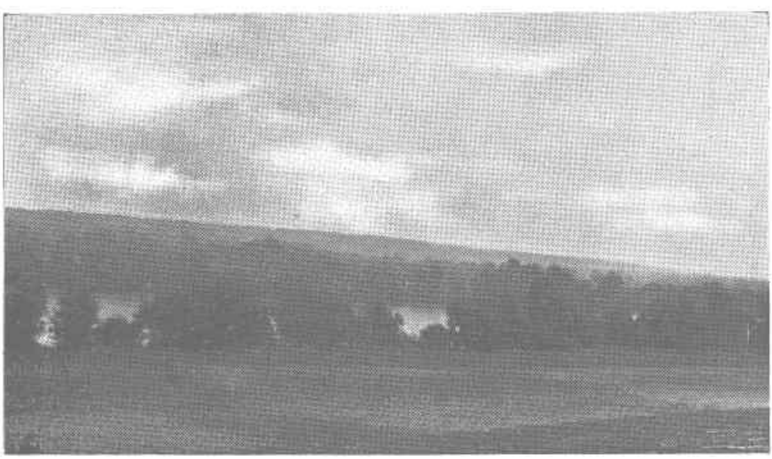


A. View along White Oak Mountain from the Chatham-Danville highway, Pittsylvania County.

B. View across the James River from the south bank, showing the flood-plain with the Triassic in the background, Goochland County.

A. View along White Oak Mountain from the Chatham-Danville highway, Pittsylvania County.



B. View across the James River from the south bank, showing the flood-plain with the Triassic in the background, Goochland County.

of this same area are drained by the Rappahannock and Rapidan rivers, respectively. The Roanoke River flows across the middle of the Danville area and the Dan River across the extreme southern end of this same area. The James River flows through both the Scottsville and Richmond areas, drains the whole of the former and the northern one-third of the latter. The Appomattox River drains most of the Farmville area and touches the Richmond area, draining its southern portion.

There are considerable overflow lands along the Rappahannock, Rapidan, James, Roanoke, and Dan rivers, and deposits of Recent age are very common in these floodplains. Canals at one time parallelled both the James and Rappahannock rivers but have been abandoned so long that in many places the old channels are almost obliterated.

The water power possibilities within the Triassic are very promising. Hydroelectric power from Goose Creek provides Leesburg, Loudoun County, with lights; a small plant on the Rappahannock River at Remington produces electric power; and the great dams at Danville and Schoolfield develop an enormous horse power which is used for lighting the city of Danville and the town of Schoolfield and for the great cotton mills in each place. Wherever there is sufficient fall and good stream banks, dams will be constructed in the near future, as at Kellys Ford on the Rappahannock and at a number of points along the Banister River.

SOILS

There are several types of soils in the great Triassic Belt, some of which have such persistent characteristics that they are of considerable service in mapping certain of the formations. Gradations from the fresh Triassic rocks can be traced through their weathered phases into the soil. Especially is this the case with the diabase and conglomerates. Using the classification of Hilgard, the most important soil types may be outlined as follows:

(1) *Athol Series*: Closely related to the Penn Series. It is a loam derived from the weathering of the limestone conglomerate. This is the most fertile of all the Triassic soils and is best seen north and south of Leesburg in Loudoun County. The soil is very productive for farming and specially suited to crops of clover, corn, wheat and oats. The top soil is a dark brown with a light brown subsoil.

(2) *Penn Series*: Consists of a loam soil derived from the weathering of the red shales and sandstones. This type of soil is the most extensively developed of all the types, since the red shales with the few intercalated red sandstones form the great bulk of Triassic areal exposures. This is good farming land, provided seasonal rainfall is normal. The land over which this type of soil is distributed is lowlands and the drainage is very sluggish. The top soil is Indian red and the subsoil is usually the same color, though often a considerably deeper red.

(3) *Lansdale Series*: Rather limited in extent. Best developed around Herndon, Fairfax County, and to the southern end of this county near

Bull Run. It results from the weathering of the gray sand and quartz conglomerate. It is fairly good farming land. The top soil is light gray to light brown and the subsoil is drab to pale yellow.

(4) *Montalto Series*: This type covers a great portion of the Triassic, particularly in the Potomac area, but towards the south, especially in the Farmville and Richmond areas, it is increasingly scarcer. It is noted for the stiff muds when wet. It holds moisture well. It is derived from the weathering of the fine grained dikes or what is commonly called trap rock. This type of soil is commonly called "Black Jack" from the fact that the "Black Jack" oak is so common a tree in the diabase belt. This soil is very difficult to farm and is better suited to grass. Plowed when too wet, the clods bear witness to this error for some time and there is not the least inducement to any farmer to plow when it is dry. The top soil is red to brown and the subsoil is a reddish brown.

(5) *Iridell Series*: Not as widely represented as the Montalto series. It is derived from the weathering of the stocks and larger bodies of diabase or gabbroid diabase, commonly seen along Goose Creek, east of Leesburg, north of Sterling, around Mt. Pony southward to Buzzard Mountain in the southern portion of the Potomac area. This soil is highly impervious. It offers about as serious a set of problems to agriculture as the Montalto series and in addition there are great masses of boulders upon the soil. The top soil is a deep red and the subsoil is red to a deep yellow.

(6) .... *Series*: There is no special name for this series. It is derived from the weathering of conglomerates around Culpeper, Raccoon Ford and Liberty Mills in the Potomac area and around Glendower and Howardsville in the Scottsville area. The soil is rather fertile due to the calcareous matrix of the conglomerate but this soil is not as productive as the Athol series around Leesburg. This soil is very hilly which interferes with agriculture. Large masses of the conglomerate boulders serve as landmarks for this type of soil just as the great limestone conglomerate boulders do in the vicinity of Leesburg.

In most of the Triassic, the soils are shallow and where the shales and sandstones and other rocks come close to the surface, the crops suffer during a dry season; but taken as a whole the Triassic soils are good farming lands. The soils in the Danville, Farmville and Richmond areas produce very good Burley tobacco.

STRATIGRAPHY

In the study of the various Triassic areas of Virginia all three types of rocks are encountered, the sedimentary and igneous of Triassic age and the metamorphics, which border the areas and are of more or less direct concern. The sedimentary rocks form the principal bulk of the Triassic rocks and they present all the various phases of rocks accumulated under residual conditions, with gradations between all the main phases. These rocks extend the entire length of all the areas in an unbroken manner and are only broken across the belt by dikes and stocks of diabase. The sedimentary rocks present many degrees of induration, from the massive conglomerates and the heavily consolidated sandstones to the little indurated muddy sandstones which crumble between the fingers. The igneous rocks are, in the main, diabases which vary in texture from a fine grain to coarsely crystalline nature and they occur as dikes, sheets, and stocks. The rocks adjacent to the Triassic areas for the most part are of the crystalline series, and in age they vary from the pre-Cambrian complex up through the Cambrian and rocks of an age probably later than the Cambrian. A considerable amount of the Triassic rocks has been metamorphosed by the action of the igneous bodies and, in dealing with the Triassic, there is a very wide range of rocks.

The sedimentary rocks fall into three main groups, namely, conglomerates, sandstones, and shales. These three groups are represented by many outcrops and show gradations from one type to another. The conglomerates occur in five distinct forms, the division being made upon the composition of the main pebbles. These five forms are: Limestone, quartz, arkose, schist, and trap conglomerates. The sandstones are gray, red, and yellow in color and are often highly arkosic. The shales are prevailingly red, but light gray, dark blue, and carbonaceous varieties are quite common. All three varieties of rocks show a very definite relation to each other in the field, except in cases where faulting interferes with their natural sequence.

BORDER CONGLOMERATES

The term "Border" for the conglomerates is proposed, inasmuch as it is about the only appropriate term which could be applied. It has been used, not so much in the sense of a formation, by Kümmel[3] in dealing with the Triassic conglomerates of New Jersey. The term is particularly applicable because the conglomerates lie exposed along the east and west borders, especially along the latter. From the Potomac River at Point of Rocks to the Carolina line the Border Conglomerate extends in a broken manner and it varies in composition over this distance, depending upon

[3]Kümmel, Henry B., The Newark system or red sandstone belt: Geol. Survey of New Jersey, Ann. Rept. for the year 1897, p. 52, 1893.

the nature of the material in the adjacent rocks, which was reworked into the conglomerate.

CLASSES OF CONGLOMERATES

Rocks along the sides of the Triassic basin and in the basins contributed to the accumulation of the conglomerates and other sediments, and there is always a close relation between the Triassic rocks and the adjacent rocks in any one locality. The pebbles making up these conglomerates are principally limestone, quartz, feldspar, diabase, slate, gneiss, granite, and schist. The classes and the sources of the pebbles are shown in the following table:

Table showing classes of conglomerates and sources of pebbles

Class of Conglomerate	Source of Pebbles
1. Limestone conglomerate	Chiefly Cambrian limestone.
2. Quartz conglomerate	Granites and quartz lenses of Piedmont crystallines and Catoctin series.
3. Arkose conglomerate	Same source as quartz pebbles in the Potomac area but chiefly from granites and granite gneisses in the other areas.
4. Schist conglomerate	Principally from the Catoctin schist.
5. Trap conglomerate	Basalts of pre-Cambrian flows of the Blue Ridge and possibly of later age.
6. Quartz arkose	Granites and gneisses of pre-Cambrian age.

Gneiss pebbles are rather common in the Border Conglomerate of the Richmond and Farmville areas and come from the metamorphosed granites in the adjacent rocks of pre-Cambrian age. Slate fragments are common in the Scottsville area and their source is the metamorphosed slates west of the area belonging to the "Undifferentiated Cambrian," which may prove to be of Ordovician age. Some of the diabase pebbles in this section resemble the Triassic diabase intrusives, and it is not impossible that some of these could have been accumulated from Triassic flows and intrusives of early Triassic time, as the sedimentary formations are clearly Middle to Upper Triassic in age. The conglomerates are easily traceable by their hill topography, flat exposures, enormous boulders, highly fertile soil and frequent pebbles over the surface.

LIMESTONE CONGLOMERATE

Extent.—The limestone conglomerate as a member of the Border Conglomerate formation is the most northern one in Virginia and is confined altogether to the western margin of the Triassic in Loudoun County. It extends from the Potomac River to a point approximately 3 miles south of Leesburg, the county seat of Loudoun County, and on the extreme west it is exposed as far south as the vicinity of Oatlands. The areal exposures of this conglomerate cover about 18 square miles or a little more than 2 per cent of the entire Triassic north of the James River. This limestone conglomerate can not be regarded as a formational unit, for it grades towards the south into the arkose conglomerate. It is nowhere over 1½ miles wide and faulting has made a very uneven surface figure of it both north and south of Leesburg.

Exposures.—Exposures typical of the limestone conglomerate are best observed around Leesburg and 2½ miles north and south of the town. The exposures are either large flats or boulders of conglomerate, the latter sometimes having a length of as much as 30 feet. These boulders often interfere with farming. They weather rather rapidly, especially in cases of the conglomerate where the cement is calcareous. The land is fertile and this conglomerate gives rise to the richest soil of the entire Triassic. In places where the conglomerate is covered by the soil mantle, it can be traced by the fertile lime soil. Large boulders are very abundant around Goresville and southward to Leesburg and on the hills south of Leesburg. Due to faulting the conglomerate has finger-like projections south around Leesburg, as shown by Keith.

Physical properties.—The lime conglomerate is so named from the fact that it contains rounded pebbles of limestone, the source of which evidently has been from the limestones of Cambrian age; pebbles of composition other than limestone have come from Cambrian formations. The limestone conglomerate has been termed "Potomac marble" and "calico marble" by many people and has been used to some extent in Maryland.

There are two distinct varieties of the conglomerate based upon the color and composition of the matrix, and the color is an excellent guide for field use. One kind has a white calcareous matrix with a low percentage of silica and the other a matrix colored red by the presence of ferric oxide. Quarries working in both of these varieties have afforded excellent material, such as the quarries in the white matrix around Leesburg and in the red matrix north of Lucketts. In both of these varieties the pebbles are about the same in all physical properties.

From the standpoint of physical composition the limestone conglomerate may be discussed under the subjects of pebbles and matrix. The pebbles consist of over 90 per cent limestone, the others being quartz and feldspar. The pebbles vary in size from microscopic up to as much as 9 feet and all are unassorted, a mark which is quite an outstanding one. All of the pebbles are round to sub-round regardless of their composition or size.

The matrix is a mixture of a similar nature to the pebbles and shows comminuted particles under the microscope below sizes which cease to show rounding. The matrix is the first part of the conglomerate to break down under the agents of erosion and this gives rise to pebbles of all sizes in and over the soil.

The pebbles vary in hardness from that of limestone to quartz, and the matrix has a hardness of about 4 in the Moh Scale. The stone is hard enough for use as a road metal and shows a high coefficient of abrasion. The State Highway Commission has furnished three physical tests made on the limestone conglomerate, which are as follows:

Physical tests of limestone conglomerate

Laboratory No.	16031	16257	16414
Sample No.	1	2	3
Specific Gravity	3.01	2.82	2.80
Weight per cubic foot	187 lbs.	175 lbs.	175 lbs.
Water absorbed per cubic foot	0.63 lbs.	0.28 lbs.	0.33 lbs.
Toughness	——	——	9
Name of rock		Conglomerate	

There appears little or no secondary mineral matter in any specimens except along contacts with diabase rocks. Such cases as this are well shown on Goose Creek east of Leesburg at the site of the old investigation shaft for copper; here contact minerals such as epidote are developed. Shannon[4] describes Xonotlite, a calcium silicate, in the limestone conglomerate at its contact with the diabase near Leesburg.

The principal minerals composing the limestone conglomerate are calcite, dolomite and quartz. The minerals show nothing unusual and calcite predominates. The amount of ferric iron controls the color of the matrix and of the conglomerate in general.

Texture.—The texture of the limestone conglomerate is rather unique, since the pebbles and boulders are without sorting. Polished surfaces show pebbles of various sizes, rounded and often subrounded, the latter penetrating the sides of the former. The texture in polished sections is very beautiful and, as a marble, gives very pleasing effects, but in smoothing and polishing the pebbles often drop out of the mass.

Occasionally some beds of the conglomerate show oriented pebbles and such suggest water assortment, possibly fluviatile conditions which prevailed at the time of accumulation. The specimens of oriented pebbles always show the pebbles more nearly the same size than other specimens.

The matter of pebble penetration has been studied in thin sections. It was thought at first that this might be due to crystalline growth, for the force of such growths is enormous. There is no evidence for crystalline growth but the penetration is the result of pressure. A study of oriented specimens on the matter of pebble penetration may show the direction of forces. What few specimens were studied suggested that the forces exerted were in a southeast-northwest direction.

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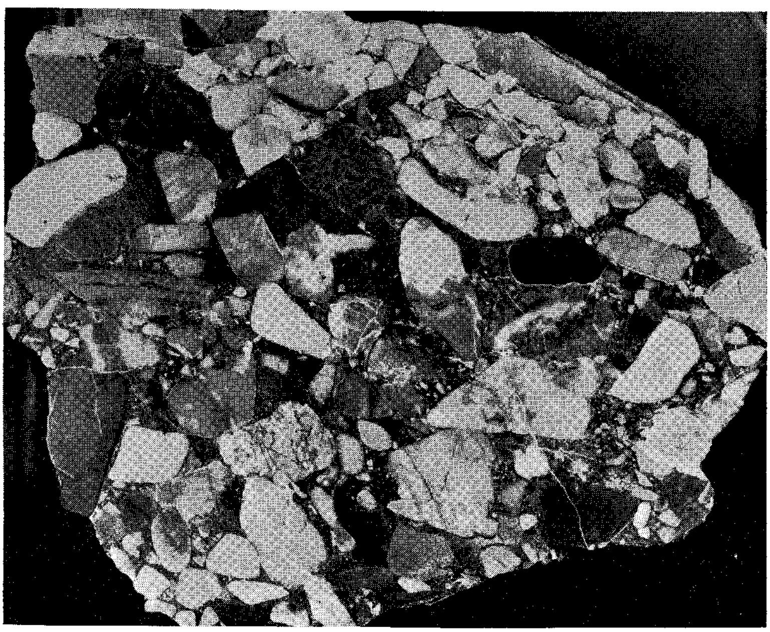
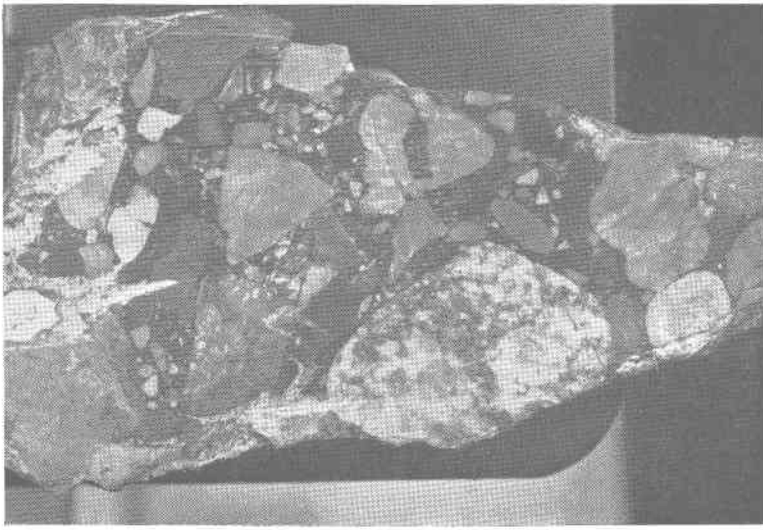
[4]Shannon, Earl V. An occurrence of Xonotlite at Leesburg, Virginia: The Amer. Min., vol. 10, No. 1, pp. 12-13, 1925.

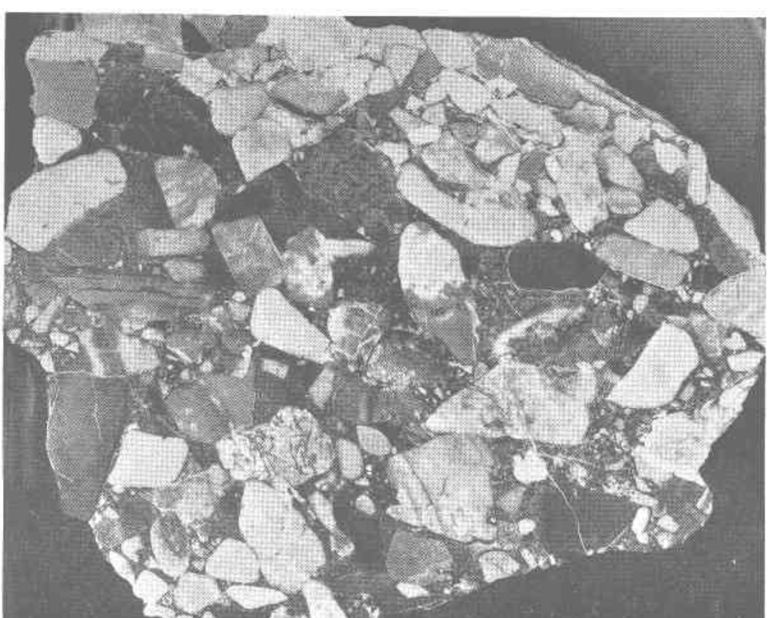
A. Polished section of Border Conglomerate (limestone phase) 2½ miles north of Lucketts, Loudoun County. (Natural size.)



B. Polished section of Border Conglomerate (limestone phase) with a red matrix, 2½ miles north of Lucketts, Loudoun County. (Natural size.)



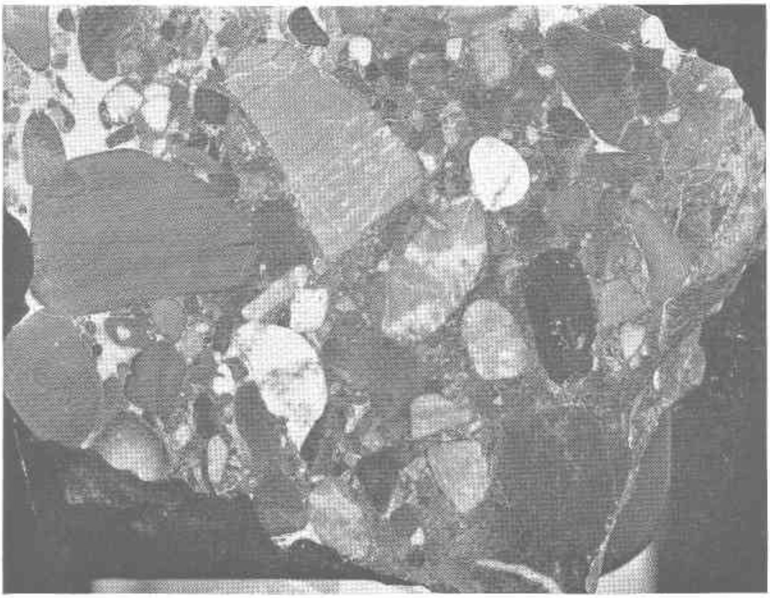
A. Polished section of Border Conglomerate (limestone phase) 2½ miles north of Lucketts, Loudoun County. (Natural size.)



B. Polished section of Border Conglomerate (limestone phase) with a red matrix, 2½ miles north of Lucketts, Loudoun County. (Natural size.)

A. Polished section of Border Conglomerate (limestone phase) one-fourth mile south of White's Ferry, Loudoun County. (Natural size.)

B. Polished section of Border Conglomerate (limestone phase) showing oriented pebbles, Leesburg Lime Company's Quarry, Loudoun County. (Natural size.)



A. Polished section of Border Conglomerate (limestone phase) one-fourth mile south of White's Ferry, Loudoun County. (Natural size.)

B. Polished section of Border Conglomerate (limestone phase) showing oriented pebbles, Leesburg Lime Company's Quarry, Loudoun County. (Natural size.)

The texture of the limestone pebble often shows thin laminae. The varied colors of white, gray, black, red, and brown give the stone a good appearance. Many of the pebbles show a mottled appearance. The matrix is usually less resistive than the pebbles for it is rare that pebbles break across but usually break out of the matrix.

Chemical composition.—The matter of sampling the limestone conglomerate is very difficult and unsatisfactory even at best and chemical analyses mean little. A number of analyses have been made and the one given below was made in 1904 by G. W. Lehman & Sons, Baltimore, Md., for Col. E. V. White, owner and operator of the Leesburg Limestone Quarry.

Chemical analysis of limestone conglomerate

	Per cent
CaO	37.75
MgO	19.43
SiO_2	13.55
Fe_2O_3 and Al_2O_3	6.97
CO_2	21.17
Moisture	1.08
	99.95

The above analysis is of the white matrix variety which runs less in ferric and ferrous oxides and about the same in alumina, silica, and magnesia as the red matrix variety. When the rock is burned it is necessary to crush and grind the clinker which is formed from the oxides of iron and aluminum before it can be used. This clinker is the result of the formation of calcium and magnesium aluminates and ferrates. The matrix, and not the pebbles, is the seat of the oxides of iron. The amount of organic matter is small and may possibly reach as much as 2 per cent. No chemical analyses of the red matrix variety are avaliable.

Weathering.—The limestone conglomerate, while it gives rise to a hilly topography, weathers rather quickly. The matrix disintegrates and releases the pebble and boulders. In spots over the country where there are flat exposures the soil mantle is thin and farming greatly hindered. The calcareous matter in the soil has given rise to much fertility. The action of the atmosphere, water and organisms are mainly responsible for its rapid erosion.

QUARTZ CONGLOMERATE

Extent.—The quartz conglomerate is best exposed between Herndon and Centerville, Fairfax County, and at intervals south of Centerville to Bull Run. The area covered by this conglomerate is much smaller than that of the limestone conglomerate. It has been mapped with the gray sandstone since it is so closely related to it and the gradation is so marked. The quartz conglomerate is restricted entirely to the eastern margin and is not found in any other of the areas except the Potomac. Quartz is very common in all the conglomerates, but this belt from Herndon to Bull Run in Fairfax County is the only one which shows quartz as the main pebble. To the north of Herndon this conglomerate is replaced by a schist conglomerate. To the east it is in direct contact with the intrusives and crystallines of the Piedmont series.

Exposures.—Three good exposures of the quartz conglomerate occur, namely, (1) in the cut of the Old Dominion Electric Railway just east of Herndon Station, (2) 1½ miles north of Centerville and (3) one-half a mile south of Centerville. None of the exposures show any great variety of rocks nor any great thickness. The Herndon exposure, however, shows some sandstone and a diabase dike. In most places this conglomerate is very resistive and is expressive of such in the hilly topography.

Physical properties.—The color of the quartz conglomerate is white through various shades of gray to black, the prevailing color being a medium to a light gray. The hardness of the conglomerate as a whole varies; the grains which compose the rock are chiefly silica and are about 7 in the scale of hardness but the cementing material is often softer. The minerals encountered in the conglomerate are quartz and feldspar as chief minerals, and the accessories are mica, magnetite and small amounts of garnet, schist, and gneiss. The mica occurs both as biotite and muscovite and some of it has been chloritized. In those phases of the conglomerate which bear the larger pebbles, quartz and feldspar are about the only minerals present.

The pebbles are all well rounded and penetrate each other to a far less extent than in the limestone conglomerate. The quartz grains are usually transparent, though some are milky. They give evidence of considerable erosion. The feldspars are of the orthoclase and plagioclases varieties, and all are remarkably fresh, especially when one considers the enormous amount of erosion through which they have gone. Most of the feldspar grains are far less rounded than the quartz, show albite twinning planes on their surfaces, and in thin sections give optical figures. Both have been derived from sources immediately to the east of the Triassic area. The peculiar feature is that rounding is so pronounced in the quartz and so far less pronounced in the feldspars when their source and distance of transportation, as well as other environmental factors, have been approximately the same. The quartz conglomerate does not have such a wide range in hardness, but it does not take a good polish due to the pebbles breaking out of the cement.

The matrix is composed of comminuted particles of quartz and possibly some of the silica may have been in colloidal condition. Much of the fine material is sharp and angular as it is below the sizes which are susceptible to rounding. The crushing strength in fresh samples will go well above that of the limestone conglomerate, though this has not been tested in the preparation of this report. The quartz conglomerate is not of any commercial importance.

Texture.—The texture of the quartz conglomerate is the most uniform of all conglomerates and the average size of the pebbles is about three-fourths of an inch as a maximum diameter. Hand specimens give the appearance of pebbles, being set in a milky matrix in much of the rock. The grains and pebbles vary from the size of coarse sand up to 3-4 inches, and there is a gradation from the east towards the west into the gray sandstone. The shapes of the pebbles are oval to round and very few are flattened. Tabular fragments are quite common with the schist and gneiss conglomerates. When the conglomerate is broken, the break in most cases is around the pebble, as the cement is less resistive than the grain.

Chemical composition.—No chemical analyses are available for the quartz conglomerate. A mechanical analysis has been made as shown under the subject of the sandstones of this report. It is quite evident that the conglomerate will run high in silica content, low in lime and magnesia, and such constituents as ferrous and ferric oxides, potash and alumina are absent or only in traces. This conglomerate is the most uniform of all from the standpoint of composition.

Weathering.—Weathering has proceeded rather rapidly with the quartz conglomerate and the soil resulting from it is not particularly adapted to agriculture. Solution from streams and percolating water has had little effect upon it as compared to the limestone conglomerate. Metamorphosed portions of the rock caused from diabase dikes are very resistive and usually are well marked in the topography.

ARKOSE CONGLOMERATE

Extent.—The areal extent of the arkose conglomerate is so small and variable that it is mapped with the red shales and their intercalated sandstones. It is restricted wholly to the western margin of the Potomac area in Loudoun and Prince William counties. It occurs first just south of Oatlands and at broken intervals south to Thoroughfare in Prince William County. The average length of the small belt is less than one-half mile. In its extent field relations clearly suggest that it is a continuation of the limestone conglomerate in which the chief pebble instead of being limestone is feldspar.

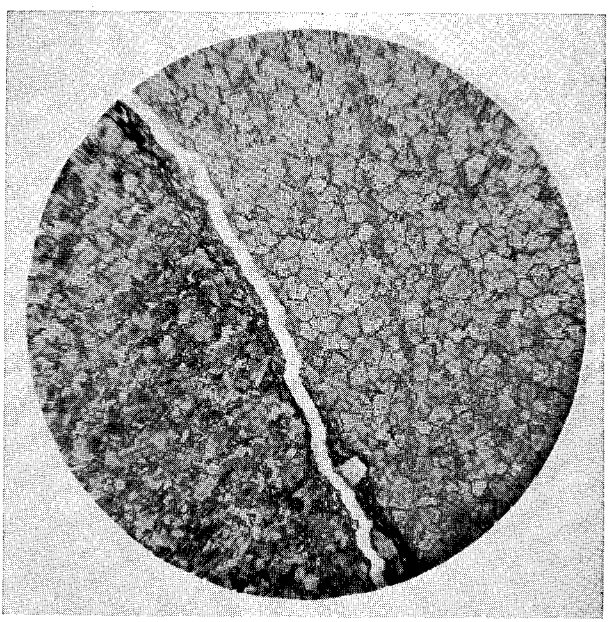
Exposures.—Good exposures of the arkose conglomerate are rare as it weathers so readily. The most typical exposures occur south of Oatlands and around Antioch in Loudoun and Prince William counties, respectively. The best exposures occur in places where fresh cuts have been made in road grading. West of Aldie on the Aldie-Alexandria road, the conglomerate occurs in flat exposures over the surface and in this habit resembles the limestone conglomerate around Leesburg and the trap conglomerate around Culpeper.

Physical properties.—The color of the conglomerate is invariably red to reddish brown and especially red on unweathered surfaces. The soil resulting from its disintegration is red and, with the pebbles, is a great help in mapping the unit. The pebbles themselves are very hard and offer considerable resistance to erosion but the conglomerate as a whole, with its weak bonding material, soon disintegrates. Feldspar is the principal mineral making up the pebbles and, in the main, is of the potash or orthoclase variety. Quartz ranks second and is rather a variable pebble, present in large quantities in some places and almost absent in others. Gneiss, schist, and slates or phyllite fragments from the Catoctin series are sparingly present. Muscovite and biotite are present in the groundmass and are often weathered. Both limonite and hematite are present, the former in all probability secondary. The specific gravity is about that of the limestone conglomerate, ranging from 2.70 to 2.95.

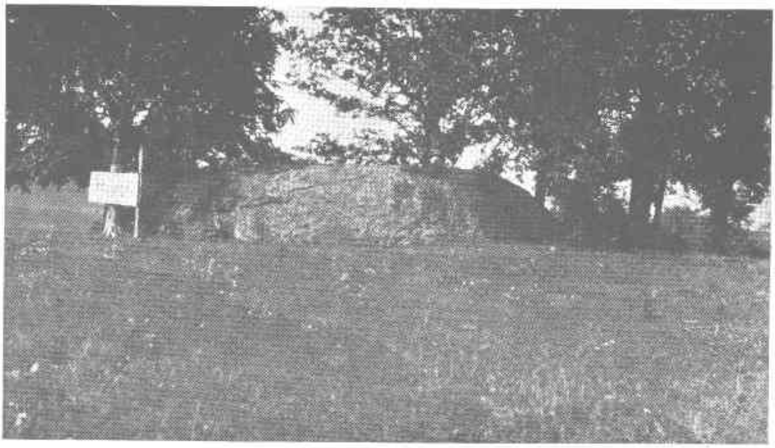
Texture.—The pebbles are smooth and many are highly polished just as though they came only recently from rapidly running water. They are in almost all cases very well rounded and flattened. Some of the feldspar pebbles are of the Carlsbad twinning habit and, though considerably worn, they still show this feature. The pebbles vary from a fraction of an inch up to 3 inches in size and, as in all of the other conglomerates, are mixed without any regard to size or specific gravity, giving ample evidence of their residual origin. The pebbles are coated with thin ferric oxide and are contained in a matrix consisting of finely divided and angular feldspar, mica, secondary calcite and other minerals thoroughly permeated with the ferric oxide. When the conglomerate is fractured it breaks around and not across the pebble, revealing the weak cement, and this is the case in practically all the Triassic conglomerates. The texture is not uniform throughout the rock and the pattern or fabric is just as variable. To secure a good polished specimen is very difficult as the flattened pebbles break out so easily and the cement shatters even under slight pressure.

Chemical composition.—The chemical composition of the arkose conglomerate stands by itself and in contrast to the phases of this rock. First of all, the percentage of ferric oxide, while not abnormally high, is more a factor for consideration than in the two previously mentioned conglomerates. It is not the high percentage of Fe_2O_3 in the matrix of the conglomerate, for it is less than in many of the Piedmont and other residual clays, but on account of its being an opaque substance a small amount seems larger than it really is. It occurs disseminated through the matrix and as an envelope around the various constituents. This phe-

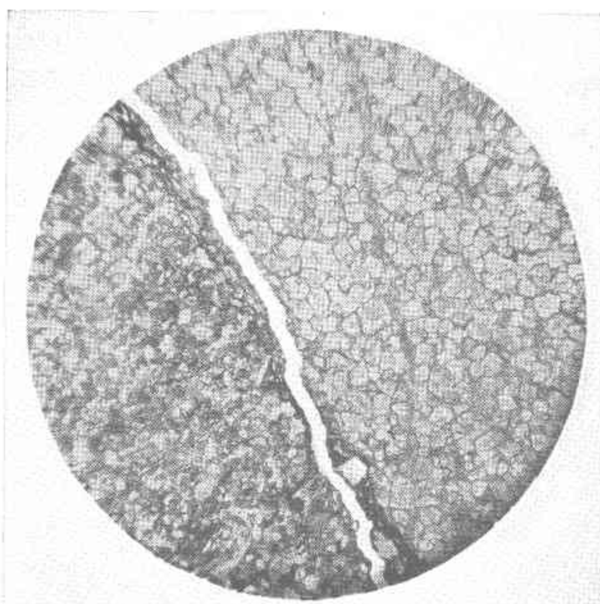
A. Large boulder of Border Conglomerate (trap phase) 1 mile south of Culpeper, Culpeper County.



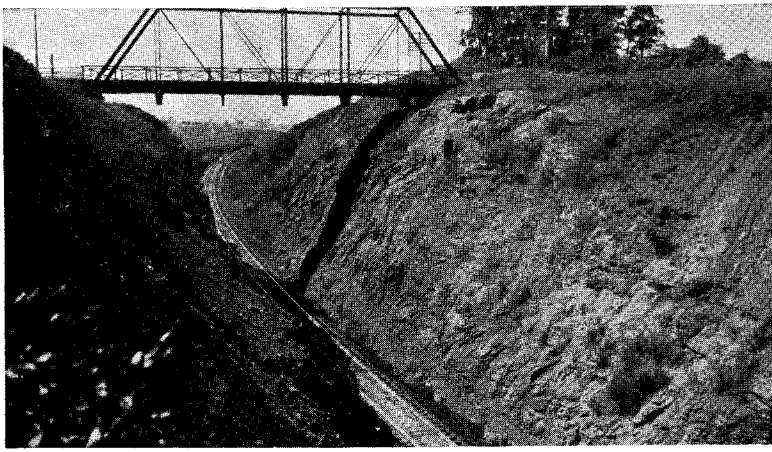
B. Photomicrograph of the contact between a dark penetrating and a light colored penetrated limestone pebble in thin section from the Border Conglomerate (limestone phase) 2½ miles north of Lucketts, Loudoun County. Single nicol. 20 Diameters.



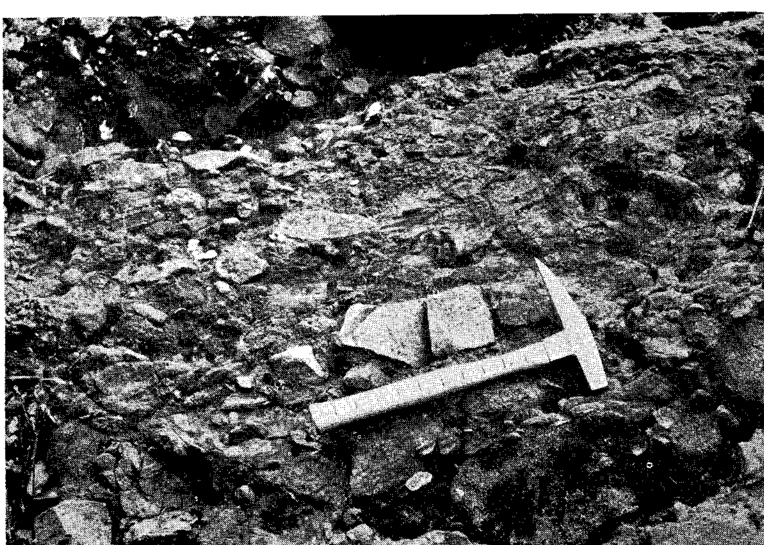
A. Large boulder of Border Conglomerate (trap phase) 1 mile south of Culpeper, Culpeper County.



B. Photomicrograph of the contact between a dark penetrating and a light colored penetrated limestone pebble in thin section from the Border Conglomerate (limestone phase) 2½ miles north of Lucketts, Loudoun County. Single nicol. 20 Diameters.

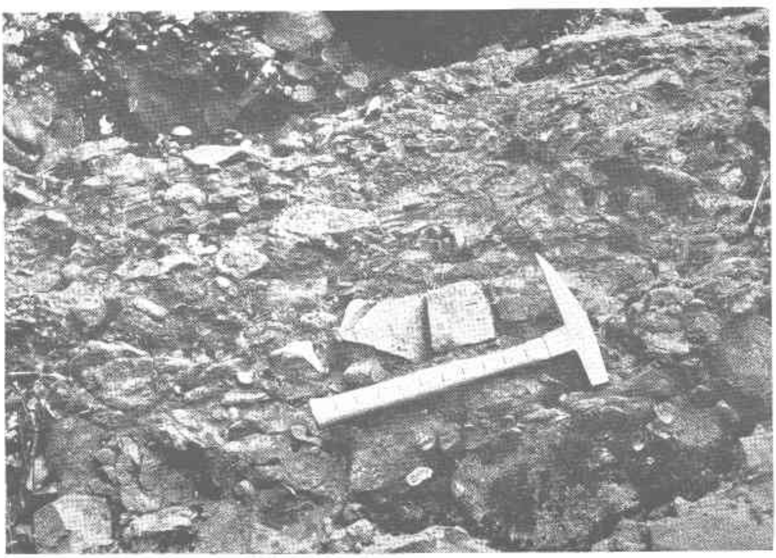


A. View of Border Conglomerate (trap phase) in the Southern Railway cut, from overhead bridge, 1 mile south of Culpeper, Culpeper County.



B. View of a weathered surface of the Border Conglomerate (trap phase) 2 miles northeast of Liberty Mills, Orange County.

A. View of Border Conglomerate (trap phase) in the Southern Railway cut, from overhead bridge, 1 mile south of Culpeper, Culpeper County.



B. View of a weathered surface of the Border Conglomerate (trap phase) 2 miles northeast of Liberty Mills, Orange County.

nomenon is best seen in the red sandstone and will be discussed later. No chemical analyses have been made except for the percentage of combined ferric and ferrous oxides which on the average runs 4.5 per cent. The conglomerate will run fairly high in silica which occurs both in the free and combined states. There is little lime or magnesia present and when present it is secondary. Seams of calcite as fracture fillings are rare.

Weathering.—In the weathered condition the conglomerate, with the large feldspar masses, looks at a distance very much like a porphyritic rock. It breaks down along with the sandstone and shale into a reddish brown soil which is characterized by various pebbles scattered over the surface. The rock disintegrates far more rapidly than the other conglomerates and forms a fairly good soil, somewhat less productive than that of the limestone conglomerate. Occasionally the conglomerate is cut across by diabase dikes and locally altered, such alteration usually being attended by a loss in the deep red color and an increased brittleness.

SCHIST CONGLOMERATE

Extent.—The schist conglomerate is so named because it contains fragments of schist as its main constituent. There are several belts of this type of schist. The most northern one occurs on the eastern margin of the Potomac area and is first exposed about 2 miles north of Herndon, Fairfax County. This belt can be traced for about 1¼ miles and gives expression to fairly high hills. It is the northern continuation of the eastern part of the Border Conglomerate, which at Herndon and south of Herndon to Bull Run is termed the Quartz Conglomerate. The width of this belt is about one-fourth of a mile.

The second belt of the schist conglomerate is on the west side of the Potomac area, beginning a short distance north of Rappahannock River in Fauquier County and extending southward as a belt, never exceeding one-half a mile in width on the average almost to Rapidan River and is broken west of Brandy Station. This conglomerate is especially well developed northwest of Brandy.

The third and last belt of this schist conglomerate is just to the east of the town of Barboursville. This belt is very small and can not be traced to any great distance but is about the best of all the exposures. It shows the conglomerate in close contact with the material from which it was derived and upon which it unconformably rests.

Exposures.—The two best exposures are seen north of Herndon and east of Barboursville. The Herndon exposure has been worked for road metal and affords a fresh section. The Barboursville exposure occurs along the road leading from that town to Gordonsville and is one of the best of all conglomerate exposures. The schist conglomerate grades into the trap conglomerate which is so well shown over the exposure from the Rappahannock River to the Rapidan, especially in the new quarries south of Culpeper. None of the exposures show any variety of lithology, and this fact is not only applicable to the conglomerates but to all the Triassic formations, for reasons discussed under the subject of topography.

Physical properties.—The color of the schist conglomerate is light gray, reddish brown and red. The conglomerate north of Herndon is a very light gray in pebbles, fragments, and groundmass. The rock west of Brandy is red on fresh surfaces and reddish brown on weathered surfaces. The rock east of Barboursville has a bright red matrix but the fragments are a bright silvery color which stands out in contrast. Just west of Scottsville, in the area which bears the name of this town, occur a very few exposures of this silvery schist set in a red groundmass, which is very similar in all respects to that near Barboursville.

The schist conglomerate with the exception of that exposed north of Herndon and east of Brandy is very soft. The conglomerate when fractured breaks across the fragment as often as around it and breaks with the same ease in all directions. The minerals which compose it are quartz, a little secondary calcite, and epidote; and the main constituents are schist and gneiss fragments. The specific gravity varies from 2.56 to 2.82.

Texture.—The texture is fairly uniform except in those cases where the gneiss pebbles assume importance. The schist fragments are tabular and do not usually exceed 2 inches in length and less than one-fourth of an inch in thickness. From a physical standpoint they are well worn. The matrix consists of a mixture of quartz, feldspar, and secondary calcite with some other minerals, and in all the exposures south of Herndon ferric oxide is an important constituent. The fragments are often coated with ferric oxide which also penetrates them along the laminæ. In the gradation over into trap conglomerate the fabric becomes a beautiful mosaic one, and these trap fragments are as much as 18 inches in length. All of the constituents, regardless of size, are intermingled.

Chemical composition.—No chemical analyses have been made, except that the iron content in the conglomerate east of Barboursville has been found to run 4.42 per cent and in the conglomerate west of Scottsville 4.64 per cent. Free silica will naturally run low, likewise lime and magnesia. The physical tests which were made on the road metal north of Herndon were fairly satisfactory. From the best observations, the rock seems to resist weathering sufficiently well to serve as base rock in road construction.

Weathering.—The belt of schist conglomerate north of Herndon is rather resistive to erosion and is responsible for the hills in that vicinity. Upon disintegration it does not produce a very fertile soil. The schist conglomerate to the south, however, weathers more readily and no hills are seen. The soil is not very fertile. Tabular fragments of the gray schist are scattered over the soil and are still fresh enough to appear unchanged when compared to their native rock. The matrix weathers more rapidly and releases the fragments.

TRAP CONGLOMERATE

Extent.—The amount of territory covered by the trap conglomerate is exceeded by none of the Triassic conglomerates, but possibly it is equaled by the granite-gneiss conglomerate. This type of conglomerate takes its name from the fact that its outstanding constituent is trap or the diabase pebbles and boulders, so well seen south of Culpeper.

The northernmost belt of this conglomerate begins at Culpeper and extends southward along Rapidan River on the western margin of the Potomac area. This belt does not exceed 2 miles in width, is over 30 miles long, and composes Cedar Mountain entirely as well as all the high hills west of Rapidan Station and the large bluffs of Rapidan River. The second belt lies along the southeastern margin of the Potomac area around Raccoon Ford. The great bulk of trap conglomerate of the Potomac area lies in Orange and Culpeper counties though a small amount of the western belt lies in Madison County. The belt around Raccoon Ford is not over one-half mile wide and is not exposed for any great distance.

The third belt occurs in the Scottsville area, extending from Glendower on the northwest of this area along the western border down to the town of Howardsville, and is broken between the two towns for a considerable distance. The upper part of the belt lies in Albemarle County, the lower or southern part in Albemarle and Nelson counties.

This conglomerate, its topography, and its weathering, all bear such a close relationship that the mapping is fairly easy. It is decidedly the most satisfactory one to map and the unconformable contact between it and the older crystallines and intrusives is often well developed. In many places schist fragments are abundant but trap fragments outnumber all others.

Exposures.—Trap conglomerate offers the finest exposures of all the conglomerates, to say nothing of the fresh quarries worked around Culpeper and the fresh cuts made by the State Highway Commission at Glendower and Howardsville. There are two quarries south and southwest of Culpeper, respectively, and these were in operation by the State when the field work on the Triassic was in progress. In neither of the Culpeper quarries nor in the great cut on the Southern Railway 1 mile south of Culpeper does any variety of Triassic rock other than the Border Conglomerate show.

The exposures along the Rapidan River west of Rapidan Station, on Cedar Mountain and at Raccoon Ford, show the conglomerate in excellent form; in these places the exposures are great ledges and precipitous bluffs and also flat exposures. Around Culpeper occur boulders of enormous size fully as large as those of the limestone conglomerate around

Leesburg. Cedar Mountain, with its major axis lying almost north and south and with a well developed depression at its upper third, is the most significant topographic feature of all the conglomerates comparable to the significance of Mt. Pony and Buzzard (Twin) Mountain in the diabase lithology. Between the town of Culpeper and the upper end of Cedar Mountain large flat exposures of the trap conglomerate occur. These make farming difficult and crops during prolonged dry seasons suffer from lack of moisture.

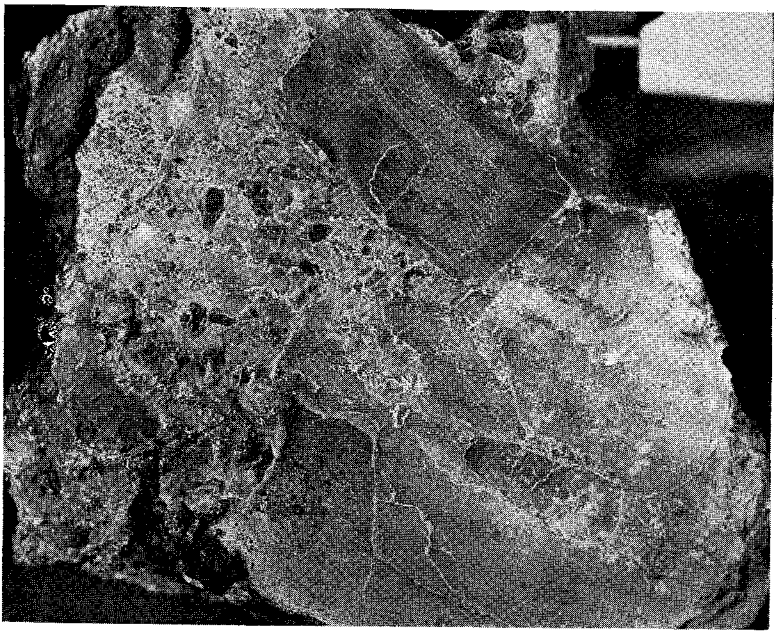
Exposures in the Potomac occur along Rapidan River and Blue Run, and while none of them are very fresh they show the conglomerate well, particularly so in its relation to the parent rock and to the soil into which it has weathered. Great boulders and flat exposures cover much of the belt and the gradation to the east into a coarse sandstone is well seen.

Exposures west of the little hamlet of Glendower on the Charlottesville-Scottsville concrete pike are very fresh and show the pebbles and boulders well. East of Howardsville along the new road leading to Scottsville fresh cuts have been made. The old road bed is to the north and passes over much of the old crystalline rock which unconformably underlies the Triassic Border Conglomerate. Ledges over 25 feet high show the trap conglomerate in its best form. This new road passes along the foot of a hill which is nearly 300 feet above the level of the nearby James River, and this hill is composed entirely of trap conglomerate. In the town of Howardsville and on the railroad between Warren and Boiling Springs there are excellent exposures. The great resistance to erosion and the high hills make it possible for the conglomerate to be well exposed and the fact that it is so well suited to road building has produced excellent quarries and road cut exposures during the past five years.

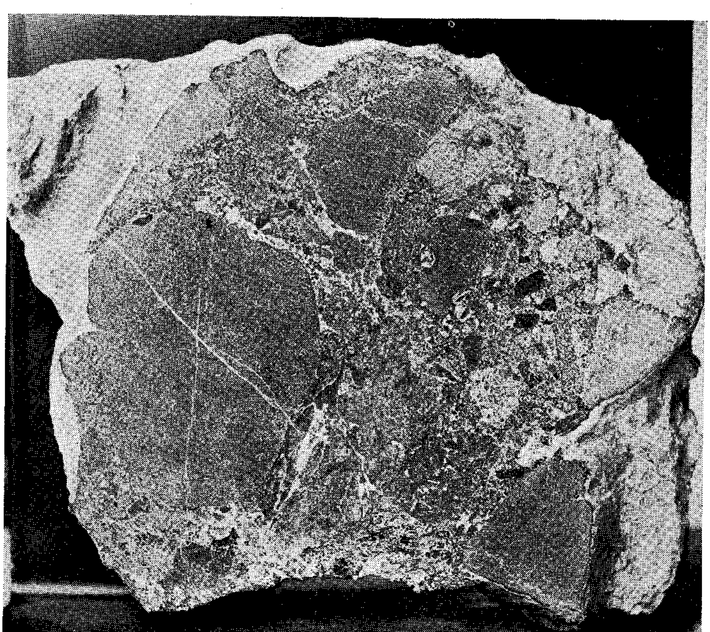
Physical properties.—The color of the trap conglomerate is always dark and varies from a dark gray through shades of red to brown. The trap or diabase pebbles, which are so abundant, are themselves a brown to a black color depending both upon the amount of iron present and the degree of weathering. In many instances the matrix is so saturated with hydrated iron oxides that it has a very bright metallic luster on fresh surfaces. The only white minerals in the conglomerate are calcite and quartz. The color is fairly constant in all the exposures and is helpful within certain limits in mapping.

The hardness is rather high in the trap conglomerate and most quarrymen claim that in crushing it for road metal it is almost as wearing on the jaws of the crushers as straight diabase. The pebbles are not so brittle but they are tough and will ring when struck with a hammer. The hardness is around 7 in the Moh Scale of Hardness and the pebbles, boulders, and matrix are equally hard. The rock makes an excellent road metal and is used extensively for this purpose around Culpeper.

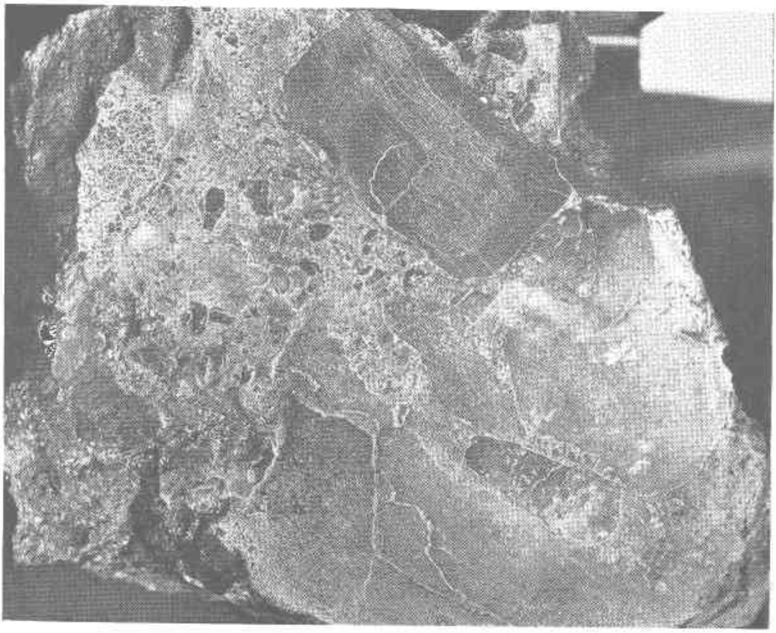
Quarrymen call the small rounded fragments pebbles and the larger



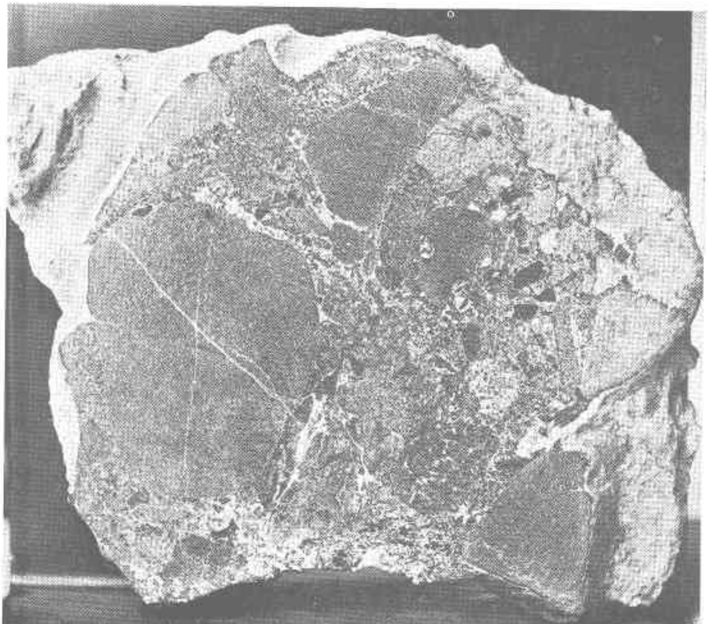
A. Polished section of Border Conglomerate (trap phase) north of Howardsville, Albemarle County. (Natural size.)



B. Polished section of Border Conglomerate (trap phase) from State Road Quarry 1¾ miles south of Culpeper, Culpeper County. (Natural size.)



A. Polished section of Border Conglomerate (trap phase) north of Howardsville, Albemarle County. (Natural size.)



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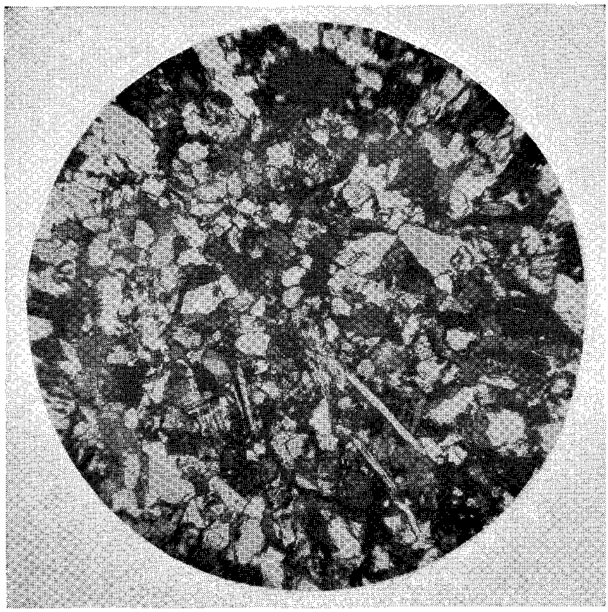
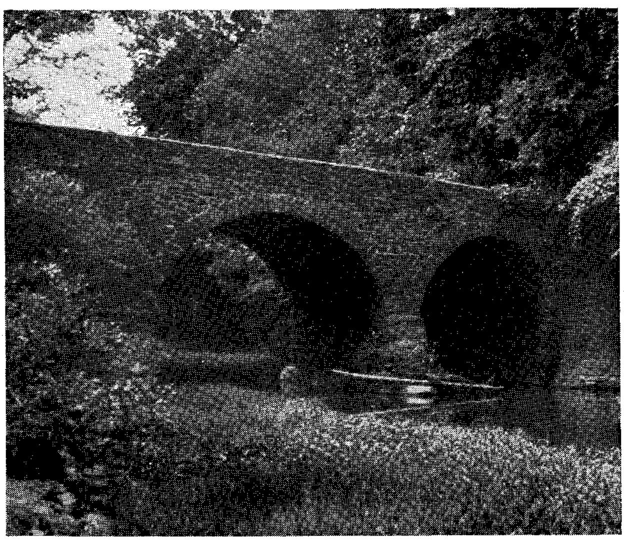
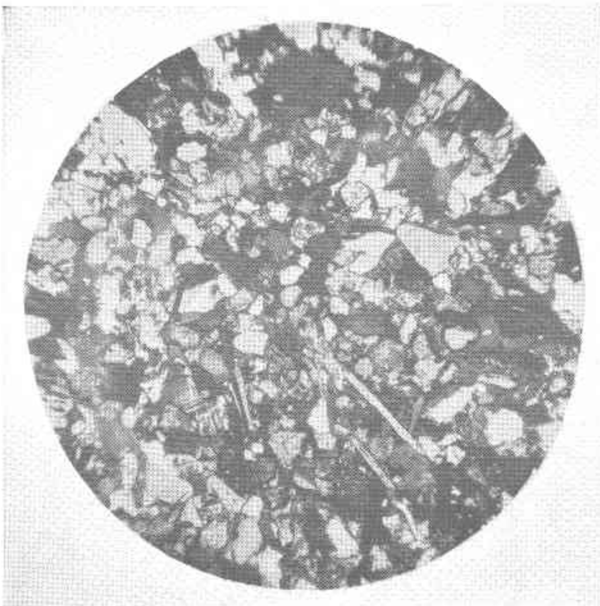


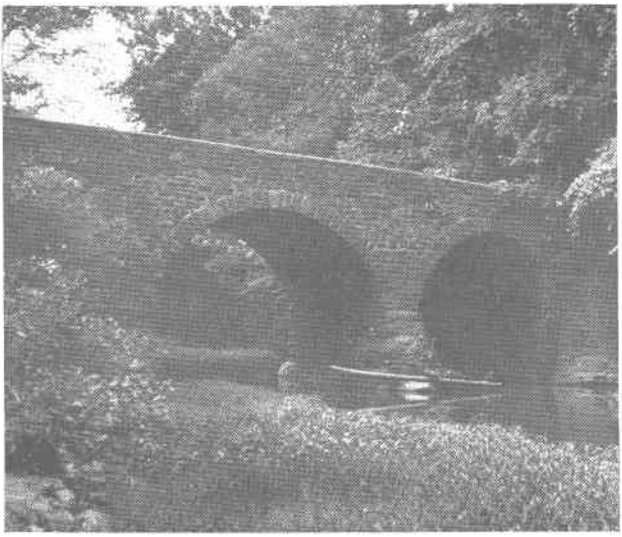
A. Photomicrograph of thin section of red Manassas sandstone from Portner sandstone quarry, Manassas, Prince William County. Crossed nicols. 20 Diameters.



B. "Old Stone Bridge" built of red Triassic sandstone, over Bull Run, 1 mile east of "Stone House" on the Bull Run Battlefield, Prince William County.



A. Photomicrograph of thin section of red Manassas sandstone from Portner sandstone quarry, Manassas, Prince William County. Crossed nicols. 20 Diameters.



B. "Old Stone Bridge" built of red Triassic sandstone, over Bull Run, 1 mile east of "Stone House" on the Bull Run Battlefield, Prince William County.

ones boulders. All the pebbles and boulders are either rounded or subrounded and show an advanced state of wear. These for the most part are trap but some quartz and schist fragments, as well as fragments of gneiss, frequently occur. Calcite and epidote and in all probability some of the iron oxides are the common secondary minerals.

Unlike the limestone conglomerate, the pebbles do not take a good polish and many of them show a fibrous structure. In thin sections these trap pebbles plainly give the ophitic or diabasic structure and, while both the feldspars and pyroxenes are often much corroded, many still show cleavage and twinning and give an optical figure. The calcite is well crystallized. The epidote is very abundant, particularly around Culpeper and Cedar Mountain, but not so much so along Robinson River in the southern part of the Potomac area, and at Glendower and Howardsville in the Scottsville area. These pebbles beyond any doubt are of Catoctin origin in the Potomac area, but in the Scottsville area they have been derived from pre-Triassic diabase intrusives and some of them possibly form the early Triassic flows, as the Triassic sedimentary rocks are Middle to Upper Triassic or Keuper in age.

Specific gravity of the conglomerate varies from 2.60 to 2.84. The high percentage of diabase pebbles and iron oxides causes the specific gravity to run high. All of this conglomerate is highly indurated.

Texture.—Both the texture and fabric have a very wide range. The pebbles vary from very small up to 4 and 5 feet and all are incorporated into a dense to fine-grained groundmass. Often the pebbles break across rather than around, showing the strength of the matrix. The shape of the large constituents is subject to considerable variation. The diabase pebbles and boulders are usually oval and the gneiss rectangular and triangular. The fabric is very irregular and in no case has there appeared any evidence of orientation of the pebbles. The texture of all of the exposures is largely the same and is soon recognized in the field.

Chemical composition.—Free silica and calcareous matter run rather low in the trap conglomerate, though the latter is high enough to have a decided effect upon the soil. To a large extent the composition of the conglomerate is that of diabase, since the diabase is so important a constituent. Epidote as a secondary mineral runs unusually high in some localities. Various physical tests have been made by the State Highway Commission, but no dependable chemical analyses are available.

Weathering.—Trap conglomerate weathers very slowly. In every locality where it is found high hills occur, as around Culpeper, Cedar Mountain, the high hills west of Montpelier, and at Glendower and Howardsville. The matrix is very slow in weathering; often pebbles and boulders are found lying upon the surface with portions of cement adhering to them, something unknown with the other phases of Triassic conglomerate.

The calcite upon weathering furnishes some calcareous material for the soil, and in every trap conglomerate locality there is good soil. Steep hillsides and ledges along river bluffs are the most favorable places to see rapid weathering. The soil mantle is not so deep on this conglomerate except in stream bottoms, and trap conglomerate soils everywhere are red.

QUARTZ-ARKOSE CONGLOMERATE

Extent.—The quartz-arkose conglomerate covers quite a large area and occurs in long and comparatively narrow belts. This phase of the Border Conglomerate in the Danville area begins southeast of Appomattox along Falling River and extends along the western margin of the area to a point a few miles south of Roanoke River in Pittsylvania County, thus taking in parts of Appomattox, Campbell and Pittsylvania counties. From this southernmost point south the conglomerate is concealed on the western side of the Danville area but it is brought up by a fault on the eastern margin of the area along Brush Creek, and especially well on the Banister River; from these points south the belt of quartz-arkose conglomerate swings towards the center of the basin and becomes wider, and east, southeast and south of Chatham it gives rise to White Oak Mountain which extends southwestward into North Carolina as a low elevation and is cut through near the Virginia-Carolina line by the Dan River. The quartz-arkose conglomerate forms a larger percentage of the Triassic rocks in the Danville area than in any of the Triassic areas of the state and the belt is less broken. The origin of the material composing the conglomerate is from the granites and gneisses which constitute the chief rocks adjacent to the Triassic area and which are of pre-Cambrian age.

The quartz-arkose conglomerate in the Farmville and Richmond areas is not so well exposed and tracing it is far more difficult. In the Farmville area it is found along the western border but the belt is very short and narrow. Along the eastern border and toward the center of the Richmond Basin the conglomerate is exposed but peneplanation and the thick mantle of soil render it obscure. A fault has brought the conglomerate to the surface in the central portion of the Richmond Basin near Otterdale in Chesterfield County.

Exposures.—The type exposures in the Danville area occur in the Virginian Railway cut one-half mile west of Long Island Station, Campbell County; along the Banister River, especially at the bridge where the Mt. Airy-Riceville road crosses the river; 6 miles south of Chatham, on the White Oak Mountain and its south flank near Chestnut Level and Spring Garden; and the last good exposure is on the western edge of the area along the Danville and Western Division of the Southern Railway 1 mile west of Cascade.

The only exposures of the Farmville area, and these are very poorly developed, are 4 miles northwest of the town of Farmville in Buckingham

County and west of Ca Ira in the same county. In the Richmond area by far the best exposures are 1 mile west of Otterdale and 1 mile south of James River along the public road east of Huguenot Springs. Other exposures, specimens of which are to be found on many of the old coal dumps, especially to the north and south of Midlothian, are common along the eastern margin. Along this border the conglomerates grade into the coarse red arkoses and arkosic sandstones but are nowhere brought to the surface. On account of not having access to the underground conditions in the coal mines a study of the conglomerate along the western border is rather difficult.

Physical properties.—The prevailing color of the quartz-arkose conglomerate is light to dark gray, but along the Banister River the color is dark red to black because of the presence of ferrous and ferric oxides. The rock upon weathering often has a yellow tone and in this condition closely resembles weathered granite and granite gneiss.

This phase of the Triassic Border Conglomerate is the most highly indurated of all the formations in cases of a heavy iron oxide matrix. This conglomerate to a small extent and a very coarse arkosic sandstone have each been used for road construction, being quarried from White Oak Mountain, 5 miles south of Chatham. The rock is very difficult to crush, though it is not tough but hard and brittle. The hardness is that of quartz and feldspar.

The chief minerals are quartz and feldspar, with many fragments in the shape of pebbles of granite, gneiss, and schist. The matrix consists of the same minerals as the larger constituents. At times fragments of silicified wood of the Araucarioxylon species occur in the conglomerate in the Richmond Basin. Calcite as a secondary mineral is rare and the scarcity increases in the eastern areas. Epidote has not been observed at all.

The specific gravity of the stone as quarried varies between the usual limits of that of granite and because of its close resemblance to granite the quarrymen call it bastard granite. The rock breaks with the same ease in all directions and is massive without any appearance of bedding planes.

Texture.—The size of the visible constituents varies a great deal and pebbles up to 14 inches have been observed. On the average the diameter is approximately 2 inches. All the pebbles are well rounded. In many places the bulk of the pebbles is quartz, but in any event all the pebbles have their source from the granites and gneisses. The quartz pebbles are usually milky to white and much better rounded than those of feldspar composition. The granite and gneiss pebbles are often elongated and subrounded and form the largest pebbles in the conglomerate. The feldspar fragments are rather fresh in many cases and some are not eroded beyond the stage where they show Carlsbad and albite twinning. The schist fragments are tabular as is their usual habit.

The matrix is usually either a fine light gray mass of quartz and feldspar or a rather dark red to black mixture of the same material impregnated with iron oxides. The matrix is not as strong as the pebbles. It gives the appearance of a medium to a finely ground rock in matrix and with the granite, quartz and large feldspar crystals, it bears a striking resemblance to a granite porphyry.

In thin sections the feldspars give optical figures, though many appear as corroded. Very little mica of the muscovite or the biotite variety appears in the conglomerate and, when found, it occurs in a large fragment of granite. In the Richmond area there is a better transition from the conglomerate to the sandstone than anywhere in the entire Triassic. Also the source of Triassic material is nowhere seen any better, for around the entire area large masses of granite and gneiss are seen as flat exposures and boulders and faults have brought the granites and gneisses to the surfaces within the areas, as at Boscobel in the Richmond area and at several points along White Oak Mountain south of Dry Fork.

Chemical composition.—The chemical composition of the quartz-arkose conglomerate as a whole is not far different from that of the adjacent granite and granite-gneiss from which it has been derived. On the whole it will run a little higher in silica and often in iron. There has been very little change chemically in the conglomerate since its formation, even though it has been subjected to profound faulting.

Weathering.—The quartz-arkose conglomerate can be found in any degree of weathering and upon disintegration it does not form a fertile soil. Along streams much of the Recent material has been formed from its decay. East of Midlothian and along the Banister and Roanoke rivers gravel and pebble deposits have been formed from it. The cement of the conglomerate, while weathering, assumes a light red to a pink color. The quartz and feldspar pebbles scattered around over the soil are indicative of the presence of the conglomerate. On the south side of White Oak Mountain it has eroded very slowly, but it has been protected by an overlying hard arkosic sandstone. A singular feature about this phase of the Triassic Border Conglomerate is that it does not form great ledges of rock upon the soil as do the limestone and trap conglomerates. This phenomenon has not been observed south of the James River due to the weakly resistive nature of the matrix of the rock.

MANASSAS SANDSTONE

Manassas sandstone for the most part is intercalated with Bull Run shales and extends in very broken belts from a few miles south of the Potomac River over all the areas to the Carolina border in the purely continental areas, and in the Farmville and Richmond areas it is quite often exposed.

In the long Triassic basins, which were valleys, the sediments accumulated under residual conditions. On the sides and bottoms of these valleys accumulated the coarse deposits formed directly from the material on which the conglomerates rest. As the basin filled the order from the margin toward the center was coarse, medium, and fine; such is the arrangement we find today, and taking this order in connection with the fossil life, its structure and character of the sediments, we work back to the physical environments of the time when the Triassic sediments were accumulated.

The sandstones occur on both sides of the basins in narrow belts and, where the natural sequence has not been disturbed by faulting and not covered by Recent material or soil, the conglomerates underlie the sandstones and the latter are, in turn, overlain by the Bull Run shales.

The term Manassas is used for the Triassic sandstone, because around Manassas, Prince William County, the formation is exposed so well and here, too, the sandstone was first studied and quarried as far back as Civil War days. The formation is not as regular in its exposures as the Border Conglomerate, but at intervals it is abundant in all the areas. It is often referred to as the New Red sandstone, Triassic brownstone, and Newark sandstone. It is the same red sandstone found in the Connecticut Valley, in New Jersey, Pennsylvania, and Maryland.

Extent.—The type locality for the Manassas sandstone is north and south of Manassas. The belt begins near Bull Run, the boundary line between Fairfax and Prince Edward counties, and extends to some few miles south of Brentsville, the old county seat of Prince William County. There are a few small patches of the material on the western margin of the Potomac area but they are not so extensive as along the eastern margin.

The Scottsville area has short narrow belts of the sandstone. A few very short belts occur in the Danville area, one north and one south of the Roanoke River, differing from each other in a number of ways. Numerous outcrops are known in the Farmville and Richmond basins, and core drill logs in both of these basins show sandstone above the conglomerate.

Exposures.—Three abandoned quarries in the sandstone around Manassas still show the material very well and two good exposures on the western margin near Greenwich in the Potomac area have been worked. The abandoned quarry 2 miles south of Bristow shows the sandstone and shale intercalated. North of Liberty Mills near the junction of Blue Run and the Rapidan River, a quarry was once worked in the sandstone and this exposure shows the gradation from the coarse sandstone into the underlying conglomerate. In the Scottsville area, there are excellent exposures in the cuts of the Chesapeake and Ohio Railway north of Warren and south of the James River in Buckingham County. One exposure in the Danville area is 1 mile west of Nowlins Bridge on Molley Creek at the Community Mill. Another exposure is along the Norfolk and Western

Railway, 2 miles southeast of Chatham on White Oak Mountain where both white and grayish red sandstones overlie the conglomerate. Eight miles west of Danville and 2 miles east of Bachelor Hall Church a grayish red coarse sandstone is exposed in the roadway.

There are no especially good exposures in the Farmville area, due to erosion and the soil mantle. In the Richmond area, 1 mile south of the town of Midlothian, the incline (coal) of the Murphy Coal Company shows a coarse red sandstone highly arkosic and containing fragments of carbonized wood. On the whole the exposures are few and very poor in this area. The best surface exposures occur 1 mile west and 2 miles south of Otterdale.

None of the exposures show a very great thickness. Some show the Border Conglomerate and the sandstone, others the Bull Run shales and the sandstone, but many show only the sandstone. Faulting has concealed the sandstone in many places, as along much of the western border from Oatlands to the Rapidan River in the Potomac area. The thickest section in the entire Triassic is on the Potomac River bluff east of Leesburg, and will be given under the shales as more of this thickness is shale than sandstone.

Varieties.—The Manassas sandstone is usually thought of as a red sandstone of fine, medium and coarse grained texture. There are several varieties of the sandstone. On the basis of color they are the following:

1. Red sandstone. This type has ferric iron as its coloring agent and the sandstone may be a deep red, grayish red or a very dull red color. The deep red sandstone has ferric oxide both as an envelope around the individual constituents and well disseminated through the groundmass. The grayish red sandstone has the ferric oxide disseminated through the groundmass but not as an envelope around the grains; thus on a fresh surface, the light colored grains stand out in the red background. The dull red sandstone is quite common and is always either a fine grained texture with much shaly material in it, or what might very properly be called a muddy sandstone. All of the variously colored sandstones are coarse, medium, fine and very fine grained and grade into conglomerates from the coarse phases and into shales from the fine phases, marks which are very common in the field except where faulting has obscured the contacts and gradations.

2. Gray sandstone. The only essential difference between the red and gray sandstones is the absence of the red ferric oxide in the latter. The constituents are about the same. There is a much greater tendency for the gray sandstone to be coarser grained than the red. The gray variety is restricted to the western side of the basins and is best seen south of the town of Herndon, grading into a conglomerate to the south and in the State Road quarry on White Oak Mountain, south of Chatham.

3. Yellow sandstone. The yellow sandstone in its essential difference from the others has limonite as a pigment. It is especially well developed west of Herndon, exposed in the cut of the Old Dominion (Electric) Railway Company. It is also found along White Oak Mountain lying above the Border Conglomerate, and in the Richmond Basin.

On the basis of the mineral content the Manassas sandstone may be divided into the normal sandstone, the arkosic sandstone, and the micaceous sandstone. The normal sandstone contains quartz grains as its major constituent with a wide range of other constituents. This variety is by far the most common of all the sandstones. The arkose variety sometimes is abnormally high in feldspar and is always red. It is well exposed south and east of Oatlands, in Loudoun County, in the State Road quarry on White Oak Mountain south of Chatham, at many places in the Farmville area and along the eastern border underlying the coal beds of the Richmond area; the coal dumps of the Murphy Coal Company south of Midlothian show excellent examples of this type of sandstone. The micaceous sandstone is of fairly wide occurrence in all of the areas, especially in the region around Manassas, on the bluffs of the Potomac River east of Leesburg and the eastern margin of the Richmond area. This variety often carries very large flakes of muscovite and some little biotite and always is a deep to a grayish red.

All the sandstones are rather highly indurated though some can be disintegrated between the fingers. In some cases diabase dikes and stocks have so metamorphosed them that they are very hard; the original color may be preserved or lost. This matter will be discussed under the subject of metamorphism.

Physical Properties.—The matter of color has already been discussed under the subject of the varieties of sandstone. The controlling factor of color in the Manassas sandstone is the ferric oxide. This oxide is very opaque and a small percentage of it will give the appearance of a sandstone of high iron content. The following table states the situation fairly well as regards the matter of color:

A. Iron oxide present:

1. Abundant Fe_2O_3:

   a. Bright red sandstones of normal, arkosic and micaceous varieties. Textures range from coarse to very fine. Here belongs the rounded coarse grained sandstone which resembles oolitic rocks.

   b. Dull red sandstone of normal and arkosic varieties. Much fine material or a muddy matrix. Mostly fine grained. Weathers easily.

2. Moderate Fe_2O_3:

   a. Sandstones which have the ferric oxide in the groundmass but not as an envelope around the grain. Light red color and often intercalated with the darker varieties.

   b. Very light red to pink sandstone with small amounts of ferric oxide in the ground mass.

B. Wanting in Fe_2O_3 and hydrated iron oxides:

a. Gray sandstone—milky to transparent quartz with much feldspar with or without muscovite or biotite or both.

b. White sandstone—milky quartz with much feldspar and with or without mica.

C. Ferrous oxides present:

The cream colored to yellow sandstones which are composed of quartz, feldspars and mica and chiefly medium to fine grain texture.

Many of the sandstones appear to run high in iron but, upon analysis, they show a smaller percentage of ferric oxide than many of the residual clays which are far less pronounced in their red color. The red color has been dwelt upon at length as an indication of aridity in Triassic time and this problem will be discussed under the physical environment of the period. Suffice it to say here that the facts are not in accord for an arid climate in the eastern United States during Triassic time, and if red color is indicative of arid climates, then, why are not the great deserts forming at the present time also red?

The hardness of the Manassas sandstone is a matter of considerable variance. The chief factors in control of it are: (1) The ratio of the quartz and feldspar; (2) the amount of mud and fine material or, in brief, the ratio of the granular material and the groundmass; (3) the amount of induration; and (4) the amount of weathering.

The sandstone of the quarries around Manassas has the normal ratio of quartz to feldspar. It resists weathering to a considerable extent and meets the requirements of a building stone. In many cases the fine-grained muddy sandstones are so soft that they soil the fingers when handled and are very low in the scale of hardness and coefficient of wear. The amount of induration is one of the controlling factors; close to diabase dikes and stocks the sandstone may be of sufficient hardness to be used as road metal, such as the red sandstone taken from the State Road quarry near Stevensburg in Culpeper County. This last named locality is an example of a Triassic sandstone metamorphosed by the Mt. Pony stock and it is one of the two very hard sandstones in the Triassic of Virginia. The white and red sandstones of White Oak Mountain and the red arkosic sandstones along the coal mining belt of the Richmond area are very hard, due to intense pressures and faulting, and also perhaps to intrusives in both localities, most certainly in the last one.

Specific gravity of the sandstone varies from 2.40 to 2.75 and the average is around 2.60. The following physical tests in road metals were made by the Division of Tests, Bureau of Chemistry, United States Department of Agriculture, Washington:

Physical tests of Manassas sandstone

	Sample No. 1312 July 8, 1905	Sample No. 1711 July 26, 1906
Specific gravity	2.49	2.70
Weight per cubic foot	155 lbs.	168 lbs.
Water absorbed per cubic foot	3.36 lbs.	1.13 lbs.
Percentage of wear	....	3.6
French coefficient of wear	....	11.0
Hardness	15.5	18.0
Toughness	47.0	28.0
Cementing value	32 Dry 101 Wet	
Material	Ferruginous sandstone	

The texture of the Manassas sandstone has rather wide limits—from very fine-grained varieties which border on the shales and are often so classed up to the border line of conglomerates. The texture is not that of a uniform water-sorted deposit and is comparable to that in the conglomerates, as will be seen from the mechanical analyses, for all sizes are intermingled.

The grains are well rounded to subrounded in all exposures and are contained in a matrix of about the same composition as the grains, though usually of a farther advanced state of weathering. Often within a thickness of a foot the texture will change several times which is, along with other facts, a very helpful guide in the interpretation of the physical conditions under which the material was accumulated.

The pattern in most cases is irregular though in the oölitic-like sandstone it is uniform and regular. The quartz grains are quite well rounded and in a great majority of cases are round to oval shaped. The feldspar constituents for the most part are elongated. The mica is tabular and lies at any angle in the rock. The quartz grains vary from 4 to 35 microns (1 micron = 0.01 millimeter), the feldspars from 10 to 32 m, and the mica plates from 10 to 45 m in length and 1 to 6 m in width. The feldspar grains are consistently less rounded than the quartz and may be found either fresh or weathered. The matter of determining the degree of weathering is a difficult one. Feldspars which still give an optical figure, which show little or no corrosion, and which have a luster, are regarded as fresh. Often feldspar grains, when well rounded, will show twinning phenomena and color, and in the same specimen, others will show little or no rounding, appear intensely corroded and give no optical figure.

The mineral composition of the Manassas sandstone is relatively simple compared to many sandstones, though some specimens contain rare minerals. From all the specimens examined, the sandstones originating from the east side of the continental basins seem to have fewer minerals than those from the west side; this can not be advanced as an undisputed fact without a large representative collection of samples and many analyses. The two chief minerals are quartz and feldspars; of the feldspars, both alkaline and plagioclase varieties are present. The accessory minerals are mica, in both the muscovite and biotite forms, and magnetite. The secondary minerals are epidote and chlorite. The rare minerals are hornblende, augite and calcite. Ferric and ferrous oxides, one or both, may or may not be present. The minerals were identified both by the thin section method and by mechanical analysis.

Mechanical analyses.—Mechanical analyses were made from eight different Manassas sandstone specimens, selected with as much care as possible to get representative material. One of the chief difficulties encountered in the Triassic material is to get sandstones in the fresh condition which are not so highly indurated that they can be disintegrated by agitating in water and without any appreciable change in the size and shape of the constituents. Many of the sandstones are so highly indurated that agitation will not break them into their constituents, certainly not without some loss to the individual grains.

The method followed in the mechanical analyses is that of Thoulet,[5] Cayeux [6] and Goldman [7] with a few minor modifications. Five of the samples were taken from the Potomac area, one from the Danville and two from the Richmond area. The individual sample was agitated from 10 to 30 hours in distilled water until the matrix was broken down and the grains were free as they were at the time of accumulation. The length of time required for the agitation varied with each sample and the individual sample was tested frequently to ascertain when the matrix was completely disintegrated. Agitation was accomplished by motor driven machinery and was done as uniformly as possible.

The various steps in the process of disintegrating the matrix and the separation of the various constituents from each other by heavy solutions and magnet may best be outlined as follows:

(1) A large portion of the sample was air dried and weighed to determine the percentage of moisture. A small amount of approximately 10 grams was weighed out and dried in an electric oven for six hours at 110° Centigrade; then the moisture content was checked.

(2) The 10 gram sample was agitated in distilled water for a sufficient time to disintegrate it, frequently testing the degree of disintegration. A little ammonium hydroxide was added to assist in the breaking down of the clay. After disintegration, hydrochloric acid was added until the solution was neutral. The period of agitation for each sample varied from 10 to 30 hours.

(3) The material was transferred from the shaking bottle into an evaporating dish, allowed to settle and then washed until the supernatent liquid was clear. Time of settling varied with samples from 10 to 15 minutes.

(4) The material held in suspension, after settling, was evaporated to dryness

[5]Thoulet, J., Précis d'analyse des fonds sous-marine actuels et anciens, Paris, Chapelot et Cie, 220 pp., 1907.
——— Instructions pratiques pour l'establissement d'une carte bathymétrique-lithologique sous-marine: Bull. de l'Inst. Oceanograph 169, 29 pp., 1910.
[6]Cayeux, L., Introduction à l'étude petrographique des roches sédimentaires, Paris, Imprimerie nationale, 504 pp., 1916.
[7]Goldman, Marcus I., The petrography and genesis of the sediments of the Upper Cretaceous of Maryland: Maryland Geol. Survey, Upper Cretaceous Text, pp. 111-182, 1916.

and kept in an electric oven for six hours at 110° Centigrade, then weighed. This residue was clay and red iron oxide; the coarser material was heated until the water was driven off and then put through the same process as the fine material. The coarse material consisted of quartz or sand grains, feldspars, mica, magnetite, etc.

(5) The quartz, feldspars, mica, magnetite, etc., were subjected to an electromagnet, which extracted all the magnetic constituents, thus leaving the quartz, feldspar, and mica in the main; in the case of the red sandstones the grains of which are enveloped with a coat of ferric oxide, the difficulty of separation in the heavy liquids would naturally arise. This difficulty is not encountered in gray sandstones. In case of the red sandstones, the sample was weighed again and treated with strong hydrochloric acid which removed the ferric oxide coat. This acid does not materially affect the quartz, feldspar and mica, though it may attack certain other constituents. The residue was washed thoroughly, dried under the same conditions as above stated and weighed. The loss in weight was the soluble matter, chiefly ferric oxide, and this was added to the matrix material, which is the proper place for it, inasmuch as it is bonding material.

(6) The residue consisting chiefly of quartz, feldspar and mica was treated with Thoulet's Liquid of a specific gravity of sufficient consistency to float the quartz and feldspar and allow the heavy material to sink to the bottom; then the heavy material was drawn off by means of a separatory funnel. The quartz and feldspars were separated some by Thoulet's Liquid after the same manner. Bromoform was used for the separations. Perfect separations were impossible as many of the quartz and feldspar grains contained ferric iron, in fractures which interfered with their specific gravity.

(7) The sand was dried, weighed and sieved, using sieves of 30, 60, 100, and 200 meshes, thus classifying the sands as follows:

	Coarse Sand
30 Mesh	....
	Medium Sand
60 Mesh	....
	Fine Sand
100 Mesh	....
	Very Fine Sand
200 Mesh	....
	Extra Fine Sand

In some of the specimens there were coarse quartz fragments, which were classed as gravel, as they did not pass a 5-mesh screen.

(8) The various sizes of quartz grains were weighed, also the feldspars and the percentage of each calculated.

The analyses were made as near those of Thoulet and Goldman as possible for the sake of comparison. The treatment with hydrochloric acid introduced an error, which may be serious in most cases. It was the only way to overcome the ferric iron content, and as thin sections show little or no calcareous matter present, perhaps, the error was not so great. The experiments show a number of important facts regarding the constituents and their origin.

Mechanical analysis No. I

Field Specimen—No. 102.
Date Collected—June 22, 1921.
Locality—¼ mile south of Centerville, Fairfax County, at the southern end of the gray sandstone belt.

Sample air dried	10.305	grams		
Sample dried 6 hours at 110 degrees C	10.244			
Moisture	0.061	grams	or less than ½ of 1%	
Quartz, feldspar, mica, etc	7.980	grams	or	77.9%
Clay	2.260	"	or	22.1
Total	10.240	grams	or	100.0%
Light Constituents:				
Quartz	6.216	grams	or	77.8%
Feldspars	1.395	"	or	17.6
Heavy Constituents:				
Mica and magnetite	0.369	"	or	4.6
Total	7.980	grams	or	100.0%
Quartz:				
Gravel or Pebble	0.415	grams	or	6.7%
Greater than 10 mesh				
Coarse	1.216	"	or	19.6
30 Mesh				
Medium	3.211	"	or	51.6
60 Mesh				
Fine	0.789	"	or	12.8
100 Mesh				
Very Fine	0.464	"	or	7.5
200 Mesh				
Extra Fine	0.112	"	or	1.8
Total	6.207	grams	or	100.0%

Mechanical analysis No. II

Field Specimen—No. 87.
Date Collected—June 15, 1921.
Locality—5½ miles south of Manassas, Prince William County, near the eastern contact of the Triassic with the Piedmont crystalline rocks.

Sample aid dried	10.010	grams		
Sample dried 6 hours at 110 degrees C	9.960	"		
Moisture	0.050	grams	or less than ½ of 1%	
Quartz, feldspar, mica, etc	8.841	grams	or	88.6%
Clay, ferric oxide, and soluble matter	1.119	"	or	11.4
Total	9.960	grams	or	100.0%
Light Constituents:				
Quartz and feldspars	8.554	grams	or	96.8%
Heavy Constituents:				
Mica	0.286	"	or	3.2
Total	8.840	grams	or	100.0%

Quartz	6.731	grams	or	79.6%
Feldspars	1.808	"	or	20.4
Total	8.539	grams	or	100.0%

Quartz:

Gravel or Pebble	0.100	grams	or	1.5%
Greater than 10 Mesh				
Coarse	2.555	"	or	38.1
30 Mesh				
Medium	2.081	"	or	30.9
60 Mesh				
Fine	0.984	"	or	14.6
100 Mesh				
Very Fine	0.840	"	or	12.5
200 Mesh				
Extra Fine	0.147	"	or	2.3
Total	6.707	grams	or	99.9%

Mechanical analysis No. III

Field Specimen—No. 92.
Date Collected—June 16, 1921.
Locality—1 mile south of Manassas on the property of Mr. Joseph Johnson, Prince William County. It underlies and is contained in shales.

Sample air dried	10.026	grams		
Sample dried 6 hours at 110 degrees C.	9.981	"		
Moisture	0.045	grams	or less than ½ of 1%	
Quartz, feldspar, mica, etc.	8.220	grams	or	82.5%
Clay, ferric iron and soluble matter	1.740	"	or	17.5
Total	9.960	grams	or	100.0%

Light Constituents:				
Quartz and feldspars	8.071	grams	or	98.4%
Heavy Constituents:				
Mica, etc	0.133	"	or	1.6
Total	8.204	grams	or	100.0%

Quartz	7.793	grams	or	95.6%
Feldspars	0.249	"	or	4.3
Total	8.042	grams	or	99.9%

Quartz:

Coarse	0.030	grams	or	0.4%
30 Mesh				
Medium	0.801	"	or	10.3
60 Mesh				
Fine	3.785	"	or	48.8
100 Mesh				
Very Fine	2.432	"	or	31.3
200 Mesh				
Extra Fine	0.712	"	or	9.2
Total	7.760	grams	or	100.0%

Mechanical analysis No. IV

Field Specimen—No. 94-a.
Date Collected—June 17, 1921.
Locality—1 mile north of Manassas, overlying a red sandstone layer of excellent building grade.

Sample air dried	10.210	grams		
Sample dried 6 hours at 110 degrees C	10.159	"		
Moisture	0.051	grams or less than ½ of 1%		
Quartz, feldspar, mica, etc	8.694	grams	or	85.6%
Clay, ferric iron and soluble matter	1.454	"	or	14.3
Total	10.148	grams	or	99.9%
Light Constituents:				
Quartz and feldspars	8.412	grams	or	97.0%
Heavy Constituents:				
Mica, etc.	0.254	"	or	2.9
Total	8.666	grams	or	99.9%
Quartz	5.789	grams	or	69.4%
Feldspars	2.553	"	or	30.6
Total	8.342	grams	or	100.0%
Quartz:				
Coarse	0.952	grams	or	16.5%
30 Mesh				
Medium	3.954	"	or	68.8
60 Mesh				
Fine	0.631	"	or	10.9
100 Mesh				
Very Fine	0.163	"	or	2.8
200 Mesh				
Extra Fine	0.050	"	or	0.8
Total	5.750	grams	or	99.8%

Mechanical analysis No. V

Field Specimen—No. 116.
Date Collected—June 29, 1921.
Locality—1½ miles east of Cedar Run and 8½ miles southeast of Nokesville at the eastern contact of the Triassic beds.

Sample air dried	10.215	grams		
Sample dried 6 hours at 100 degrees C	10.166	"		
Moisture	0.049	grams or less than ½ of 1%		
Quartz, feldspar, mica, etc	9.150	grams	or	90.1%
Clay, ferric oxide and soluble matter	1.010	"	or	9.9
Total	10.160	grams	or	100.0%

Light Constituents:			
Quartz and feldspars	9.033 grams	or	99.4%
Heavy Constituents:			
Mica, etc	0.052 "	or	0.5
Total	9.085 grams	or	99.9%
Quartz	5.176 grams	or	57.4%
Feldspars	3.854 "	or	42.6
Total	9.030 grams	or	100.0%
Quartz:			
Gravel or pebble	0.054 grams	or	1.0%
Greater than 10 Mesh			
Coarse	1.106 "	or	21.4
30 Mesh			
Medium	2.621 "	or	50.6
60 Mesh			
Fine	0.966 "	or	18.8
100 Mesh			
Very Fine	0.319 "	or	6.2
200 Mesh			
Extra Fine	0.097 "	or	1.8
Total	5.163 grams	or	99.8%

Mechanical analysis No. VI

Field Specimen—No. 325.

Date Collected—August, 1922.

Locality—8 miles west of Danville.

Sample air dried	10.190 grams		
Sample dried 6 hours at 110 degrees C.	10.136 "		
Moisture	0.054 grams	or	0.54%
Quartz, feldspars, mica, etc	8.450 grams	or	83.4%
Clay, ferric oxide and soluble matter	1.680 "	or	15.8
Total	10.130 grams	or	99.2%
Light Constituents:			
Quartz and feldspars	8.122 grams	or	96.2%
Heavy Constituents:			
Mica and magnetite	0.321 "	or	3.8
Total	8.443 grams	or	100.0%
Quartz	4.986 grams	or	61.4%
Feldspars	3.132 "	or	38.6
Total	8.118 grams	or	100.0%

Quartz:

Coarse	1.054 grams	or	21.2%
30 Mesh Medium	3.085 "	or	62.0
60 Mesh Fine	0.608 "	or	12.2
100 Mesh Very Fine	0.184 "	or	3.6
200 Mesh Extra Fine	0.045 "	or	0.9
Total	4.976 grams	or	99.9%

Mechanical analysis No. VII

Field Specimen—No. 414.
Locality—1 mile west of Otterdale.
Date Collected—July, 1923.
Appearance—Gray Conglomerate.

Sample air dried	10.150 grams		
Sample dried 6 hours at 110 degrees C	10.026 "		
Moisture	0.124 grams	or	1.2%
Quartz, feldspars, mica, etc	9.320 grams	or	93.1%
Clay	0.688 "	or	6.8
Total	10.008 grams	or	99.9%

Light Constituents:

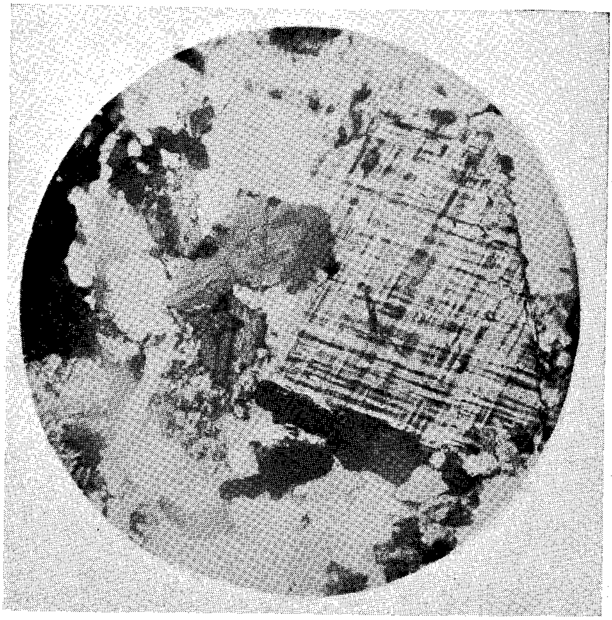
Quartz and feldspars	9.252 grams	or	99.37%

Heavy Constituents:

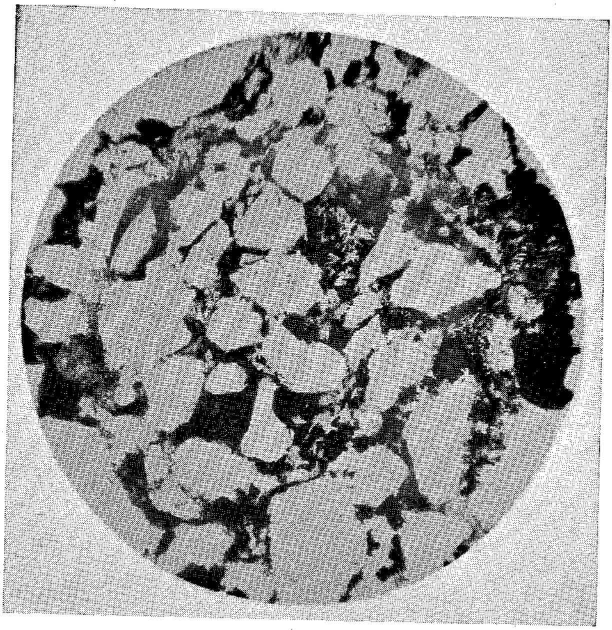
Mica, etc.	0.058 "	or	0.62
Total	9.310 grams	or	99.99%
Quartz	6.442 grams	or	69.70%
Feldspars	2.800 "	or	30.29
Total	9.242 grams	or	99.99%

Quartz:

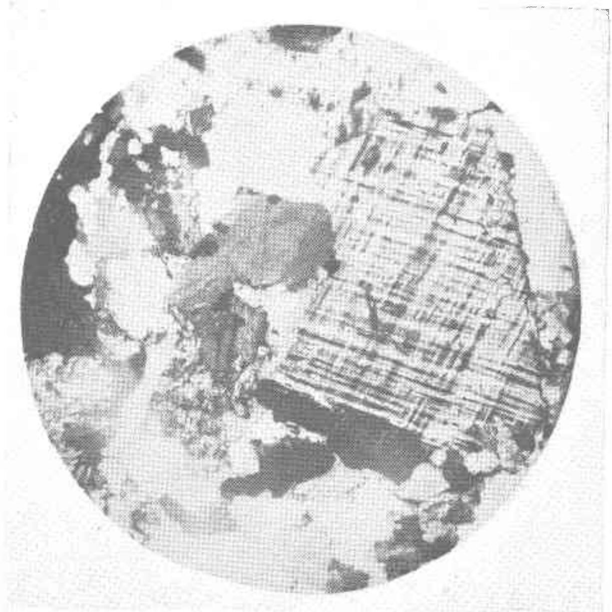
Gravel	1.013 grams	or	15.74%
Greater than 10 Mesh Coarse	3.226 "	or	50.13
30 Mesh Medium	1.011 "	or	15.73
60 Mesh Fine	0.682 "	or	10.60
100 Mesh Very Fine	0.380 "	or	5.90
200 Mesh Extra Fine	0.122 "	or	1.90
Total	6.434 grams	or	100.00%



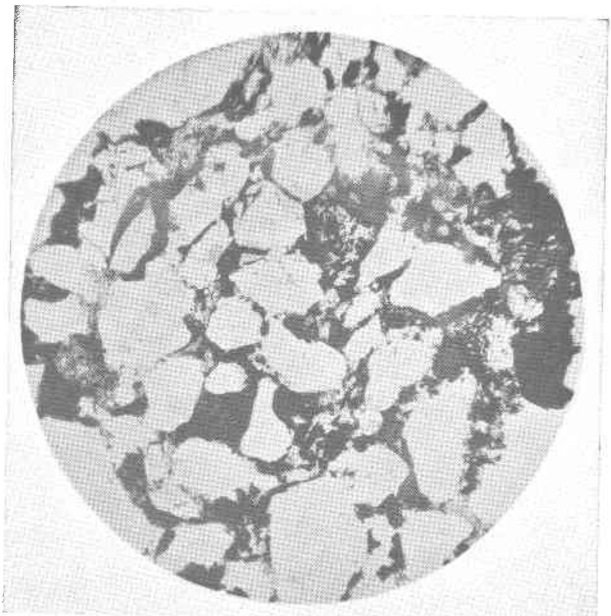
A. Photomicrograph of the Border Conglomerate (arkose phase) showing a lathed feldspar, State Road Quarry, 5 miles south of Chatham, Pittsylvania County. Crossed nicols. 20 Diameters.



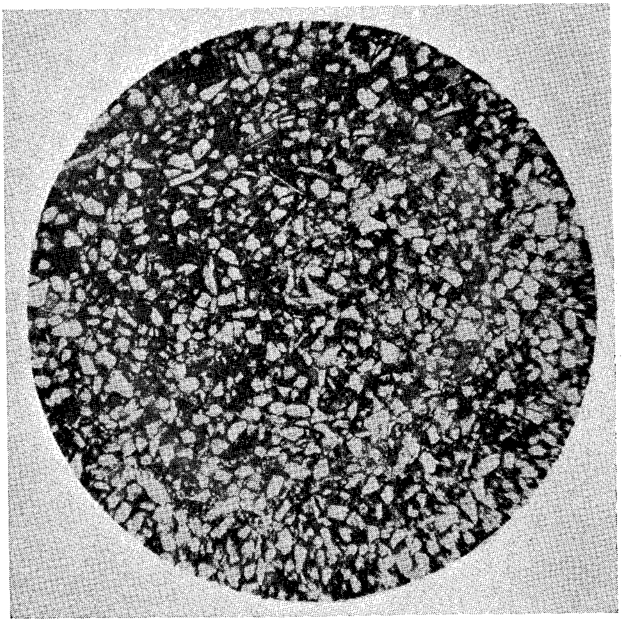
B. Photomicrograph of a thin section of arkosic Manassas sandstone, 1 mile northeast of Oatlands, Loudoun County. Single nicol. 20 Diameters.



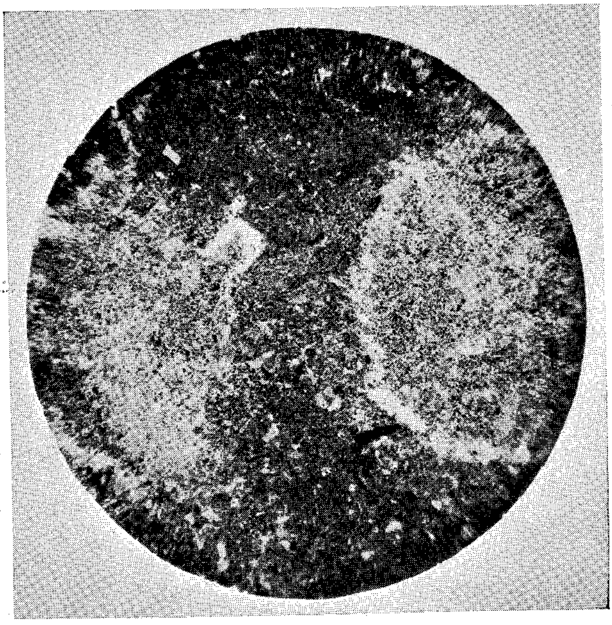
A. Photomicrograph of the Border Conglomerate (arkose phase) showing a lathed feldspar, State Road Quarry, 5 miles south of Chatham, Pittsylvania County. Crossed nicols. 20 Diameters.



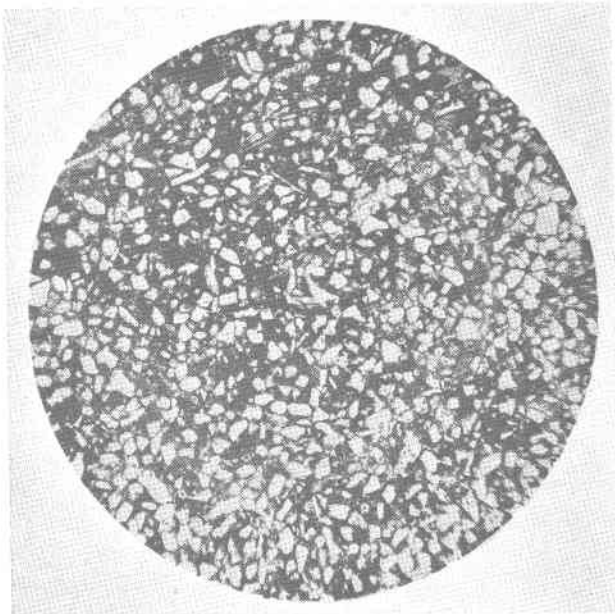
B. Photomicrograph of a thin section of arkosic Manassas sandstone, 1 mile northeast of Oatlands, Loudoun County. Single nicol. 20 Diameters.



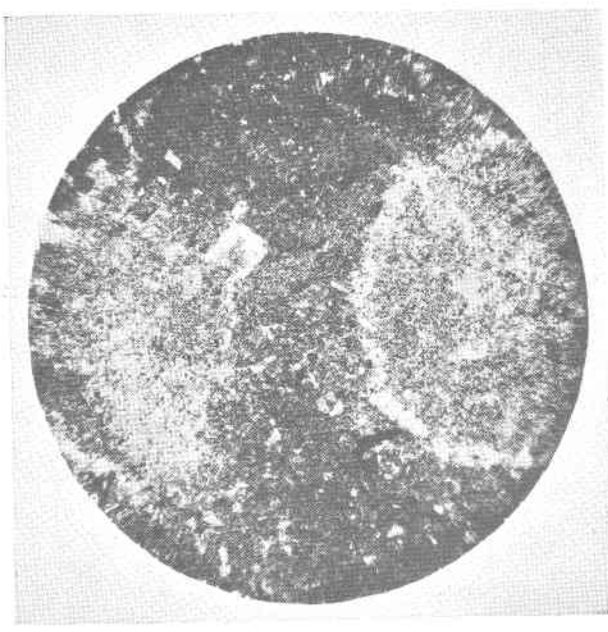
A. Photomicrograph of red Bull Run shale, three-fourths mile east of Hickory Grove, Prince William County. Single nicol. 20 Diameters.



B. Photomicrograph of gray Bull Run shale of concretionary nature, showing angular spaces previously occupied by pyrite, 1 mile south of Remington, Fauquier County. Single nicol. 20 Diameters.



A. Photomicrograph of red Bull Run shale, three-fourths mile east of Hickory Grove, Prince William County. Single nicol. 20 Diameters.



B. Photomicrograph of gray Bull Run shale of concretionary nature, showing angular spaces previously occupied by pyrite, 1 mile south of Remington, Fauquier County. Single nicol. 20 Diameters.

Mechanical analysis No. VIII

Field Specimen—No. 415.
Locality—1 mile south of Otterdale.
Date Collected—July, 1923.
Appearance—Reddish Conglomerate.

Sample air dried	10.212 grams		
Sample dried 6 hours at 110 degrees C.	10.099 "		
Moisture	0.113 grams	or	1.1%
Quartz, feldspars, mica, magnetite, etc.	10.017 grams	or	99.41%
Clay, ferric oxide and soluble matter	0.059 "	or	0.58
Total	10.076 grams	or	99.99%
Light Constituents:			
Quartz and feldspars	9.769 grams	or	97.59%
Heavy Constituents:			
Mica and magnetite	0.241 "	or	2.40
Total	10.010 grams	or	99.99%
Quartz	6.421 grams	or	65.78%
Feldspars	3.341 "	or	34.22
Total	9.762 grams	or	100.00%
Quartz:			
Coarse	3.216 grams	or	50.12%
30 Mesh			
Medium	2.209 "	or	32.87
60 Mesh			
Fine	0.432 "	or	8.31
100 Mesh			
Very Fine	0.408 "	or	6.35
200 Mesh			
Extra Fine	0.151 "	or	2.35
Total	6.416 grams	or	100.00%

Chemical composition.—No quantitative analyses are available for any of the Manassas sandstone. The Division of Tests, Bureau of Chemistry of the United States Department of Agriculture, Washington, made an analysis of a Triassic red sandstone from the Manassas quarries, which is as follows:

Red Sandstone Test No. 1312

	Per cent
Essential Minerals:	
Orthoclase, Quartz	67.1
Accessory Minerals:	
Magnetite	1.1
Muscovite	0.4

Secondary Minerals:	
Limonite	23.6
Calcite	7.8
Total	100.0

The above analysis is rather an unusual one, and of the many tests the writer made for ferric iron, none ran far over 5 per cent, inclusive of any ferrous oxide. Calcite is far higher in this analysis than in the representative red sandstone around Manassas. The iron content was run on some 22 red sandstones and the range in ferric oxide is from 1.82 to 5.58 per cent, averaging 2.67 per cent.

The chemical composition is quite variable and the percentage of silica is possibly the least variant. Much secondary material has been formed since the time of accumulation, such as epidote, chlorite and calcite, with occasional pyrite, barite, malachite and other copper minerals.

Weathering.—The Manassas sandstone weathers at a very variable rate, one of the main factors being the character of the bonding material. The sandstone is far less resistive to the factors of erosion than any of the Border Conglomerates except the Arkose Conglomerate. In some cases where the conglomerate has been metamorphosed through contact with and intrusion by igneous bodies, and also in cases of profound faulting and pressure, it is very resistive.

It weathers into a sandy soil which is a fairly good agricultural soil though it does not compare with the rich soils of the limestone and trap phases of the Border Conglomerate. Some of the more resistive sandstones give rise to the small hills over the various areas. The sandstones and shales have suffered more from erosion since Triassic time than any of the other formations, for in many localities both the Border Conglomerate and the Triassic diabase occur as monadnocks.

Frequent jointing and good bedding planes have aided the factors of weathering. In many cases the shales which are intercalated with sandstones have protected them, unless the shales themselves are of a character which disintegrates very rapidly.

BULL RUN SHALES

Bull Run shales represent the youngest of the three Triassic formations in Virginia. These shales cover at least 60 per cent of the Triassic in the State, and in the areas north of James River the region covered is approximately 507 square miles or 62 per cent. In mapping the formations all of the red sandstones and shales have been mapped together because of the close relation of the two and the relative scarcity of sandstone. To map the two formations separately would require far more time than was allotted to the work.

In extent and composition the shales are the most uniform of all the formations. They are always found near the central portion of the area, except in cases of faulting and erosion. The term for the shales is taken from Bull Run, a small stream between Prince William and Fairfax counties. Bull Run battlefield, named from this stream, lies 6 miles due west of Manassas. Almost the only rocks outcropping over this region are the Bull Run shales. The Potomac area was the first Triassic area studied by the writer and the terms used there have been applied elsewhere in order to simplify the nomenclature as much as possible.

Extent.—The one unique feature about the shales, on comparison with the other formations, is that they occur in an unbroken manner from north to south in each of the six areas and their outliers. These belts of shale are never over 4 miles wide and usually are narrower. In the Potomac area there are several belts of shale, due to the fact that the one former belt has been cut into a number of smaller ones by diabase intrusives in the form of dikes. Along Rappahannock River are four such belts alternating with belts of diabase.

Shale in the Potomac area begins at the Potomac River where it is little intruded by diabase dikes and the number of the belts increases toward the south. In many places the shale, through faulting, is the adjacent member to the Border Conglomerate. The shales are cut by stocks such as Mt. Pony and Buzzard Mountain. In the Danville area there is but one belt and this extends from the northeastern portion of Campbell County through Pittsylvania County and is cut obliquely by two small diabase dikes. Both in the Farmville and the Richmond areas shale is poorly exposed and well peneplained and its width is greater as compared with the width found in the other areas.

Exposures.—There are many exposures of Bull Run shale in all of the areas except Farmville and Richmond, the most northern being on the bluffs of the Potomac River 3½ miles east of Leesburg where it is 204 feet, the thickest anywhere in the Triassic. Here the shales are fine and coarse grained and the beds are alternate. An exposure at an abandoned quarry on the Southern Railway 2 miles south of Bristow affords good jointing and approximately horizontal bedding. Southeast of Nokesville are fairly good exposures of blue shales.

Of the entire Triassic the best exposure of blue shale is seen in the Danville area at Cascade and west of Leaksville Junction, both near the Virginia-Carolina border. Red shales outcrop at a number of places but the only outcrop of importance is east of Gladys on the Durham Division of the Norfolk and Western Railroad. Lack of river bluffs and of mountain gaps prevents exposure of any thick sections. The thickest section is on the Potomac River and this does not go through the Triassic rocks, nor do the James, Roanoke, and Dan rivers cut through and expose the underlying rocks of the Triassic basin.

Varieties.—There are several varieties of Bull Run shale. Using color as a basis, the following table may be outlined:

1. Red shales: The coloring agent is ferric oxide in the ground mass of the shale; ferrous oxide may be present but it is obscured by the red oxide. There are several kinds of this red shale.

   a. Bright red shale: This variety is very fissle and brittle and rarely contains any evidences of fossils. It may or may not contain mica and always shows excellent lamination.

   b. Dull red shales: This kind of shale is always thick bedded, weathers readily and colors the fingers when handled. It usually shows fossil trails and often contains clay lenses.

2. Gray shales: The coloring agent is ferrous iron, a black, fine grained mineral which disseminated through the white or light colored quartz and feldspar gives a gray color. In all probability these shales were formed under conditions in which decaying organic matter was present and reduced the iron from the ferric state. This kind of shale may be concretionary and may locally contain cubes of pyrite.

3. Blue shales: The coloring matter in this variety of shale is ferrous iron in somewhat equal quantity with the light colored constituents. It is the most indurated of all the shales and ranges from light to dark and black, and often to blue-black.

4. Black shales: The coloring matter of the black shales is carbonaceous. Such shales are found only in the Farmville and Richmond basins associated with the coal beds. The coal is usually overlain by thinly laminated black shale and there are frequent shale partings in the coal.

5. Decolorized shale: The shales occur at or near igneous rock contacts and the color is due to ferric iron being changed to ferrous iron. The resulting color is usually light to medium gray. However, all shales intruded by igneous dikes are not metamorphosed as to color and in case of retention of color they show progressive brittleness from the diabase body out to the unaffected portion of the body of shale.

Shale might be divided into fossiliferous and non-fossiliferous varieties and it might also be classed on its feldspar and mica content. Some shales are heavily arkosic and others are rather free from feldspars. The red variety is by far the most important and probably forms about 80 per cent of all the Triassic shales. Color change is due merely to varying physical conditions and all the varieties are of the same age, namely, Upper Triassic or Keuper.

Physical properties.—As regards color, shales have been treated under the subject of varieties. There are three important factors controlling the color phenomenon in all of the Triassic shales of Virginia and these are the presence of ferric and ferrous oxides and carbonaceous matter. In the present report a full discussion of the causes of the presence of these colors will be left until later. Suffice it to remark at this point that from all data known at the present time and suggested from the Triassic beds themselves the red ferric oxide represents the accumulation of sediments under abundant plant life in a warm and moist climate. Ferrous iron, which imparts the gray color, exclusive of the gray colors resulting from igneous contact changes, is an expression of the presence of abundant organic matter and stagnant water environment. Carbonaceous shales are due to the mesophytic swamp vegetation which at the same time gave rise to the coal beds of the Richmond Basin and the thin coal seams of the Farmville area. While color can not be used any more than lithology in mapping in the same sense as the application of persistent or fossiliferous beds, yet it is a great aid provided its limitations are recognized. The red, blue, and black shales of the Bull Run formation are just as constant as the black shale of the Chattanooga formation of Virginia, Tennessee and Kentucky.

Hardness of the shale is a matter of much variation. It may be very soft, and its hardness never equals that of sandstone except in the blue shales. The fissile variety is very brittle and the thick bedded or muddy varieties are the softest. The degree of induration is far from constant. The blue shales, such as occur around Cascade and Leaksville Junction (Shale Post Office) in Pittsylvania County and southeast of Nokesville in Prince William County, are as hard as any sandstones and are the most highly indurated of all the shales; in fact they are not so far from slates.

Mineral composition of the shales does not differ greatly from that of sandstones, the greatest mark of difference being in the rare minerals. The accessory minerals are limonite and possibly other hydrated oxides of iron, and micas in form of muscovite and biotite. The secondary are chlorite, calcite, epidote, pyrite, chalcopyrite, malachite, and barite. There may be present concretions varying up to several millimeters in diameter. Organic matter may be present in fairly high amounts in the black shales.

Texture.—Texture of shale varies from an extra fine to a relatively coarse and gritty nature. The grains of quartz and feldspar are sharp and angular, being below the size which is rounded by the agents of erosion. In all the very fine textured shales there is close resemblance to the fine residual muds which are at the present time being accumulated in valleys under ordinary residual conditions, and if such shales are agitated until the matrix disintegrates the material on settling has all the properties of residual sediments. The matrix is a finely divided mass composed for the most part of quartz and feldspar. Ferric oxide has served in the capacity of a cementing agent in the red shales.

The size of quartz and feldspar grains varies from 1 to 15 microns (1 micron equals 0.01 millimeter). The shape of the grains may be regular, elongated, or rod-like. The regular shape is most frequent. Size and shape are of course much more regular than in sandstones and conglomerates. Many of the particles possess re-entrant angles. Quartz grains are generally without inclusions. There is considerable clay in the matrix and this is the main cementing constituent.

The blue variety of Bull Run shale bears more concretions than any or all of the others. These concretions are usually less than a centimeter in diameter and show neither radical nor concentric structure in thin sections. They are usually white on the periphery and are a much lighter gray color than the shale. Associated with the concretions and sometimes within them are small cubes of pyrite and small particles of ferric oxide. The ferrous oxide, being smaller in the concretions, is responsible for the light gray color.

Chemical composition.—Chemical composition of the shales does not differ greatly from that of sandstones. Often mica and ferric iron are much more pronounced, which would materially alter the composition. Shales were collected from a number of localities in order to compare their ferric iron content with that of sandstones collected nearby. The ferric iron content was tested in a number of shales and sandstones over the areas and was found to average approximately 4.82 per cent for the sandstones and 4.42 per cent for the shales. The two sets of analyses are given in the following table. No analyses have been made for the shales as a whole. Near Leaksville Junction, Pittsylvania County, alluvium from the Dan River bottoms, which is reworked Triassic shale, is used for manufacture.

Iron oxide content of shales and sandstones

(D. F. FARRAR, *Analyst.*)

Field Number	Rock	Locality	Fe_2O_3 Content Per cent
62	Red shale, bright red	2 miles northwest of Sterling, Loudoun County	4.02
110	Red shale, medium red	⅛ mile west of Cartharpin, Prince Edward County ..	3.91
125	Red shale, medium red	Quarry 1½ miles northeast, Nokesville	3.85
187	Red shale, medium red	⅛ mile northwest Raccoon Ford, Culpeper County ...	4.16
276	Red shale, bright red	Nowlin Bridge, Campbell County	6.14
94-C	Red sandstone, medium grain	Quarry, 1 mile north of Manassas	4.82
212	Red sandstone	1⅛ miles East of Liberty Mills, Orange County	5.04
371	Red sandstone	1 mile west of Stevensburg, Culpeper County	4.66
241	Red sandstone, medium grain	2 miles north of Warren, Albemarle County	5.24
313	Red arkosic sandstone	White Oak Mountain, Pittsylvania County	4.41
		Average of the specimens	4.63

Weathering.—The red shale disintegrates rather easily compared with the conglomerates and sandstones. It forms most of the flat lands over the different areas and is reworked along most of the streams. It breaks down into a fine silty soil which is fairly productive. The frequent jointing and bedding planes cause it to disintegrate. The blue shale found in the Potomac and Danville areas is the most resistive of all the shales and forms hills wherever it outcrops.

Some very characteristically weathered red shales and an extremely flat topography may be seen between Ashburn and Leesburg, between Cedar and Buzzard mountains near Rapidan Station, and over much of the Farmville and Richmond areas.

IGNEOUS ROCKS

The Triassic rocks of igneous origin occupy quite a significant place among the rocks of this period and have received more attention than any of the Triassic phases except the coals of the Richmond area. These igneous rocks fall under the classification of diabases, and as a class they stand out separately from all other Triassic rocks, so much so, that there is little danger of confusing them except in the variety which possesses a very fine texture.

Triassic diabases in eastern North America have received much discussion in both scientific meetings and geologic literature. The earliest work on the Virginia diabases was done by H. D. Campbell and W. G. Brown [8] from a standpoint of chemical composition. In connection with the natural coke in the Richmond area, quite a number of references have been made to the diabases. As early as 1855, W. B. Rogers [9] noted metamorphic changes in the sedimentary rocks of the Triassic in Prince William County and called attention to the same. A number of references were made later by Dr. Rogers but no detailed work was done. In 1899 Shaler and Woodworth [10] published a report on the geology of the Richmond Basin in which there is some discussion of the igneous rocks. Thomas L. Watson [11] made a study of the diabase dikes around his home, at Chatham, Pittsylvania County, and contributed two short articles. He stated to the writer that he had traced one of the small dikes which cuts across the Triassic in the Danville area for a distance of 60 miles.

The writer [12] after a field study of two summers and a laboratory study of two winters, made a report on the diabases, along with the other Triassic rocks, in the areas north of James River, as a dissertation, and an abstract of this appeared later.

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[8]Campbell, H. D. and Brown, W. G., Composition of certain Mesozoic igneous rocks of Virginia: Geol. Soc. Amer. Bull., vol. 2, pp. 339-348, 1892.

[9]Rogers, W. B., Local metamorphism produced by trap rocks (dikes) in Prince William County, Virginia: Boston Soc. Nat. Hist. Proc., vol. 5, pp. 202-204, 1855.

[10]Shaler, N. S. and Woodworth, J. B., Geology of the Richmond Basin, Virginia: U. S. Geol. Survey, 19th Ann. Rept., pt. 2, pp. 385-519, 1899.

[11]Watson, Thomas L., Weathering of diabase near Chatham, Virginia: Amer. Geologist, vol. 22, pp. 85-101, 1898.

——— Some further notes on the weathering of diabase in the vicinity of Chatham, Virginia: Amer. Geologist, vol. 24, pp. 355-369, 1899.

[12]Roberts, Joseph K., The Triassic of Northern Virginia, Dissertation, Johns Hopkins University, Baltimore, Maryland, 270 pp., 68 figs., 4 maps.

——— Abstract of the Triassic of Northern Virginia: Pan Amer. Geol., vol. 39, pp. 185-200; vol. 41, pp. 22-30, 1924.

The most recent work is by Shannon[13] of the United States National Museum on the diabase stock south of Leesburg. This work is in great detail and of a very high grade, dealing with the mineralogy and petrology of the great diabase stock and showing a number of minerals in addition to those usually found in diabase.

Extent.—The areal extent of diabase in the various Triassic areas is a considerable figure. In the Potomac area the Triassic belt covers approximately 250 square miles, or 30 per cent of the entire area, and by far the best exposures are to be observed in this area. The belts run parallel to the main axis of the area and there are nine belts of the diabase. In length they vary from a few hundred feet up to 40 miles and in width reach as much as 1 mile or more. These belts, for the most part, are either dikes or stocks. There are four large stocks, two of which are the Belmont Stock southeast of Leesburg and the Sterling Stock north of Sterling, both in Loudoun County and relatively close to each other. The other two stocks are in the southern part of the area, Mt. Pony Stock 1½ miles south of Culpeper and Buzzard Mountain Stock one-half a mile east of the Southern Railway flagstop, Buena, and 6½ miles south of and in line with the Mt. Pony Stock.

Only one diabase dike has been observed in the Triassic rocks south of Rapidan River and little metamorphism resulting from such intrusions or from extrusions is shown in any of the Triassic formations of this region. In the Scottsville area there is only one small dike which cuts the Triassic series but there are dikes outside of this area, two east and one west of the town of Scottsville. These dikes outside the area cut the older strata and can be traced for some distance. The belts of diabase around Scottsville are not as long or nearly as wide as are those to the north in the Potomac area. The direction of extent is in general the same and they do not have the crescent shape which is sometimes the case in the dikes between Remington and Manassas. Everywhere these belts of diabase, whether they be dikes or stocks, constitute a very significant part in the topography of the country. Streams cutting such bodies have developed falls and rapids, and wherever cliffs have formed they are abrupt and good exposures are available.

In the Danville area dikes constitute the only form of diabase bodies, and these have a more northern extent than those previously discussed. The dikes cross the area in a slightly east of north extent and their outcrops in the adjacent old rocks are fully as plain as in the Triassic rocks. Four long dikes are found in the area; the longest one can be traced from Chatham southward to a point a few miles north of Reidsville, North Carolina. All the dikes are very narrow, the widest ones being only a few hundred feet. They are easily traced by the huge and concentrically weathered boulders over the country.

[13]Shannon, Earl V., The mineralogy and petrology of intrusive Triassic diabase at Goose Creek, Loudoun County, Virginia: U. S. Nat'l Mus. Proc., vol. 66, Art. 2, pp. 1-86, 1924.

Only three dikes of any size and extent occur in the Farmville area and these extend almost north and south. The longest one extends through the small outlier of the Farmville area on Briery Creek and will be referred to as the Briery Creek outlier; it passes west of the town of Farmville and into the older rocks. The other dikes are small. In the coal investigations some years ago diabase was encountered in the form of dikes and in some places it had cut through the coal seams, metamorphosing the coal into a natural coke.

The dikes of the Richmond area more closely resemble those of the Farmville area than any other and can not be traced for any great distance. Four dikes have been located and it is very probable that one of these can be traced to the southern end of the area as after a few miles it appears again south of the Appomattox River in the granites and crystallines. In one place in the Richmond area a fault has brought up the underlying granite and a dike has cut through this mass of granite.

The cutting of the coal beds by the diabase dikes in the Richmond area is a very familiar feature in that basin and has received no little attention in the literature. Many of the early pits showed the dikes, and in a few cases contacts showed on the surface in which the natural coke could be sampled with diabase adherent to it. Some places show no outcrops whatever but natural coke occurs 60 to 200 feet below the surface.

There has been so much peneplanation in the vicinity of Richmond that even the diabase bodies, which elsewhere find topographic expression, lend themselves to very little tracing. The widest part of the area is around 10 miles and the short and narrow belts of diabase do not supply much in the way of comparison with the other areas. The small outliers of the Richmond area, one to the northeast and several close to the eastern contact, show no diabase dikes.

Between the northern end of the Richmond area and the Scottsville area, along the James River a number of small dikes are encountered. Some of these are mentioned by Taber [14] and mapped by him in his study of the gold belt in the James River Basin. These dikes show well between Goochland and Columbia, north of the James River.

Exposures.—There are a great many exposures of diabase rocks over the Triassic areas but the best and greatest number of exposures occur in the Potomac area. In this area there are six very large exposures where fresh material is available and a great number of small dike exposures. The large exposures are stocks and their locations are as follows:

1. Belmont quarry on Goose Creek, 4 miles southeast of Leesburg, Loudoun County on the Old Dominion Electric Railway.

2. The Sterling Stock, 2 miles north of Sterling, Loudoun County.

[14] Taber Stephen, Geology of the gold belt in the James River Basin: Virginia Geol. Survey Bull. VII, pp. 85-87, 1913.

3. Arcola (Gum Spring) region southeastern part of Loudoun County.

4. River bluff, on the Rappahannock River near the public highway bridge at Remington and on the Fauquier County side.

5. Mt. Pony, the great diabase peak, 1½ miles south of Culpeper, Culpeper County.

6. Buzzard (Twin) Mountain, 1 mile east of Buena and 1½ miles north of Rapidan, Culpeper County.

The Belmont quarry is the best exposure anywhere in Virginia in which to see fresh diabase and some of the features, such as faulting, fissuring, jointing, mineral constituents, pegmatites, etc. This quarry has been worked for a considerable time and a large opening affords an excellent place for study. The mineralogy and petrology of this exposure have been studied and presented in a recent paper by Earl V. Shannon.[15]

This large area on Goose Creek affords numerous exposures besides the quarry and there are enormous boulders and flat exposures extending from a point a little to the east of Leesburg southeast almost to Bull Run, south of Centerville. This stretch of diabase is the largest in the entire Triassic.

The Sterling exposure has no quarry but the many boulders and flat exposures show the same general surface conditions as in the Belmont Stock. The exposures are very good in this locality and exhibit quite a bit of alteration caused by intrusives upon the Triassic shales and sandstones.

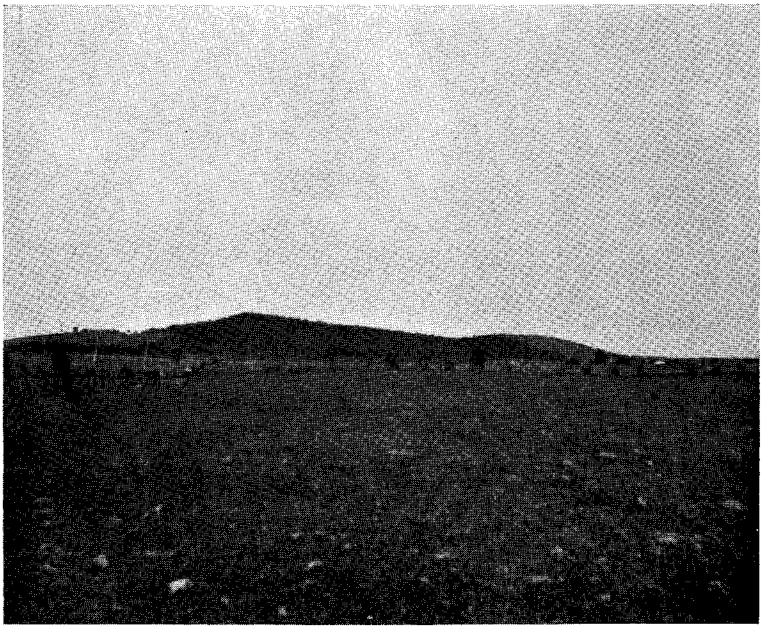
Exposures at Arcola and around the hamlet consist of innumerable large and small boulders—as many or more than are seen in any other locality. This is a continuation of the same stock of diabase which is exposed at Belmont and it can be traced by the great number of boulders over the surface.

The Rappahannock River near Remington has cut through the diabase which is in the form of a dike. Great masses and boulders of the material occur and this body gives the impression of a stock, which it may be.

Mt. Pony is an enormous mass of diabase. The peak is oval in shape with its major diameter extending approximately east and west. The west side of the peak contains much shale and sandstone but this is not the case at other points. The summit of the peak is over 800 feet above sea level and 450-500 feet above the surrounding country. There are no very good exposures of diabase, as there are no quarries, and the immense growth of trees, underbrush, and ferns makes it almost impenetrable during the summer.

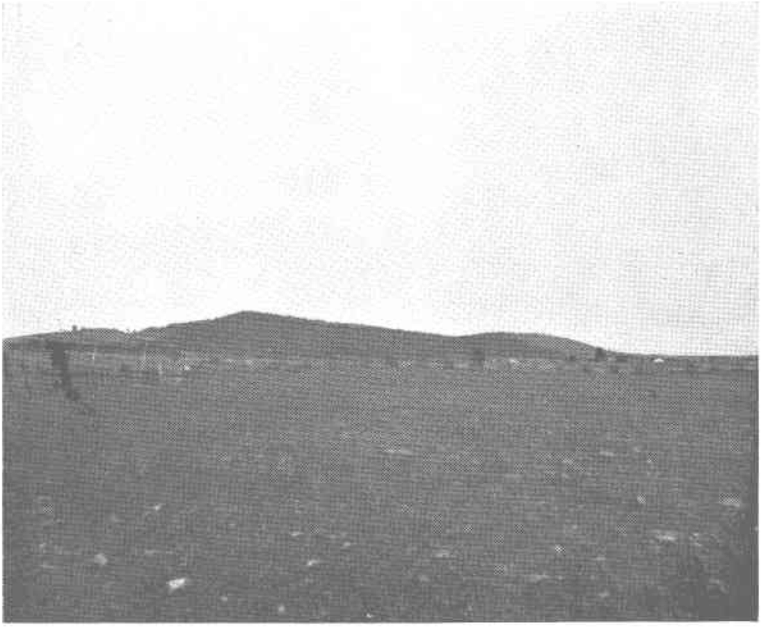
The Buzzard Mountain exposure is excellent, as the quarry opened and operated for a time by the Southern Railroad gives an excellent opportunity for collecting fresh material. This mountain is a double peak

[15]Shannon, Earl V., The mineralogy and petrology of intrusive Triassic diabase at Goose Creek, Loudoun County, Virginia: U. S. Nat. Mus. Proc., vol. 66, Art. 2, pp. 86, pls. 8-9, 1924.



A. View of Mt. Pony looking north from the Culpeper-Rapidan road, Culpeper County. (Photographed by Thomas L. Watson.)

B. View of Mt. Pony looking southwest from Stevensburg, Culpeper County.



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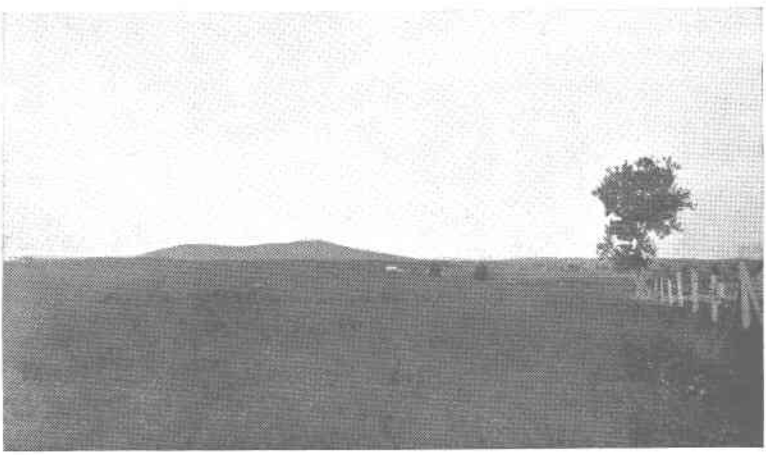
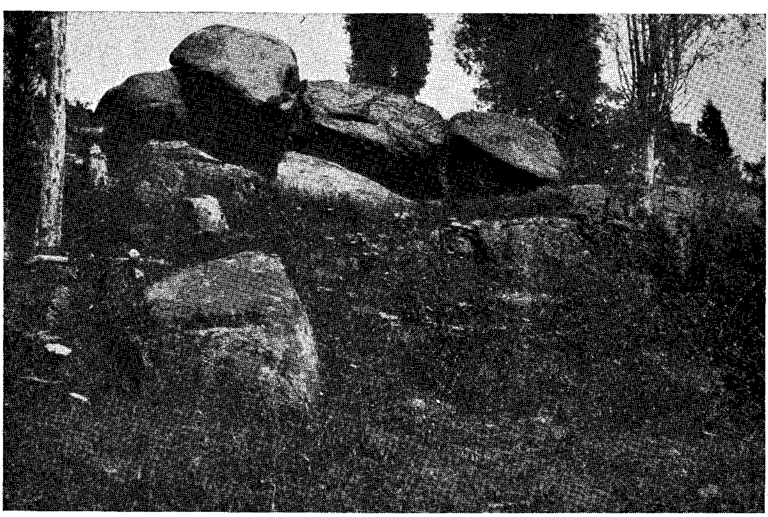


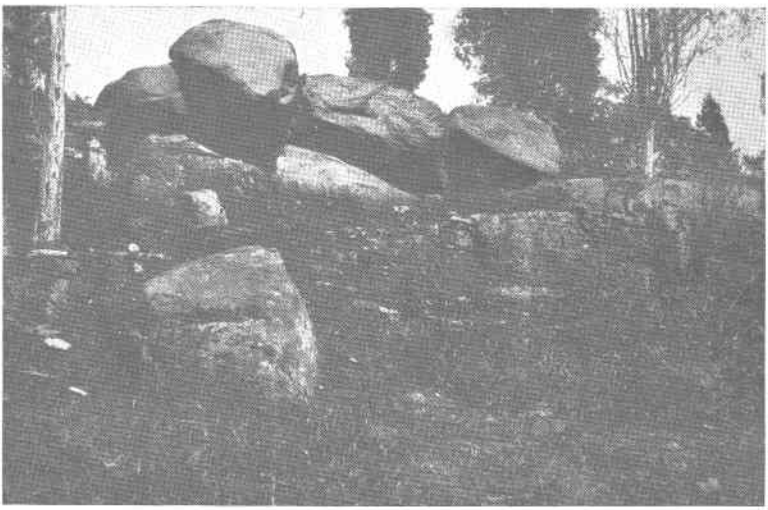
B. View of Mt. Pony looking southwest from Stevensburg, Culpeper County.

A. View of Buzzard Mountain (The Twins) looking north from the road near Rapidan Station, Culpeper County. (Photographed by Thomas L. Watson.)



B. Surface diabase boulders on diabase stock, southeast of Leesburg, Loudoun County. (Photographed by Thomas L. Watson.)

A. View of Buzzard Mountain (The Twins) looking north from the road near Rapidan Station, Culpeper County. (Photographed by Thomas L. Watson.)



B. Surface diabase boulders on diabase stock, southeast of Leesburg, Loudoun County. (Photographed by Thomas L. Watson.)

and, for this reason, is sometimes referred to as Twin Mountain. All around the base of the mountain are great boulders and everywhere there is excellent material. Here trees growing in the crevices of diabase rocks afford fine examples of the effect of growing plants as agents of weathering. This mountain is on the north side of Rapidan River and on an average a mile away from it. On the south side of the river is Clark Mountain which is made up of the old crystalline intruded by diabase dikes of Triassic age. The southeastern slope in very precipitous with vertical exposures of more than 50 feet.

Besides these six remarkable exposures of stocks, there are a great many exposures of dikes. From the Potomac River towards the Carolina border, there are two singular features about the dikes, namely, they decrease in width and in number. In the Potomac area there are excellent exposures of the small dikes in railway cuts east of Herndon, to the west of Ashburn, and at Sterling. Several dikes are exposed near Aldie and east of Aldie along the old Alexandria turnpike. In the vicinity of Catlett there are several large dikes and all are marked by numerous small and large boulders scattered over the surface. Like the stocks, these dikes cut all three of the Triassic formations, but unlike the stocks, they do not always show the effects in the intruded rocks. North of Kellyville (Kelly's Ford) 6 miles south of Remington there is a wide dike which is cut across by the river, and rapids have resulted from the resistance of the diabase as compared to the soft red shales of the Bull Run formation. South of Culpeper there are three fine exposures and these are crossed by a traverse from Cedar Mountain to Raccoon Ford.

A singular feature of the southern portion of the Potomac area is the absence of diabase rocks. Many concentrically weathered boulders of Manasses sandstone often resemble diabase boulders. In the Scottsville area there is only one good exposure and this outcrops along the railroad 2 miles north of Warren at Boiling Springs, Albemarle County. This exposure is similar in all its characteristics to the dikes east of it which outcrop on the edge of the town of Scottsville.

Good exposures of diabase in the Danville area are few as well as small. East of Long Island Station on the Virginian Railway a narrow dike shows good material but cannot be traced for any distance. West of Danville fairly wide dikes are seen at Bachelor Hall Church and near Oak Hill. The longest dike in the Danville area is exposed in railway cuts due south of Chatham. It can be traced into North Carolina, passing to the east of Danville but exposed 12 miles south of Danville. The exposures in the southern portion of the State do not compare with those in the Potomac area. All of the exposures show diabase of a medium grained texture and an even fine grain, but never aphantic; or at least such has not been found.

There is one good exposure in the Farmville area 1 mile southwest of Farmville. The rock is medium to fine grain in texture. Northwest of

Farmville along the Farmville-Buckingham road in the vicinity of Willis Mountain there is a good exposure which without much doubt is an extension of the same body which outcrops 1 mile southwest of Farmville and in the Briery Creek outlier of the Farmville area south of Hampden-Sidney. Willis Mountain resembles Mt. Pony and Buzzard Mountain from a distance but it is composed of crystalline rocks which are intruded by Triassic diabases.

Exposures of igneous rocks in the Richmond area are all dikes and only two are good. Two miles south of Skinquarter occurs a rather singular exposure in which diabase has intruded the pre-Cambrian granite, the latter being exposed as the result of a fault bringing the underlying rocks of the basin to the surface and the overlying Triassic rocks being removed by erosion. Contact specimens of the intruding diabase and intruded granite can be obtained. Another very good exposure, which is a very narrow dike, occurs in the southern end of the area near Appomattox River. The outstanding feature of the diabase of the Richmond area is the fact that it intrudes and alters the coals. At the time field work was done for this report, only one mine of any depth was in operation and this did not show any natural coke. Most of the old mines which did show this phenomenon were east and northeast of Midlothian and north of James River at Gayton. Such mines were closed some 30 years ago and all of the material upon the old dumps has weathered until it is of no value for collections.

There are no good exposures of intrusive sheets throughout the entire Triassic and the only two observed are east of Brandy Station and south of Winston, both near the Southern Railway in Culpeper County. In both localities these sheets have altered the red shales and red sandstones to a light gray color. They have been intruded along bedding planes of the sedimentary rocks and have essentially the same strike and dip. No extrusive sheets have been observed in any of the areas.

Varieties of diabase.—Diabase rocks from the Potomac to the Dan River fall into several classes and in every way each variety bears a very close resemblance to the Triassic intrusives further north. A number of comparisons of Virginia diabases have been made with those of Maryland, Pennsylvania, New Jersey, Connecticut and Massachusetts. On the basis of texture there are four distinct varieties of diabase, namely, coarse, medium, fine, and very fine grained, the latter variety possessing such a fine texture that none of the components are visible to the naked eye. The coarse diabase is not of very wide occurrence, being limited to the stocks in Loudoun County. This variety Shannon [16] calls diabase pegmatite, and it has also been called gabbroic diabase and gabbro. It contains very large crystals of plagioclase feldspar and augite. Sometimes the latter measure much over an inch in length. Such coarse grained diabase is best

[16] Shannon, Earl V., op. cit., pp. 14-22.

found in the quarry at Belmont Park on Goose Creek and to a less extent north of Sterling, though at the latter place there is no opportunity to collect fresh material.

Medium grained diabase is the most common of all the varieties and is found both in the stocks and dikes. This variety, as far as observation has gone, composes the entire rock mass of Mt. Pony and Buzzard Mountain. North of James River practically all of the larger and many of the smaller dikes show medium grained diabase. Almost without exception, the diabase grain becomes finer towards the south.

Fine grained diabase composes many of the small dikes over the Triassic areas north of James River and this is practically the prevailing variety in the Danville, Farmville and Richmond areas. This variety and the medium grained diabase correspond in a general way to what Shannon [17] terms normal diabase.

The very fine grained variety is aphanitic and is found on the periphery of large dikes, making up the small dikes and the sheets. The small dikes over all the areas show this aphanitic diabase. A remarkable feature of some of the very small dikes is that they are sometimes of a fine to medium texture. These fine grain diabases exhibit fracture and jointing much better than do the coarse varieties.

On a basis of mineral composition, the writer has been able by means of a number of thin sections to distinguish three varieties in the various areas. These varieties are: (1) Normal diabase, (2) hypersthene diabase, and (3) pegmatitic diabase. Shannon [18] in a detailed study of the Belmont Stock finds on a basis of mineral composition four varieties of diabase which are: (1) Normal diabase, (2) diabase pegmatite, (3) albitic pegmatites and (4) aplitic albite rocks. Composition of the normal, hypersthene and pegmatitic varieties will be discussed later. Other varieties have been described, such as olivine-hypersthene diabase,[19] but this variety is rare.

Physical properties.—The color of fresh diabase varies from medium to dark gray and to black. The size of the grain has something to do with the color, as in the pegmatitic variety feldspar is noticeably greater in amount. Dark gray is the prevailing color in medium and fine grained diabases, with the exception of Mt. Pony and Buzzard Mountain, and these are decidedly light gray and medium gray. Often great masses of medium gray diabase will have irregular masses or "schlieren" of light gray diabase and vice versa. Some of the small dikes, especially in the Danville, Farmville, and Richmond areas, are very dark gray to black. The aphanitic varieties are dull black and steel gray at times. The luster of all of the diabases is very bright, except the finest grained rocks or those rocks which are often termed basalts. The color of Buzzard Moun-

[17]Shannon, Earl V., op. cit., pp. 9-14.
[18]Shannon, Earl V., op. cit., p. 4.
[19]Campbell, H. D. and Brown, W. G., Geol. Soc. Amer. Bull., vol. 2, p. 346, 1891.

tain diabase usually shows a dull luster and a dark brownish tone, depending upon the degree of disintegration. Diabase boulders with concentric shells and of many degrees of weathering are common over the Triassic areas. The colors range from several tones of gray to red. This was well brought out with regard to diabase dikes in the Danville area by Watson.[20] In describing the color he writes:

> While the color of the decay is prevailingly red, frequently a mottled gray color is seen, and is especially noticeable in the boulders, which have not reached the limit in decomposition, but those in which the shelly structure is still shown.

Diabase when fresh possesses a more or less uniform hardness. Its two chief minerals, plagioclase feldspar and augite, have a range in hardness on the Moh Scale of 6-6.5 and 5-6, respectively. The rock is very difficult to crush, not only from its hardness but on account of its toughness. Feldspar and pyroxene crystals are so interwoven that breaking it is rendered all the more difficult. It is necessary to replace the jaws of the crushers frequently and the only quarry which has operated the diabase is the Belmont Trap quarry near Goose Creek in Loudoun County. Specific gravity of samples tested varies from 2.953 to 3.104.

Mineral composition.—The mineral composition of Virginia Triassic diabases is one of the most interesting phases of the whole Triassic problem and one upon which little had been done until it was studied by Thomas L. Watson and Earl V. Shannon. While the chief minerals are the same without regard to locality, the accessory minerals change a great deal, thus giving quite a number of minerals. For convenience the minerals may be divided into principal, accessory, and secondary. These may be arranged as follows:

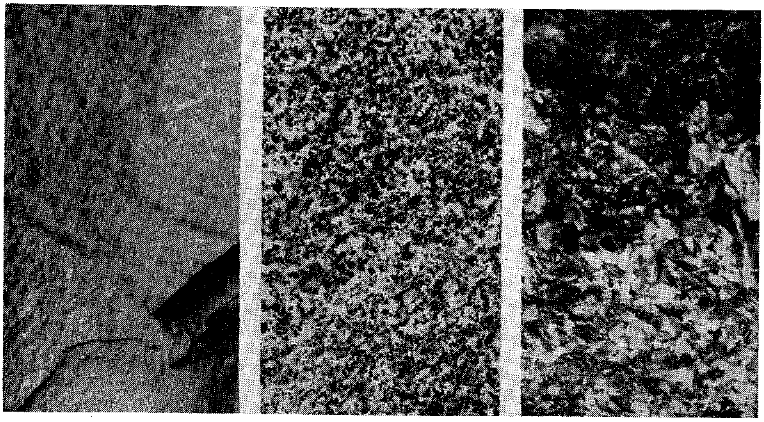
A. Principal Minerals:

1. Feldspars:
    a. Alkali feldspars—Orthoclase and albite (accessory).
    b. Plagioclase feldspars—Labradorite chiefly.
2. Pyroxenes:
    Augite.

B. Accessory Minerals:

1. Apatite
2. Hypersthene
3. Biotite
4. Quartz } Micropegmatitic intergrowths
5. Orthoclase } Micropegmatitic intergrowths
6. Iron minerals
7. Hornblende
8. Albite
9. Olivine

[20] Watson, Thomas L., Weathering of diabase near Chatham, Virginia: Amer. Geol., vol. 22, p. 87, 1898.



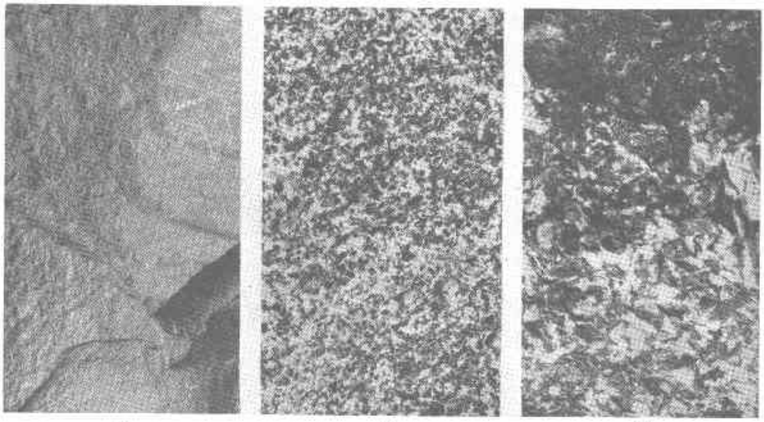
A. B. C.

A. Very fine-grained to aphanitic diabase (basalt) from a small dike in railroad cut west of Ashburn, Loudoun County. (Natural size.)

B. Medium crystalline or normal diabase from Buzzard Mountain, Culpeper County. (Natural size.)

C. Coarsely crystalline or pegmatitic diabase from Belmont Trap Quarry, Loudoun County. (Natural size.)

D. Typical ophitic texture from photomicrograph of diabase from the Sterling stock, one-fourth mile north of Sterling, Loudoun County. Crossed nicols. 12 Diameters.



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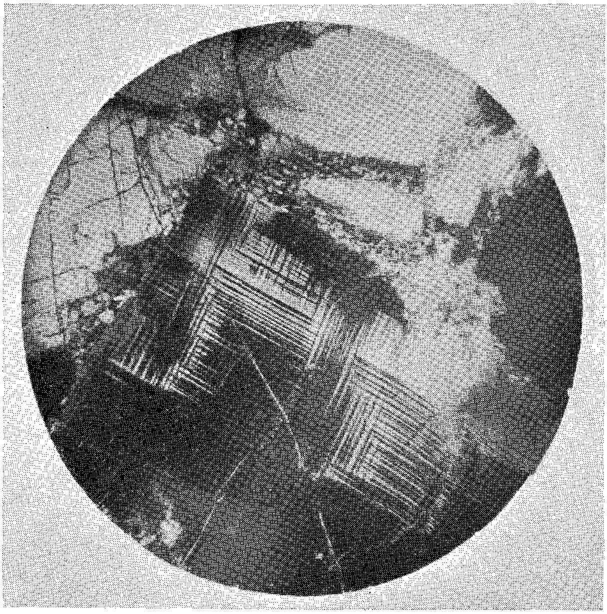
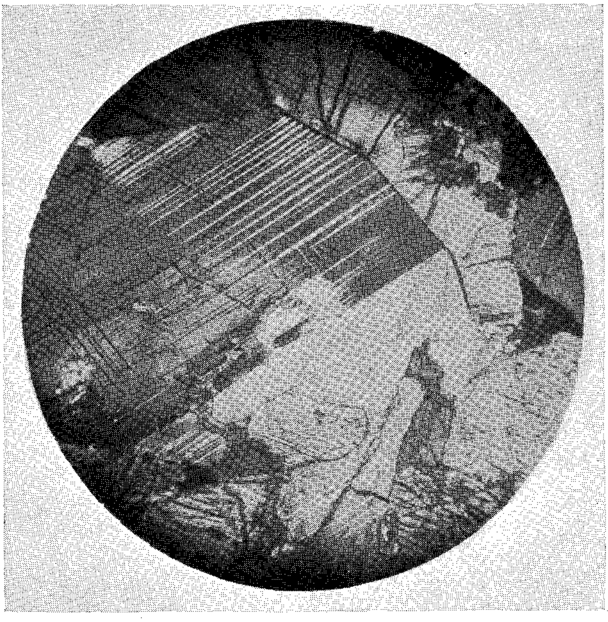
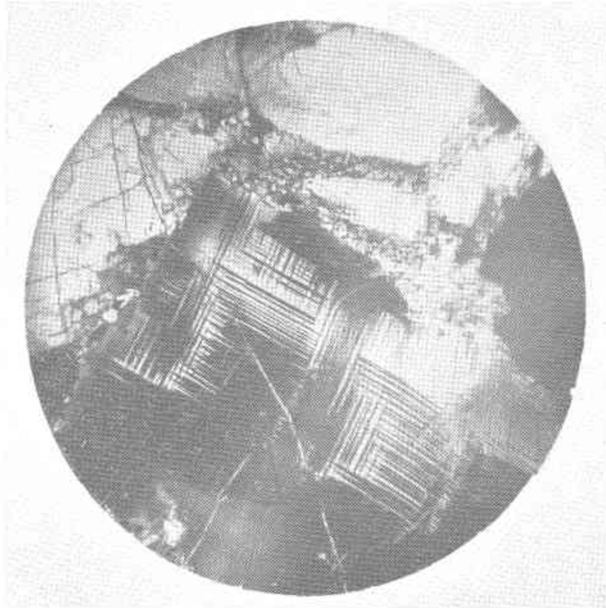


A. Photomicrograph of a pegmatitic diabase showing combined albite and pericline twinning in labradorite from Belmont Trap Quarry, Loudoun County. Crossed nicols. 20 Diameters.



B. Photomicrograph of a pegmatitic diabase showing albite twinning in plagioclase feldspar from Belmont Trap Quarry. Crossed nicols. 20 Diameters.



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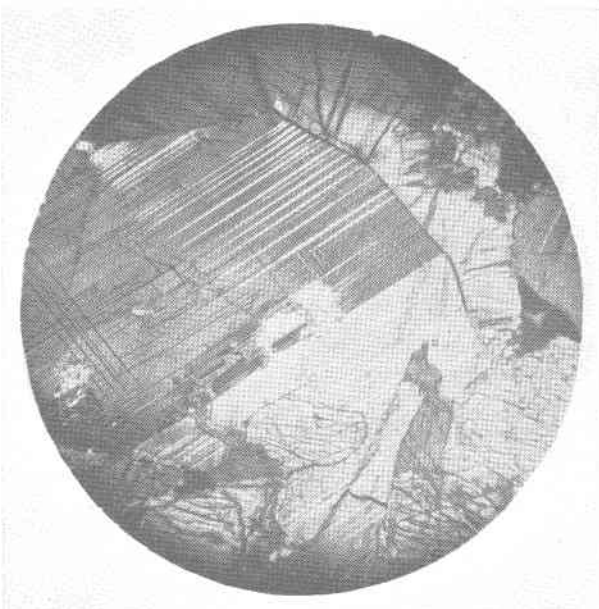


B. Photomicrograph of a pegmatitic diabase showing albite twinning in plagioclase feldspar from Belmont Trap Quarry. Crossed nicols. 20 Diameters.

C. Secondary Minerals:
1. Chlorite
2. Epidote
3. Serpentine
4. Calcite
5. Pyrite
6. Chalcopyrite.

Feldspars.—The feldspars are towards the basic end of the plagioclase series, chiefly labradorite, Ab_1An_1-Ab_1An_3. They occur as prismatic crystals with excellent twinning, and the mass resembles a complex intergrowth of lath-shaped crystals. Twinning is of the albite type for the most part, but pericline and Carlbad twinnings are also present. The size of the feldspar crystal varies from 2 microns up to several millimeters in length. The twinning planes are usually widely spaced and characteristic of the plagioclase feldspars. The twinning may or may not extend the entire length of the crystal. The feldspars are usually fresh, but some are weathered, in which condition they appear as corroded with the twinning lamellæ indistinct or destroyed, and it is not possible to get an optical figure. Sometimes in fairly large crystals the plagioclase will exhibit a play of colors typical of labradorite. Shannon [21] by means of the extinction angle determined some of the plagioclase as indicating $Ab_{35}An_{65}$ and by index of refraction method made other determinations indicating compositions of $Ab_{47}An_{53}$ and $Ab_{42}An_{58}$.

The physical properties of the feldspars remain quite the same over the entire Triassic. The ratio of feldspar to augite is the controlling factor in the color of the rock. The only analysis showing anything with regard to this ratio was made by the Division of Tests, United States Department of Agriculture, about 1910. The analysis is as follows:

Mineral analysis of sample No. 1991 of diabase
Belmont Trap Quarry, Loudoun County

(U. S. Dept. of Agriculture, Office of Public Roads.)

	Per cent
Essential minerals:	
Plagioclase	48.3
Augite	41.7
Accessory minerals:	
Magnetite	3.3
Apatite	0.5
Secondary minerals:	
Chlorite	4.0
Kaolin	2.0
Biotite	0.2
	100.0

[21]Shannon, Earl V., op. cit., p. 10.

Pyroxene.—Pyroxene in the form of augite is the other chief mineral of the Triassic diabases. In fresh hand specimens the augite appears as the dark mineral mixed with the white feldspar. In thin sections the augite in some instances has a pale green color, also a faint brown, and is weakly pleochroic.

In fresh sections the augite shows good cleavage in one or two directions. Twinning is quite common, though not as much so as with feldspar, and is parallel to crystallographic C, giving a roof-shaped effect. The size of the crystal is a matter of much variation—from the microscopic size of the crystal up to 3 and 4 centimeters in length. Like the feldspars, the crystal boundaries are well formed.

Weathered augite shows a gradation into magnetite and possibly other oxides of iron. It may appear as corroded and the cleavage and twinning will be very obscure or entirely lost. From all appearances augite seems to have weathered by the rims and inclusions of iron oxide more than feldspar. An analysis [22] of fresh pyroxene from the Goose Creek locality in Loudoun County was recently listed by Shannon which is as follows:

Analysis of augite

	Per cent
SiO_2	50.26
TiO_2	0.80
Al_2O_3	2.10
Fe_2O_3	.00
FeO	18.20
MnO_2	0.35
CaO	15.56
MgO	13.30
	100.57

Often the pyroxene is diallagic and this is especially true of the diabases at Buzzard Mountain, in the dikes of the Scottsville region, and of the Piedmont area. The pyroxenes are very prominent throughout the Triassic diabases both in the fresh and altered condition giving the dark color to the rock. They give a metallic appearance when very fresh. In case they are weathered to a state in which iron oxides occur, they exhibit sinuous boundary lines between the rich brown augite and the opaque iron oxide.

Apatite.—Apatite, while it is not the most abundant of the accessory minerals, is a spectacular one. It occurs in thin sections as white six-sided forms, cut normal to crystallographic C, and as elongated or acicular masses cut parallel to the same axis. In the elongated form it shows transverse fractures characteristic of the mineral. Many oblique sections occur. It is intricately interwoven with the feldspars and pyroxenes and gives evidence of its primary character. It is not constant in its oc-

[22]Shannon, Earl V., op. cit., p. 11.

currence. It may occur in clusters, which are uniformly disseminated through the section. It is fresh and ranks with the feldspars and pyroxenes for its excellent euhedral form.

Hypersthene.—Hypersthene is rare in the diabases and is best seen in the Mt. Pony and Buzzard Mountain rock. The mineral is pleochroic in the dark variety and stands out well in thin sections. In some of the specimens from the Buzzard Mountain quarry the mineral is abundant enough to see with the naked eye. In one of the recent analyses of diabase from the above named locality the prominence of the mineral justifies the rock term hypersthene diabase.

Biotite.—Biotite is relatively scarce but when present is usually in small amounts and occurs as a primary mineral. The mineral is dark colored except in a few cases. It shows weathering in many of the rocks and also occurs as a secondary mineral itself after augite.

Quartz and orthoclase.—These two accessory minerals may be considered together since they are closely associated. Wherever orthoclase occurs quartz is found, the two forming what is commonly known as a micro-pegmatitic intergrowth. This intergrowth is limited to the gabbroic or pegmatitic variety of the diabase and is only formed in the stocks in the northern portion of the Potomac area, especially in the Belmont Trap quarry. Quartz is often found in very small quantity over the whole Triassic from the Potomac to the Dan River but it is not as constant as apatite and biotite. When occurring without orthoclase it is in the majority of cases secondary. The micro-pegmatitic intergrowth is rare and the size of the quartz and feldspar components is rather small, but it is so significant with the macrocrystalline rocks of the stocks that one thin section may show as many as three patches. The feldspar in this intergrowth shows no twinning and is light pink to colorless.

Iron minerals.—The iron mineral most common to a great deal of the diabase is probably magnetite. In many of the sections this mineral shows under the microscope an outline common to the octohedral form, yet it may appear as rounded when bordered by or included in weathering augite. Some of these iron masses are probably of secondary origin. In the pegmatitic variety of the diabase the masses are more abundant than in other varieties. In the weathered diabase the iron minerals are secondary and are the hydrated oxides, limonite probably being the chief one.

Hornblende.—Hornblende is relatively scarce but is a primary mineral as it is found in very fresh diabase. It is a dark green mineral with strong pleochroism and shows good cleavage, making it rather conspicuous among the other minerals. In some instances this mineral is in sufficient quantity to term the rock a hornblende diabase.

There are other accessory minerals, such as albite and olivine, but they are rather small in quantity. A number of these are mentioned by Shannon in his study of the diabase specimens from the Belmont Stock.

The secondary minerals are rather numerous. The earliest papers on secondary minerals resulting from weathering of diabase were published by Thomas L. Watson over 20 years ago, and the recent paper by Shannon is very comprehensive. The four very common secondary minerals are chlorite, epidote, serpentine and calcite, taking the rocks over the entire Triassic. Wherever diabase occurs in a weathered condition these four are usually found, especially chlorite, epidote and serpentine. The spheroidally weathered boulders are crusted with shells of brown color and in these shells the secondary minerals are common.

One of the common secondary minerals found chiefly in the Belmont Stock is the black varnish-like mineral which Shannon [23] found to be diabantite. This mineral occurs in fractures and faults in the diabase and thin sections show much crushing as a result of movements. Such diabantite filled fractures are to be found near Buzzard Mountain and in the Farmville area.

Calcite is found in fractures and is plainly of secondary origin precipitated from percolating waters. Pyrite and chalcopyrite occur quite often, always in very small masses either in clusters or disseminated through the rock.

Texture.—Texturally, igneous rocks of the Triassic areas are of four kinds, namely, coarse, medium, fine and dense in grain. The very coarsest textured rocks are found in the stocks, the fine to medium in the stocks and larger dikes, and the dense or aphanitic ones in the small dikes. One of the best means of classifying diabases in the field is by texture.

The structure of medium to fine grained diabases is of ophitic type, the intergrowth of the plagioclases and pyroxenes with the several accessory minerals. The twinned and lath-shaped feldspars with augites form a beautiful network and this texture is the one so common all over the Triassic in eastern North America. The very coarse varieties have often been referred to as gabbros and the texture might well place them there. Shannon [24] suggests that the texture is not that of a true diabase and in speaking of the variety he terms normal diabase of the Belmont Stock says:

> Although not possessing a strictly diabasic texture, the rock making up the body of the intrusion will be designated diabase, especially since most of the intrusive rocks of the Triassic of similar attitude and composition have long been referred to in the literature as diabase; and to call the present intrusion a gabbro or diorite, which it approaches in texture might lead to some confusion.

Feldspars and pyroxenes show well formed crystal boundaries, which indicates that they were the first minerals to form upon cooling of the

[23] Shannon, Earl V., op. cit., pp. 50-51.
[24] Shannon, Earl V., op. cit., p. 9.

mass. All of the primary minerals are euhedral to a large degree. The fine to medium varieties are equiangular in their grain, more so than their extremes. Nowhere have any porphyritic varieties been found. In the aphanitic or dense variety the size of feldspar and pyroxene crystals is only a fraction of a millimeter. Hand specimens of diabases collected from all parts of the Triassic show sizes of grain as follows:

1. Coarse grained diabase or diabase pegmatite—crystals up to 4 cms.
2. Normal diabase—medium grain up to 2 mm.
3. Normal diabase—fine grain up to 1 mm.
4. Aphanitic diabase or basalt less than 0.1 mm.

As a rule the finer the grain, the darker the color of the rock. The dense and dull variety has been termed basalt and may very properly be so called. This type is found in the small dikes and their apophyses and in the sheets. It breaks with an irregular fracture and has joint planes far better developed than in the coarser varieties. Its occurrence is less noteworthy than the ophitic diabase. The region between Remington and Rapidan Station is the best locality for this basalt and here it has weathered into what is commonly termed a "Black Jack" soil, which is a splendid guide for tracing weathered diabase or basalt.

Chemical composition.—A number of chemical analyses, totalling 70, have been made of Triassic diabases in eastern North America, but some of the earlier ones are not very reliable. To date 17 analyses have been made of the Virginia diabase. The specimens for analysis came from various parts of the state, though there were none from the Farmville and Richmond areas. Some of the bodies of diabase sampled for chemical analysis lie outside of the Triassic sedimentary series, but the age of such bodies is not later than Upper Triassic or Keuper. This is true of the diabase analyses of specimens from Albemarle, Fluvanna and Nelson counties.

The analyses listed in the accompanying table are those of Virginia diabases, the first four of which have been made expressly for this report. The 17 analyses spoken of above do not include those made from weathered and disintegrated diabase by Thomas L. Watson; these analyses are given and discussed under the weathering of diabases.

Recent analyses of Triassic diabases of Virginia

	I	II	III	IV	V	VI	VII	VIII
SiO_2	48.39	51.74	53.09	53.86	51.56	52.94	68.74	71.60
Al_2O_3	23.14	21.30	12.70	12.86	13.81	14.80	13.24	13.16
Fe_2O_3	.75	1.83	1.75	2.08	.96	.16	1.22	1.28
FeO	9.20	7.44	12.17	11.80	11.32	12.00	1.38	.38
MgO	3.87	3.18	4.67	5.12	7.40	5.42	2.02	2.12
CaO	11.33	12.39	9.85	9.66	10.08	8.32	5.90	3.76
Na_2O	1.72	1.22	2.44	2.54	2.08	1.98	5.76	5.92
K_2O	.48	.30	.78	.40	.96	1.50	.36	.70
H_2O-	.21	.07	.15	.13	....	....	.46	....
H_2O+	.66	.18	.32	.33	....	....		
TiO_2	.26	.67	1.69	1.13	1.48	2.32	1.44	.34
CO_2	Trace	....	....	Trace	....	....	....	....
P_2O_5	.14	.06	.16	.29	.16	.28	.59	Trace
MnO	.18	.14	.26	.35	.19	.24	.05	.03
S	....	....	....	.08	....	....	....	....
	100.33	100.52	100.03	100.63	100.00	99.96	101.16	99.29
Sp. G.	3.056	3.104	3.048	....	....	....	....	....

I. Diabase from dike. Scottsville-Richmond highway, Driver's Hill, three-fourths mile east of Scottsville, Albemarle County, Virginia. S. D. Gooch, analyst.

II. Hypersthene diabase. Culpeper Granite Company's quarry, three-fourths mile east of Buena, on Buzzard (Twin) Mountain, Culpeper County, Virginia. S. D. Gooch, analyst.

III. Diabase from dike. 100 yards south of Boiling Spring Station, Nelson and Albemarle Railway, Albemarle County, Virginia. S. D. Gooch, analyst.

IV. Diabase from dike cutting Cambrian schists of the soapstone belt, 1 mile northeast of Taylor's Store, near Alberene soapstone quarries, Albemarle County, Virginia. Lee and Wight, analysts.

V. Average diabase. Goose Creek, 4 miles southeast of Leesburg, Loudoun County, Virginia. E. V. Shannon, analyst. U. S. Nat. Mus. Proc., vol. 66, Art., 2, p. 13, 1924.

VI. Diabase pegmatite. Same locality as V. E. V. Shannon, analyst, op. cit. p. 19.

VII. Albitic pegmatite. Same locality as V and VI. E. V. Shannon, analyst. op. cit., p. 25.

VIII. Diabase aplite. Same locality as V-VII. E. V. Shannon, analyst, op. cit., p. 28.

Analyses I-IV were made during the winter of 1921 under the administration of Thomas L. Watson. Analyses V-VIII were made by Earl V. Shannon from his field collections at Goose Creek and are later than the first four analyses. These eight analyses represent diabases of various phases between the Potomac and James rivers, from stocks and dikes, and from dikes cutting both the Triassic beds as well as the beds of Cambrian and pre-Cambrian.

Other analyses of Triassic diabases of Virginia

	IX	X	XI	XII	XIII
SiO_2	45.73	50.88	51.08	51.31	52.06
Al_2O_3	13.48	13.17	23.58	13.64	13.67
Fe_2O_3	11.60	1.11	6.85	0.52	15.97
FeO		9.66		8.49	
MgO	15.40	13.05	4.95	12.73	5.01
CaO	9.92	10.19	9.36	12.41	8.15
Na_2O	3.24	1.17	2.34	1.40	3.36
K_2O	0.47	0.31		0.32	0.86
H_2O-	0.94	0.14	....	....	1.05
H_2O+					
TiO_2	....	Trace	....	Trace	....
P_2O_5	....	Trace	....	Trace	....
MnO	....	Trace	0.39	Trace	....
	100.78	99.68	98.55	100.82	100.13
Sp. G.	3.026	3.100		3.090	2.953

IX. Olivine diabase. Near Chatham, Pittsylvania County, Virginia. T. L. Watson, analyst. Amer. Geol., vol. 22, p. 87, 1898.

X. Olivine hypersthene diabase. Dike near Twins (Buzzard Mountain), Culpeper County, Virginia. W. G. Brown, analyst. Campbell and Brown, Geol. Soc. Amer., Bull., vol. 2, p. 346, 1891.

XI. Diabase. Near Chatham, Pittsylvania County, Virginia. T. L. Watson, analyst. Amer. Geol. vol., 24, p. 360, 1899.

XII. Hypersthene diabase. Twins (Buzzard Mountain), Culpeper County, Virginia. W. G. Brown, analyst. Brown and Campbell, Geol. Soc. Amer., Bull., vol. 2, p. 346, 1891.

XIII. Quartz diabase. Near Chatham, Pittsylvania County, Virginia. T. L. Watson, analyst. Amer. Geol. vol. 22, p. 87, 1898.

The chemical analyses IX-XIII represent the earliest analyses made of the Triassic diabases in Virginia. Two of these analyses, made by W. G. Brown, represent samples from the southern portion of the Potomac area and may be compared with No. II collected from the Buzzard Mountain stock during the field season of 1921. There can be little doubt about the age relations of the diabases from which these 13 analyses were made. In cases where dikes cutting the older strata were sampled the dikes have been traced over the Triassic belt and found to be intruding the Triassic sediments.

However, there are certain diabasic and basaltic dikes, lying to the west and northwest of the Scottsville area and along the eastern foothills of the Blue Ridge, where age relations are not clear. Such dikes appear in Nelson County and have been studied and described by Watson and Taber[25] in connection with their work on the titanium and apatite deposits of Virginia. These dikes were regarded by Watson and Taber as the

[25] Watson, Thomas L. and Taber, Stephen, Geology of the titanium and apatite deposits of Virginia: Virginia Geol. Surv. Bull. III-A, pp. 155-160, 168-170, 192-193.

youngest of the intrusives. In microscopic character they resemble the diabases and basalts of the Triassic belt but in most cases they show profound alteration. These have been studied in the field and thin sections have been studied in the laboratory, and it is entirely possible that such dikes may be of Triassic age. They have the same general strike and follow along the eastern foothills of the Blue Ridge like the dikes found close to and within the Triassic belt. Four superior analyses of these diabases have been made and are listed below. Though the age relations with regard to these dikes are somewhat obscure, yet due to the facts that they may be Triassic and that their physical and chemical properties are so similar to those occurring farther to the east and north of known Triassic age the four analyses are given for comparison.

Analyses of Triassic and basaltic dikes of Nelson County Virginia

(Va. Geol. Surv., Bull. III-A, p. 158)

	XIV	XV	XVI	XVII
SiO_2	48.99	49.65	52 34	52.83
Al_2O_3	13.93	13.93	12.46	13.79
Fe_2O_3	2.45	4.11	3.37	4.42
FeO	10.94	9.78	10.08	7.86
MgO	6.29	4.89	3.97	5.61
CaO	10.02	9.05	7.88	8.99
Na_2O	2.59	2.86	2.26	2.42
K_2O	0.80	1.71	1 66	1.46
H_2O-	0.09	0.09	0.14	0.71
H_2O+	1.47	1.49	1.46	1.30
TiO_2	3.33	3.03	2.96	1.18
CO_2	Trace	Trace	Trace	Trace
P_2O_5	0.33	0.32	1.19	0.31
S	Trace	0.20	0.18	Trace
MnO	0.11	0.14	0.11	n.d.
	100.34	101.25	100.06	100.88
Sp G	....	....	3.097	....

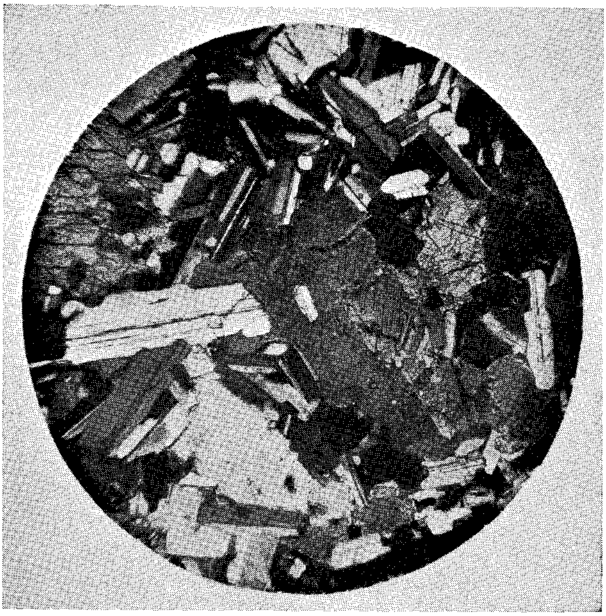
XIV. Diabase (basalt) dike on south side of Piney River, opposite General Electric Company's mine, 1½ miles northwest of Rose's Mill. W. M. Thornton, Jr., analyst.

XV. Diabase (basalt) dike, Roseland-Arrington road, near Mr. Adams' house, 100 yards south of Roseland Post Office. W. M. Thornton, Jr., analyst.

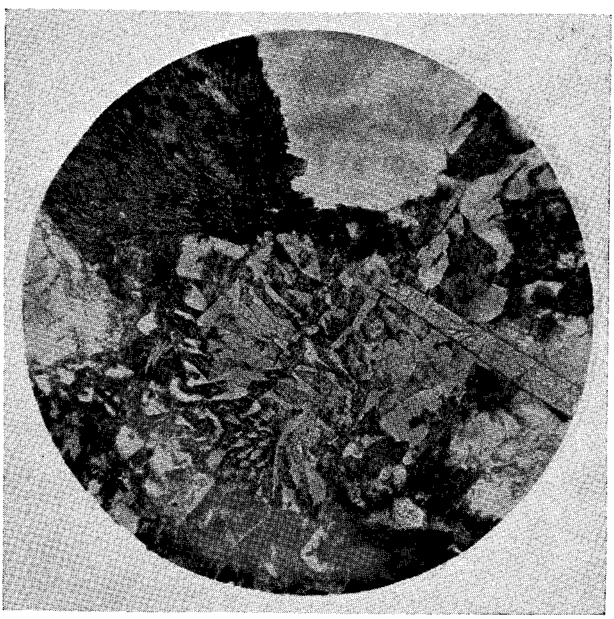
XVI. Diabase (basalt) dike, east side of Tye River, 425 feet south of the American Rutile Company's south quarry. W. M. Thornton, Jr., analyst.

XVII. Diabase dike, east side of county road, 100 yards north of Piney River at Rose's Mill. W. M. Thornton, Jr., analyst.

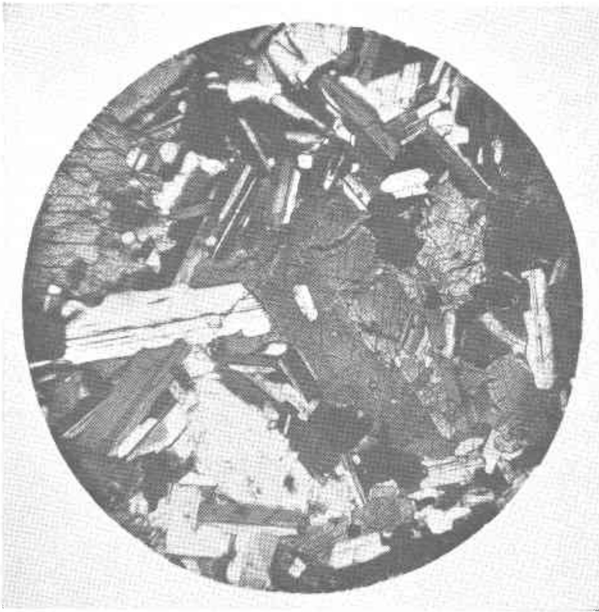
In the recent analyses of diabase the silica content ranges from 48.39 to 53.86 per cent in the normal rock but in albitic pegmatite it reaches 68.74, and in diabase aplite 71.60 per cent. The amount of free silica is relatively small and is not of importance outside of the pegmatites and the



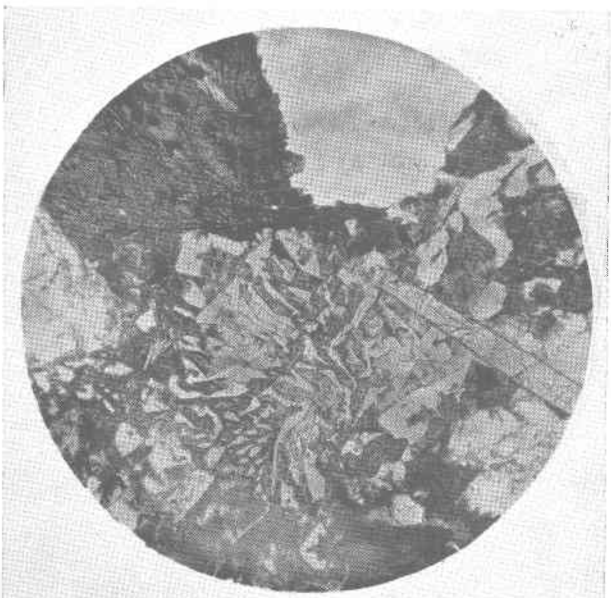
A. Photomicrograph of diabase from Buzzard Mountain showing augite twinning. Crossed nicols. 20 Diameters.



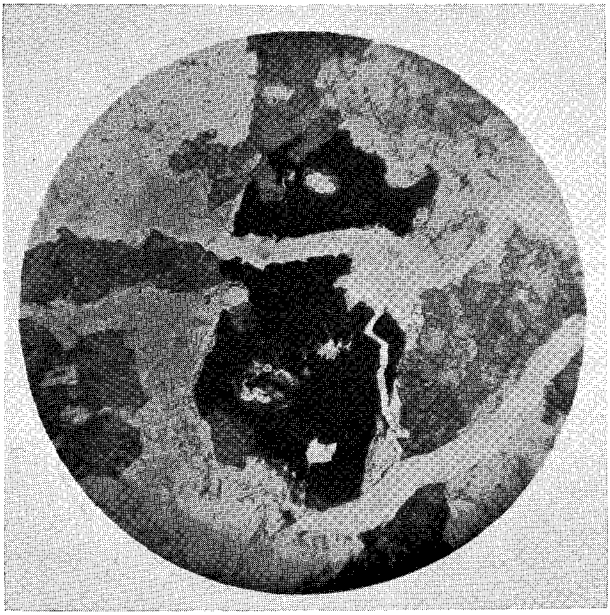
B. Photomicrograph of pegmatitic diabase, showing micropegmatitic intergrowth and an apatite crystal, from Belmont Trap Quarry, Loudoun County. Crossed nicols. 20 Diameters.



A. Photomicrograph of diabase from Buzzard Mountain showing augite twinning. Crossed nicols. 20 Diameters.

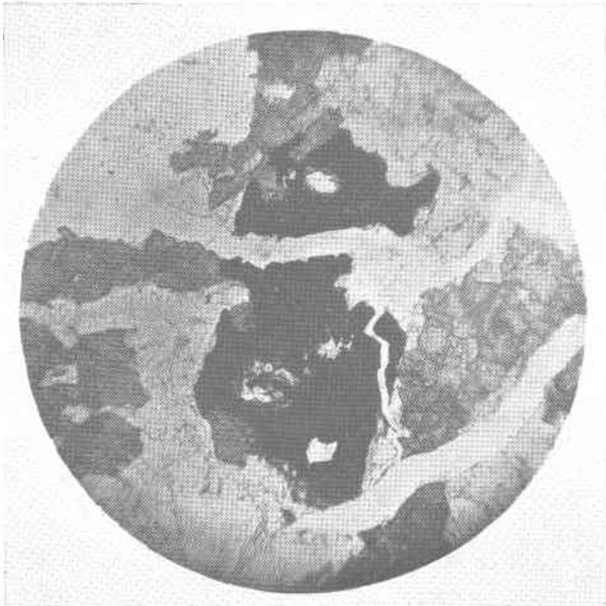


B. Photomicrograph of pegmatitic diabase, showing micropegmatitic intergrowth and an apatite crystal, from Belmont Trap Quarry, Loudoun County. Crossed nicols. 20 Diameters.

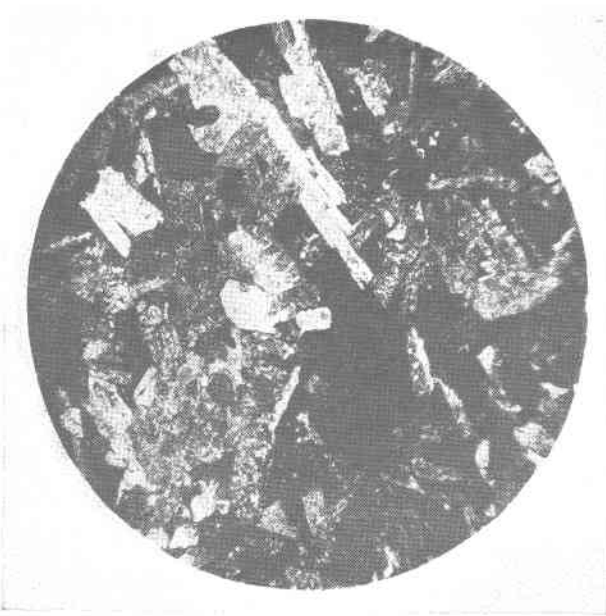


A. Photomicrograph of diabase 3 miles east of Leesburg, Loudoun County, showing a magnetite crystal in feldspar and augite. Crossed nicols. 20 Diameters.

B. Photomicrograph of a weathered diabase from 1½ miles south of Oatlands, Loudoun County, showing corroded augite and feldspar. Crossed nicols. 20 Diameters.



A. Photomicrograph of diabase 3 miles east of Leesburg, Loudoun County, showing a magnetite crystal in feldspar and augite. Crossed nicols. 20 Diameters.



B. Photomicrograph of a weathered diabase from 1½ miles south of Oatlands, Loudoun County, showing corroded augite and feldspar. Crossed nicols. 20 Diameters.

stocks. The general average of silica in the eight recent analyses compares very closely with that in the diabase and basaltic dikes of Nelson County. The older analyses of Triassic diabase will run a little lower in silica content. There is little out of the ordinary in the chemical constituents of the diabases; they compare favorably with other rocks of their age along the Atlantic and in general with the diabases of other areas.

The norms of the various diabases of which chemical analyses are listed above determine the positions of these several specimens as follows:

No. of Analysis	Quantitative Symbol	Quantitative Name
I	II. 5. 5. 5.	Lazonose
II	II. 4. 5. 5.	(a)
III	III. 5. 3. 4.	Camptonose
IV	III. 9. 4. 5.	(a)
V	III. 5. 3-4. 4 or 3.	Camptonose
VI	III. 5. 3. 3.	Kentallenose
VII	III. 3. 2. 5.	(a)
VIII	I. 2. 2. 5.	(a)
IX	Fe″ and Fe‴ iron not separate and too high for quantitative classification	
X	III. 5. 4. 3.	Auvergnose
XI	II. 4. 4. ?.	?
XII	III. 5. 4. 3.	Auvergnose
XIII	Fe″ and Fe‴ iron not separate and too high for quantitative classification	
XIV	III. 5. 3-4. 4-5.	Camptonose-Auvergnose
XV	III. 5. 3. 4.	Camptonose
XVI	'III. 5. 3. '4.	Vaalose
XVII	'III. '5. 3'. 4.	Camptonose

(a) No name in the Quantitative System.

Weathering of the diabase.—Weathering of Triassic diabase into soil is one of the noticeable features throughout the several areas. All stages of weathering from the concentrically weathered boulders and the concentric shells to the finely divided soil can be seen in the field. The weathered products, while subject to considerable variation, serve as a valuable guide in mapping dikes, as weathered diabase or basalt resembles none of the weathered sedimentary formations of the Triassic. The stages easily detected in the field are: (1) Fresh diabase of a gray to dark color and of a coarse through medium grain to a dense texture which rings with a metallic sound upon blows from a hammer; (2) light to dark brown shells which have sloughed off of the boulders and in which the various sizes of twinning lamellæ are faint or destroyed, and the augite weathered to chlorite, biotite, magnetite and other secondary minerals; (3) light yellow through red to brown lumps of weathered feldspars and augites, the mass being spongy and often fibrous, all the primary constituents in this condition being far weathered and none giving an optical figure; (4) light yellow and various shades of red and brown soils.

The soil, as the end product, is composed chiefly of kaolin and clay, with varying amounts of ferrous and ferric oxides, alumina, lime, magnesia, a little potash, and soda. This soil, while somewhat similar to the soils resulting from the disintegration of red shales and sandstones, has certain physical properties which make it unique. It is so well known among the farmers that it has acquired the name "Black Jack" or "Nigger head" soil. It is composed of a high clay content and its pigment is ferrous and ferric iron. The farmer knows too well the result to try to plow such land when it is wet, as this forms clods which sometimes require more than a year to disintegrate. It requires especial attention and most farmers advise that such land be used for grass lands. Dirt roads through the diabase soils are almost impassable when wet and equal in every way the stiff and unyielding clays of the Piedmont sections where the granites have disintegrated.

The bodies of diabase which have weathered to such an advanced state that vegetation and soil have concealed all exposures of the rock can often be traced both by the character of the soil and by the vegetation. Black oak of small size and conifers, especially the pine, are the predominant types of trees growing on this soil and the term "Black Jack" is derived from the black oak, the provincial term for which is "Black Jack." This soil is by no means an infertile one but it is often neglected due to the extreme difficulty in cultivating it. In some communities it is fine grass land, in others it is often unfenced.

A number of chemical analyses have been made of diabase soils in the eastern United States. Some analyses of the fresh, slightly weathered, and the completely decomposed diabase rocks were made about 25 years ago by Thomas L. Watson [26] from specimens collected by him near Chatham, Pittsylvania County.

Bulk analysis of fresh and disintegrated diabase from Chatham, Virginia.

(THOMAS L. WATSON, *Analyst.*)[27]

Constituents	Fresh Olivine	Partially Weathered Diabase Rock	Decomposed Olivine Diabase Rock
SiO_2	45.73	47.87	37.09
Al_2O_3	13.48	14.43	13.19
Fe_2O_3	11.60	11.55	35.69
CaO	9.92	10.45	0.41
MgO	15.40	10.58	0.57
Na_2O	3.24	3.47	1.75
K_2O	0.47	0.61	0.33
H_2O	0.94	1.82	11.83
	100.78	100.78	100.86

[26]Watson, Thomas L., Weathering of diabase near Chatham, Virginia: Amer. Geologist, vol. 22, pp. 85-101, 1898.
——— Some further notes on the weathering of diabase in the vicinity of Chatham, Virginia: Amer. Geologist, vol. 24, pp. 355-369, 1899.
[27]Watson, Thomas L. Amer. Geol., vol. 22, p. 87, 1898.

One of the best sections in Virginia for study of the weathering of diabase is exposed on the Richmond-Scottsville pike just east of Scottsville. Here, at the time field work was done, recent workings by the County for road improvement showed cross sections of weathered diabase boulders in which concentric shells were very marked, being as much as 2 feet in radius. Very few fresh minerals of primary rock occur at the centers of the weathered boulders and these decrease towards the periphery. From the center outward change in color is very marked. All of the centers are medium to dark red and grade into brown and finally into brownish yellow. After these boulders have broken down they seem to form first a fibrous mass, followed by a flaky and finally a pulverulent mass. The material is composed of secondary minerals, many of which are evidently hydrated, judging from the high amounts of water coming off of various samples after they have undergone air drying for several months.

Agents of weathering affecting the diabases include about all of the main agents commonly known under dynamical geology for continental conditions. Alternate thawing and freezing and the action of organisms, particularly the organic acids, are the most effective agents. Great numbers of boulders from small sizes up to several tons in weight mark much of the dike territory. Large flat exposures are common all over the several areas. The stocks show the largest masses of diabase, such as occur along Goose Creek between Leesburg and Ashburn and southwest of Belmont Park, and north of Sterling. The boulders may present a rusty brown or a dull black color.

Of all the Triassic members diabase is most stubborn toward disintegration, and this is well shown by streams which cross the belts. The Rappahannock River shows three sets of rapids due to diabase dikes and similar cases occur in Goose Creek, Bull Run, and Rapidan, James, and Roanoke rivers, as well as in many of the smaller streams. Percolating water has been a very active agent in disintegration of diabase and is mainly responsible for the presence of secondary calcite in the weathered material.

Age of the diabase.—Because of scarcity or lack of exposures of extrusive sheets the problem of age of diabase in Virginia is by no means as easy as it is in New Jersey and New England. Dikes and stocks are known to cut all three of the sedimentary formations and they have produced certain physical and chemical changes upon these intruded members. The matter of trap sheets in Virginia is a great problem, for as observations are made in the field one is quite certain that they were formed, but their concealment is so complete that no good exposures have been found.

Only one sheet of extrusive origin has been located and this is in Culpeper County south of Winston along the Southern Railway. The sheet has about the same dip and strike as the shales and a difference in structures at its base and top suggests that it was extruded upon the red shale and that sedimentation continued. This would indicate that there was a period of igneous action during the Triassic age. In New Jersey Kümmel[28] has found evidence of three trap sheets which indicates at least three periods of igneous activity separated by periods of seeming quietude and during which accumulation continued.

Bull Run shales, the youngest of the Triassic rocks, are found in many localities to be profoundly altered by intrusion of diabase dikes and stocks. Coal seams of the Richmond area have been cut across by diabase dikes. It is to be remembered that the coal seams are closer to the base than the top of the Triassic series and that the dikes are known in this area to cut the youngest of the Triassic beds.

To the east of the Triassic area in Virginia unconsolidated sediments of the Cretaceous occur. Diabase dikes which intrude sediments of this age have not been found anywhere in the State. This fact is true not only of the Virginia Cretaceous but also of the whole Coastal Plain and Gulf regions. It is quite likely that were these dikes as late as early Cretaceous time they would be found intruding the Lower Cretaceous somewhere along the Coastal Plain.

During Jurassic time in Virginia there were probably few sediments accumulated and such may have been removed either contemporaneously by erosion or later. Triassic valleys had been filled chiefly under residual conditions and in all probability there were no large depressions during Jurassic time to receive sediments.

In the light of present data it seems best to regard dikes and stocks as of the late Triassic age. Probably there were two periods of igneous activity, one during Triassic deposition somewhere near the middle of the period and another near the close. There is no reason favorable to placing the time of intrusion in the Jurassic. Since we are rather definite as to the age in areas further north, it is more likely that intrusion was not a matter of local nature but involved the whole territory from Prince Edward Island to the Carolinas. In the region around Mt. Pony in Culpeper County the sandstones seem to be more altered than the shales, which indicates that this body of diabase was formed during Triassic sedimentation. The diabase dikes in the Valley of Virginia so far have not been correlated with those of the Triassic belt.

METAMORPHOSED TRIASSIC ROCKS

Wherever Triassic diabase bodies have intruded the Border Conglomerate, Manassas sandstone or Bull Run shales, and such contacts are exposed, metamorphism is usually found. Intrusion for the most part has taken place in two ways, namely, parallel with the bedding planes of the sedimentary rocks or obliquely across these planes.

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[28]Kummel, Henry B., The Newark system or red sandstone belt: Geol. Survey of New Jersey, Ann. Rept. for the Year 1897, pp. 144-145, 1898.

The Border Conglomerate at a number of points shows exposures which have been altered by intruding diabase. Prospecting was done 40 years ago on the west side of Goose Creek 3 miles east of Leesburg, Loudoun County, and north of the Washington-Leesburg pike. At this point the diabase, which is probably the northern extension of the Belmont stock, has evidently altered the Border (limestone) Conglomerate, and epidote, calcite, chalcopyrite and pyrite are the contact minerals.

Shannon[29] has described a contact mineral from the Leesburg quarry which is the result of action of diabase upon the conglomerate. The mineral described is Xonotlite, a hydrated calcium metasilicate, which occurs in thin bands in the conglomerate and is fibrous, sometimes in radiating form.

The Border Conglomerate shows a mineralized exposure 2 miles south of Culpeper, Culpeper County, 100 feet west of the Southern Railway tracks. Here the minerals formed are pyrite, chalcopyrite, and various iron oxides, and copper minerals are secondary. Calcite and epidote are common.

Wherever altered the Border Conglomerate shows a lighter color and is more indurated. The pebbles have lost all organic matter in the case of the limestone phase. The pebbles or boulders and the matrix have both increased in brittleness. In the trap phase of the Border Conglomerate south of Culpeper the contact minerals are found in the matrix and this conglomerate has suffered an increase in color from dull dark gray to lustrous black. The width of the altered zone in the conglomerate rarely exceeds 20 feet and usually less than 10 feet. Wherever it is exposed the conglomerate when altered shows diabase stocks as the form of intrusive diabase.

Manassas sandstone shows alteration in a great number of localities. Some of the more noted ones are found along the railroad to the east and west of Herndon, near Manassas, southeast of Bealeton and Remington, east of Brandy, and around Mt. Pony and Buzzard Mountain. Diabase dikes are involved in the above named localities with the exception of the last two, which are diabase stocks.

Development of minerals was not observed in any of these intruded sandstones except southeast of Bealeton where pyrite and chalcopyrite occur. In most cases, metamorphism has been accompanied by change in color and increase in brittleness. The red sandstones have assumed a dark to light gray color, which in thin sections shows the iron oxide to be in a ferrous condition and disseminated through the mass. These black masses mixed with white feldspar and quartz grains impart a gray tone to the rock. The rocks are all very much increased in brittleness. The sandstone west of Brandy is of a very light gray color and extremely brittle. The sandstone near Stevensburg, 6 miles southeast of Culpeper,

[29]Shannon, Earl V., An occurrence of Xonotlite at Leesburg, Virginia: Amer. Min., vol. 10, No. 1, pp. 12-13, 1905.

has not lost its red color but its brittleness has been increased. A State quarry has been operated at this point and shows the fresh material in abundance.

South of Chatham, in the State quarry on the top of White Oak Mountain, sandstone and conglomerate are both very highly indurated but without change in color. However, in this quarry no exposure of diabase was observed, but dikes occur both east and west of the quarry along the flanks of the mountain. Metamorphosed sandstones are exposed in all of the areas except the southern portion of the Potomac. The distance outward from the dike or stock in which alteration has taken place varies from a fraction of a foot up to 15 or 20 feet.

The Bull Run shales show more profound alteration than any of the sedimentary series. The dikes have been the main form of diabase bringing about the change. Both the red and the blue Triassic shales show intrusion in all the areas except the extension of the Potomac to the south.

Metamorphic changes accompanying the intrusion were a loss of original color or an increase in brittleness, or sometimes both. The small dikes of any aphanitic texture often show no effect upon the color of the intruded rock. Thin sections from rocks altered in color have been examined and the loss of the deep red color is due to the same phenomenon as in the case of alteration of the red sandstones. The red ferric iron coating of the sand grains and of the matrix has changed its valence due to heat from the intruding diabase and has become disseminated in small patches more or less evenly spaced throughout the rock. The color of the red shales is light to dark gray.

The presence of minerals at contacts of shales with diabases is not shown. A number of minerals occur in the shales, such as pyrite, chalcopyrite, calcite and barite, and while these may be due to ascending thermal solutions from the diabase bodies, no definite evidence was found for this.

The distance outward from the diabase in which alteration has taken place varies up to 15 feet and gradation from the contact into the shale with full original color is well shown. Some of the best places to observe shale alteration are in the railway cuts at and near Ashburn, Loudoun County, on Bull Run battlefield, south of Remington, and near Raccoon Ford. Blue shales altered by diabase are best shown southeast of Bealeton in Fauquier County and near Cascade in Pittsylvania County. In almost all cases the dikes show an increase in the size of the grain towards their contact with the intruded rocks, except in cases of very small dikes where the entire structure is very dense and no difference is noticeable to the unaided eye.

ROCKS ADJACENT TO THE TRIASSIC AREAS

Rocks bordering on the various Triassic areas throughout the State consist of three major classes, namely, metamorphic, sedimentary, and igneous.

In age they vary from Archeozoic through Cambrian to Ordovician, the great bulk however being pre-Cambrian. Wherever Triassic rocks are found in contact with older members such a contact is a marked discordance, and is so plainly marked by lithology, by the degree of induration, and by structural differences of the two systems in question that the tracing and establishing of the boundaries are made difficult only by deep mantles of soil and by vegetation. There is close similarity everywhere between the constituents of Triassic rocks and the adjacent rocks from which they have been derived—such a similarity being one of mineral content. The order in which the rocks are named in the beginning of the paragraph is their rank in abundance as rocks adjacent to the Triassic areas.

ADJACENT SEDIMENTARY ROCKS

Sedimentary rocks bordering on the Triassic area extend only a very short distance, limited largely to the northwestern side of the Potomac area, and are Cambrian in age. At the Potomac River, where the Triassic rocks begin in Loudoun County, the adjacent formation on the west is the Loudoun formation of Lower Cambrian or Waucobian time. This formation borders the Triassic toward the south over a distance of nearly 4 miles by an unconformable contact with the Border Conglomerate and the Bull Run shales. The Loudoun formation, which is basal Cambrian, consists of dark colored slates and shales grading into sandstones containing lenses of slate and limestone, all more or less metamorphosed and to such an extent that the few fossils contained are badly preserved. The strike of the Loudoun beds is to the northeast and the dip 25° to 35° S. E. The Loudoun rests unconformably upon the Catoctin schist from which series the Loudoun has been to a large extent derived, and with the Catoctin series it has furnished much of the material for adjacent Triassic members, more especially Bull Run shales. The feldspars of the Loudoun formation have to a large extent undergone kaolinization, alteration products of which are quartz and muscovite. The feldspars of the Loudoun formation have been derived from the Catoctin Series and the pre-Cambrian granites. The dipping of the Loudoun to the southeast and the Triassic rocks to the northwest gives a good contrast whenever exposures occur, but bedding planes in the conglomerate are rare and the dip and strike are not so well ascertained in this vicinity except in the case of shales.

Four miles south of Potomac River, at the southernmost point of the Loudoun formation, the Weverton sandstone becomes the contact member and continues so southward over a distance of approximately 18 miles, broken at intervals by Catoctin schist becoming the contact member. The Weverton sandstone overlies the Loudoun formation in a conformable manner and, like the Loudoun, it is metamorphosed until the term quartzite is not misapplied in some places. The Weverton has about the same strike and dip as the Loudoun. It is composed chiefly of quartz grains of various sizes ranging from medium to coarse grained and conglomeratic at times. The grains are well rounded. With the others, this formation has been a source of Triassic sediments.

The Shenandoah limestone of the older usage, while not a contact member, is evidently an underlying member of the Triassic around Leesburg, Loudoun County, from which the boulders and matrix of the limestone phase of the Border Conglomerate are derived. Evidence of this is seen 1 mile northeast of Leesburg in an abandoned quarry where a fault has brought up this more or less homogeneous Cambrian limestone and shows it with the Border Conglomerate resting directly but unconformably upon it. At many points within the Triassic areas the underlying rocks are brought up by faulting, and such is well seen in the Potomac, Danville, Farmville, and Richmond areas.

The above formations comprise the sedimentary rocks and while to the south certain limestones are adjacent members they are so distorted and recrystallized that they can better be treated under metamorphic rocks. The agents of metamorphism have been very intense with all the rocks along the Triassic border and with the Triassic rocks themselves, since they are highly indurated compared to the unconsolidated Cretaceous sediments which lie only a few miles to the east of the Triassic belt.

ADJACENT METAMORPHIC ROCKS

The adjacent metamorphic rocks consist of schists, phyllites, and gneisses of many varieties. The metamorphic rocks comprise the most important of the major classes which border on the Triassic and have been the chief source of sediments for the Border Conglomerate, Manassas sandstone, and Bull Run shales. They stand in absolute contrast to Triassic rocks and while their contacts with the red beds are concealed, yet often over relatively small distances both the metamorphics and Triassic rocks outcrop and the contacts can be estimated.

CATOCTIN SCHIST

The Catoctin schist extends all along the western border of the Potomac area, except where the Loudoun and Weverton formations are the contact members. This schist is highly altered and contains abundant epidote and chlorite and other minerals. The color of the Catoctin schist is dark gray to dull black. Much of this schist is a metamorphosed basalt and is regarded as of Algonkian age. The schistostity planes, which are well developed in the Catoctin schist, strike a little east of north and dip usually to the east at very high angles and often are vertical. Keith [36] recognized three varieties of the Catoctin schist which are as follows: (1)

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[36]Keith, Arthur, Harper's Ferry Folio (Va.-Md.-W. Va.): U. S. Geol. Surv. No. 10, p. 2, 1894.

Coarse texture and associated with granite; (2) fine texture with lenses of quartz and epidote; (3) schists with amygdules of quartz and epidote. This Catoctin schist makes up the entire Bull Run Mountain, Catoctin and Hog Mountains, and the ridges which parallel the Potomac area on the west. Also it is seen on the eastern portion and on the summit of the Blue Ridge. One of the best sections through the Triassic and Catoctin schist is from Batna in Culpeper County, through Culpeper and across the Piedmont region and the Blue Ridge Mountain, along the Culpeper-Luray road. The schistose basalt is the most noticeable of all the Catoctin material and this is well seen on Bull Run Mountain from Thoroughfare Gap northwest to "The Plains" Station along the Harrisonburg Division of the Southern Railway. Also from Afton in Albemarle County to the summit of the Blue Ridge, the Catoctin is exposed in great ledges and affords one of the most if not the most typical of all exposures.

The Catoctin schist is the border member of the entire western side of the southern extension of the Potomac area, and the Border Conglomerate lying along the western side of this area shows many of its fragments to be of Catoctin origin. South of the limestone and arkose phases of the Border Conglomerate, the principal source for conglomerates, sandstones and shales has been the Catoctin schist. Frequent basalt pebbles are found in the conglomerates which, though well rounded and highly fractured, show fresh minerals in thin sections.

SCHISTS OF UNDIFFERENTIATED CAMBRIAN

Various other kinds of schists are adjacent to the areas north of the James River which belong to the "Undifferentiated Cambrian" and very probably much of this so-called material is of Ordovician age. These schists begin near the point where Rapidan River leaves the Triassic beds at Raccoon Ford, Culpeper and Orange counties in the Potomac area. From this point these schists extend along the eastern boundary of the Potomac area and completely surround the Scottsville area.

Compared to the Catoctin schist, these schists of the "Undifferentiated Cambrian" bear little resemblance. They are very gray to grayish blue in color and the laminae are extremely thin. They make up Southwest and Clark mountains, especially the former. In many instances this schist is a metamorphosed limestone, shaly in its nature, but acid is often necessary to detect the presence of calcareous material; this is especially the case at Warminster in Nelson County in the Scottsville area. In the Border Conglomerate large tabular fragments of this satin-luster schist are found so little changed to the unaided eye that no points of difference can be pointed out in the field. The schistosity planes of these rocks dip at very steep angles to the east, rarely to the west, and often are vertical.

PRE-CAMBRIAN SCHISTS

The third type of metamorphic rocks bordering the Triassic areas is what is termed the pre-Cambrian crystalline schists and gneisses. This assemblage of rocks for the greater part comprises micaceous schists and acid and basic intrusives which extend from the Potomac River entirely across the state. These rocks border the eastern side of the Potomac area beginning at the Potomac River in Loudoun County and ending near the Culpeper-Orange County line or the Rapidan River near Raccoon Ford. This same series borders both the eastern and western sides of the Danville area, in fact it surrounds this area; it also borders on the west and the south of the Farmville area and surrounds the small outliers of this same area. This is the most extensive of all the contact members and has a greater range in field appearances.

From a standpoint of composition, the pre-Cambrian schists and gneisses are composed essentially of quartz, feldspars and micas, the latter two more or less altered by kaolinization. Epidote, chlorite, and iron oxides are very common as weathered products and the soil is a deep red clay typical of the Piedmont region. A portion of this material is basic and is characterized by pyroxenes, amphiboles, corundum, and ferro-magnesian minerals. The great bulk of rocks are light colored and occasional lenses of quartz are found. This series has contributed considerably to the formation of the three Triassic units in the above mentioned areas. The Triassic diabase dikes often cut this series. One of the most interesting of all the various sections examined in this series is northwest of Chatham in Pittsylvania County, in the locality in which Hoegbomite [31] was recently described as occurring in a spinel emery. Spinel emery and magnetite are very common in the basic crystalline rocks and the variety of rock known as the emery rock is quite common along the western side of the Triassic from Rustburg in Campbell County south to the North Carolina line. A great number of specimens from this adjacent area were collected by the writer for Thomas L. Watson during the field work on the Danville area.

The schistosity planes of these rocks dip to the east, southeast and northeast and are almost always steep. Faulting is common in all these rocks as shown by fault breccia and slickensides. Great boulders of gneiss and granite occur in the Border Conglomerate and in the sandstones and shales. Among the accessory minerals are the spinels and minerals from the crystalline rocks.

PRE-CAMBRIAN GNEISSES AND GRANITES

There is one other series of rocks which borders the Triassic areas and these rocks are also pre-Cambrian in age. They border on the north and

[31] Watson, Thomas L., Hoegbomite from Virginia: Amer. Min., vol. 10, No. 1, pp. 1-9, 1925. (This contribution was published shortly after Dr. Watson's death, which occurred on November 10th, 1924.)

east of the Farmville area and completely surround the Richmond area and its several small outliers. These rocks consist of the ultra-acid types and are light colored without exception. They are granites, granite-gneiss and schists, intruded by pegmatites and Triassic diabase dikes.

In mineral composition these rocks have quartz, feldspar, and mica as the chief minerals. The pegmatites in Amelia County, west of the Richmond area, have furnished some rare minerals and upon further investigation may be found to contain many features of scientific interest. Much of the granite and granite gneiss has undergone kaolinization and numerous lenses of clay are common. Willis mountain northwest of Farmville is composed of a granite gneiss and many of the high points around the Richmond area are due to this rock. One of the best exposures of the granite-gneiss is in the Boscobel quarries, near Boscobel, on the Chesapeake and Ohio Railway, in the Richmond area. Here the granite-gneiss has been brought up to the surface by a fault of post-Triassic time. Triassic sandstones and shales occur on the east and west of the granite-gneiss and are involved in the fault. Megascopically there are at least three varieties of this granite-gneiss, exposed in these quarries, namely, (1) granite gneiss with well developed gneissoid banding and composed of flesh colored orthoclase and quartz with little muscovite, this variety being quite common; (2) very light colored gneiss, chiefly quartz with some orthoclase, albite and little plagioclase feldspars; (3) highly altered gneiss with numerous black bands, whose coloring matter is chiefly iron oxides, but some hornblende biotite and a few secondary minerals.

Bordering the Richmond area are great masses of granite which occur as large flat exposures or in great boulders. This granite is composed chiefly of quartz, feldspar and mica. The feldspar shows abundant Carlsbad twinning and such crystals sometimes measure 3 inches in length. West of Huguenot Springs, just over the western Triassic contact, some of the largest flat exposures of granite are found. Some of these exposures cover as much as 3 acres and have no soil or overburden. Such rocks have contributed the great bulk of material during Triassic time and since that time to the younger sediments lying to the east of the Triassic belt. The conglomerates of the Farmville and Richmond areas are far more arkosic than those of any other areas, except the arkose phase of the Border Conglomerate, south of Oatlands in Loudoun County. The sandstones immediately underlying the coal seams on the eastern limit of the Richmond area can well be termed conglomerates in a great number of cases. In some of them the large and fresh crystals of feldspar with a medium to fine grained matrix more nearly approach granite in composition than any of the other sedimentary rocks. The rocks taken from the Midlothian mines, 1 mile south of Midlothian, in driving through one of the great "rolls" show the gradation from a coarse conglomerate on the bottom to a coarse and medium sandstone toward the top. These rocks rest unconformably upon the great granite and granite-gneiss masses from which they were derived. The adjacent igneous rocks around the Richmond and Farmville areas are frequently intruded by Triassic diabase and such intrusions are even exposed within the Richmond area south of Skinquarter, being brought up by a fault. There is no doubt but that these granites and gneisses underlie the whole of the Richmond and a considerable portion of the Farmville area.

STRUCTURE

The structure of the Triassic rocks in the five main areas and their outliers remains about the same. This structure, though quite simple, is difficult to study and locate due to the enormous erosion which has peneplained the region, the thick mantle of soil, the absence of high bluffs made by rivers and creeks, and the scarcity of quarries, coal shafts and tunnels. The trend and disposition of the beds is not particularly difficult to study. The main structural features, which offer so difficult a problem, are the tracing of faults and location of trap or basalt sheets. Very few faults can be traced any great distance. The forms of diabase, except the sheets, are easy to locate and serve as means of interpreting the structure of the sedimentary rocks.

FOLDING

Folding throughout the Virginia Triassic is that of the simple monoclinal type, faulted at many places and with from one to three systems of jointing. The Triassic rocks have a strike which on the average is a little east of north, though in many instances west of north. Strikes have been measured which are N. 15° W. but many are a few degrees east of north and the most extreme ones reach N. 45° E. The monocline dips west and northwest from a few degrees up to 45°; some beds are almost horizontal, as the shales and intercalated sandstones in the quarry 2½ miles southwest of Bristow, Prince William County. Nowhere has any trace or suggestion of anticlinal structure been detected, but faulting in a few places has developed very shallow synclines, as will be found north and northeast of Mt. Pony and east of Buzzard Mountain toward Raccoon Ford. The folding of the four areas lying to the west along the foothills of Catoctin and Bull Run mountains and the Blue Ridge Mountains is the same as that of the Farmville and Richmond areas which are of a mesophytic swamp origin and situated further to the east and nearer the fall line.

The red shales north of Mt. Pony in Culpeper County have a strike of N. 80° W. and a dip of 13° NE. East of this location and 2 miles west of Stevensburg there is a radical change in the strata showing a strike of N. 60° E. and a dip of 9° NE. This shift in strike and dip may be the result either of faulting or a disturbance from the Mt. Pony intrusion which might have been laccolithic in its nature, a matter which will be considered later under the subject of the various forms of the diabase.

The shales and sandstones from Gladys in Campbell County through White Oak Mountain region to the North Carolina border show nothing but the monoclinal folding and no departures from the northwest and western dip. The sandstones underlying the coal seams and the carbonaceous shales dip to the west and the northwest and in the Richmond area a peculiar feature appears which is seen nowhere else. In the incline of the old Grove shaft 1 mile south of Midlothian, lately opened up for a short distance, the tracks of mine cars are laid on sandstone. This slope which pitches approximately 40 per cent on the average or with an average dip of the strata of 30°, has what is termed "rolls." These "rolls" are due to buckling of the strata and they become very steep and flatten out again, thus having a variation in dip of from 19° to 70°. Of these rolls, three main ones become further apart on depth. Evidently where the movement was extreme and pressures too inadequate the strata faulted instead of buckling and producing folds. Such a feature in the folding of the Triassic rocks is not known outside of the Richmond area, but it must be recalled that in none of the other areas except the Farmville has any shaft or incline been opened.

FAULTING

Faulting has played quite a significant rôle in the Triassic rocks and is largely responsible for their present position, which is unique to say the least when compared to other formations in eastern North America. The high degree of peneplanation has made the detection of faults extremely difficult, especially in tracing them over any distance, but taking into consideration the great number known and the fact that the basin is so narrow it is quite evident that faulting has been prominent, otherwise the seemingly great thickness so commonly reported in the past can not be explained. From the standpoint of location the faults may be divided into three classes, namely, the great faults lying along the edge of the basin, always on the western side; those within the Triassic belt; and those cutting across the basin. The first of these classes will be Triassic faults and cross faults. The various faults so far recognized are as follows:

I. The Border Faults:
  Western Border Faults, one along the western border of every area.

II. The Inter-Triassic Faults:
  1. Potomac Area
    a. Leesburg fault, Loudoun County
    b. Harrison fault, Loudoun County
    c. Belmont fault, Loudoun County
    d. Culpeper fault, Culpeper County
    e. Raccoon Ford fault, Culpeper County
    f. Liberty Mills fault, Orange County.
  2. Scottsville Area
    g. Glendower fault, Albemarle County
    h. Howardsville fault, Albemarle and Nelson counties.
  3. Danville Area
    i. White Oak Mountain fault, Pittsylvania County.

4. Farmville Area
   j. Farmville fault, Prince Edward County.
5. Richmond Area
   k. Otterdale fault, Chesterfield County
   l. Boscobel fault, Goochland and Powhatan counties.

III. Various cross faults mapped by Miss Anna I. Jonas.

EVIDENCES OF FAULTING

The field evidences of faulting though few are well pronounced. The absence of fossiliferous or persistent strata adds to the difficulty in detecting the faulting and the enormous amount of peneplanation, with the thick soil mantle in many places, has so concealed the faults that tracing over any great distances is impossible, except in those cases of juxtaposition of conglomerates and shales, a position which is caused in these regions only by faulting. Such faulting as this is well marked in the Potomac and Scottsville areas and to a less extent in the other areas.

The Western Border fault is recognized chiefly by the opposite dips of the two systems of rocks, the Triassic rocks on the eastern side of the fault dipping west and northwest, and the older rocks of the Cambrian and pre-Cambrian on the western side of the fault with bedding or schistosity planes dipping east at angles varying from 30° to vertical. This mark is commonly seen over the areas and is best developed along Bull Run Mountain in the Potomac area and along the western margin of the Scottsville area north of Howardsville; in the former area, the two contact lithologic units are the Triassic Border Conglomerate, involving both the arkosic and the trap phases, and the Catoctin series, and in the latter area the units are the Triassic Border Conglomerate of the trap phase and the schists of the undifferentiated Cambrian.

The phenomenon of slicken-sides is the important mark of faulting in all of the areas, not so much with the great border fault as with the local and inter-Triassic faults. Slicken-sides are best developed in the limestone conglomerate of the Leesburg quarry and vicinity, in the large diabase quarry at Belmont Park 4 miles southeast of Leesburg, on White Oak Mountain, and in the coal mines south of Midlothian. This mark is a dependable one and with juxtaposition of Triassic units far apart texturally and the oppositely inclined rocks along the western borders, most of the faults have been detected.

The presence of fault breccia is often noted even when slicken-side phenomena are not to be had. The best place for such breccia is the diabase quarry at Belmont Park where it is seen to fill fault fissures as much as 4 feet in width. Fault breccia is common in the State road quarry 2½ miles north of Lucketts, in the Leesburg quarry, and west of Aldie. The Boscobel fault shows abundant material of this nature. Thin sections were made of the fault breccia which occurs in the Belmont stock and it was found to be composed of the same material as the adjacent phanerocrystalline diabase, but very much comminuted due to fault movements along the fissure. The fault breccia in the limestone phase of the Border Conglomerate often shows the development of secondary calcite in very scaly structures. Fault breccia can be detected all along White Oak Mountain and the width of the fissure and fault spaces reaches as much as 8 feet.

The topography often indicates a fault over the various areas. Depressions a few feet in width and extending short distances are seen and many of them when carefully noticed show fault breccia in the depression or trough and the resistive and less fractured rock on the sides from which the breccia originated. Many such faults show in the regions of diabase stocks and sandstone outcrops.

Actual displacements are seen in many instances in fresh cuts. All such displacements are small and at most involve less than 10 feet. Often diabase dikes will be faulted and show up to 6 and 8 feet displacement. Such faulting is rather significant since it places the age of faulting later than the dike intrusion, or post-Triassic at any rate. Sometimes in fresh excavations along roads and railroads shales with clay lenses will show the clay faulted with slight displacements.

Faulting is well distributed through the whole sedimentary series and through the diabase rocks, and of the latter both those within and without the Triassic belts. In the Potomac area faulting seems more prevalent toward the western side, but in the Danville and Richmond areas toward the eastern side, though this may be partly attributed to better knowledge of the western side of the Richmond Basin due to so many shafts for coal investigation and mining. Along White Oak Mountain, which begins on the eastern side of the Danville area, faulting is better shown, due to high elevations and ravines. Faulting took place in later Triassic time, but more probably in post-Triassic time, and has not been limited to any one formation or any particular class of rocks.

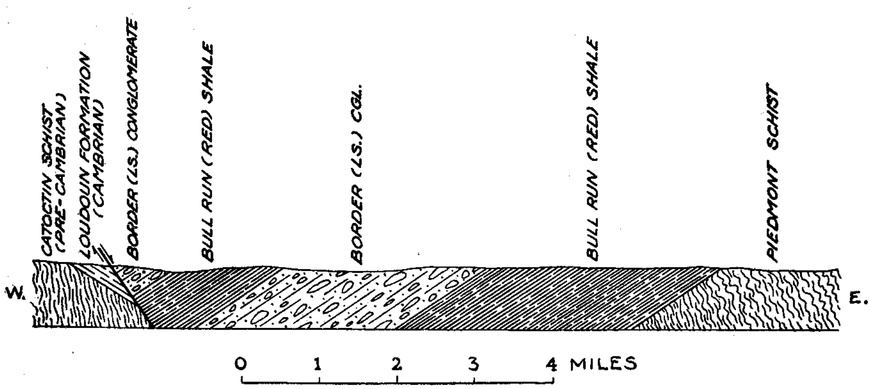


Figure 1. Cross section of Triassic through Lucketts, Loudoun County.

WESTERN BORDER FAULT

This fault is so named because it runs the entire length of every Triassic area in the State. The portion of this great fault covered by the Harpers Ferry Folio was termed by Arthur Keith the Bull Run fault. The eastern border of all of the areas is not faulted and everywhere the Triassic rocks rest unconformably on pre-Cambrian crystallines. In all probability this fault is more or less straight but rock creep and soil movements have so changed it that the contacts on the map appear in a sinuous manner and such contacts are understood to be the fault plane.

The various types of adjacent rocks involved in this Western Border fault are as follows:

Potomac area—The Loudoun and Weverton formations of the Lower Cambrian beginning at the Potomac River, and the Catoctin schist beginning southwest of Leesburg and continuing as the contact member to the end of the area at the Rapidan River.

Scottsville area—The schists of the Undifferentiated Cambrian, some of which in all probability are Ordovician, but termed on Virginia Geological Survey map as "Undifferentiated Cambrian."

Danville area—The pre-Cambrian schists and gneisses of both the acid and basic rocks.

Farmville area—The pre-Cambrian schists and gneisses of same type which border on the Danville area with a small portion of the Pre-Cambrian granite and granite gneisses.

Richmond area—The granites and granite gneisses of pre-Cambrian age—all light colored and for the greater part highly altered rocks.

The dip of the Loudoun and Weverton formations is from 20° to 25° to the east and the dip of the schistosity planes of the schists and gneisses is to the east at very high angles, some of the planes of which are vertical. The Border Conglomerate, when it shows bedding planes, and the Manassas sandstone and Bull Run shales all dip 20° to 30° to the west or northwest, and these two systems with opposite dips afford a good fault. Nothing but a downthrow of the Triassic system on the

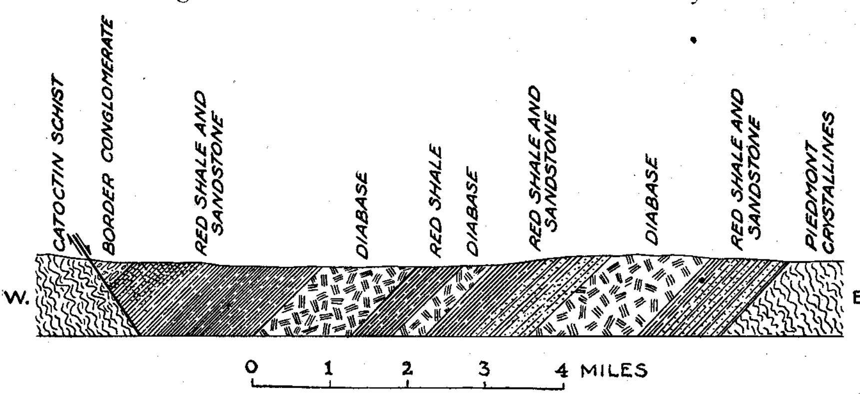


Figure 2. Cross section of Triassic through Manassas, Prince William County.

west with frequent faulting in the various basins can explain the present day structures.

Motion along this Western Border fault plane has been upward on the footwall or on the older rocks, or it has been downward on the hangwall or on the younger rocks, or probably both walls have been involved in the movement. This normal faulting has left ample evidence of its having taken place all along the western margin of all the areas and there can be no doubt but that it is of normal type as indicated by slicken-side phenomena and the position of the strata at the present time in their relation to the older rocks. The dip of the fault plane is usually at high angles varying from 45° to 60°. The throw of this fault is in most cases difficult to approximate. Nowhere along the western border has the amount of displacement been estimated, but east of Leesburg a fault has brought the Shenandoah limestone to the surface and the displacement along the border must be greater than it is within the area. Keith[32] in discussing the throw of this fault, which he terms the Bull Run fault, says:

> The direction of its throw can rarely be determined on account of the total difference in the ages of the adjacent rocks. In two places a minimum displacement can be inferred with certainty. At Catoctin Furnace, two miles southwest of Mechanicstown, Maryland, a small body of Shenandoah limestone east of the fault lies against the Loudoun slate west of the fault. The east side is, therefore, the downthrow since it contains the younger formation. Again, 4 miles west of Mechanicstown, Shenandoah limestone east of the fault lies against the Loudoun slate west of the fault. Here, too, the throw side is on the east. West of Frederick, Maryland, the Cambrian sequence under the Newark is apparently normal. If there is any fault, it is probably in the form of a slip on the bedding planes of the schist below the Shenandoah limestone. Southwest of Mechanicstown its minimum throw is the thickness of the formation between the Loudoun slate and the Shenandoah limestone, a measure of 2,400 feet. It is probable that this is not much too small, for the fault has a high dip. In no other cases has it been possible to measure the throw.

A throw of 2,400 feet is too much when all the field evidence is considered. It is a little early to bring in the matter of thickness of the Triassic beds, the probable depth of the residual basins, and the order of deposition, but mention must be made here to meet the argument for such a tremendous downthrow. Various geologists in the past have argued that the Border Conglomerate at Leesburg on the western side of the basin is the youngest of the Triassic areas and the quartz phase of this conglomerate on the eastern margin is the oldest. Sections have been measured across the Triassic from Leesburg to Herndon, a distance of approximately 10 miles, and, without taking into consideration the matter of faulting and the duplication of strata, there have been derived enormous thicknesses of the Triassic beds reaching as much as 35,000 feet. How

[32] Keith, Arthur, Geology of the Catoctin belt: U. S. Geol. Survey, 14th Ann. Rept., pt. II, p. 356, 1888-89.

a narrow basin could have received a thickness as great as this can not be explained in such a manner. The two conglomerates on the west and east sides of the basin are not the oldest and youngest Triassic sediments at all, but are contemporaneous in age. There was never a basin of this width deep enough to hold 35,000 feet of sediments. A shallow basin was filled along the sides and bottom by coarse materials close at hand and as the basin was filled up the finer materials worked toward the center. In all probability the basin did not exceed 1,000 feet in depth, and in many places fell far under this; likewise, after the basin faulted, the downthrow did not amount to more than 500 feet, probably less. The matter of position and age relations will be discussed later and this matter of accumulation will be discussed in greater detail.

The contacts of the Western Border fault are better shown in the four areas to the west, as erosion has not progressed to such advanced stage as further east in the Farmville and Richmond areas. The length of this fault is the length of the various areas, and the fault may not be broken between the areas but its continuance was not observed in any way commonly used in detection of faults. This normal fault of the western margin represents the first faulting of the Triassic beds and the other faults within the belts, which are of the block type, are younger. From a standpoint of location this great Border fault system of Virginia stands in contrast to the border fault of the Connecticut Valley in that the latter occurs on the eastern margin. Border faulting in New Jersey, Pennsylvania, Maryland and North Carolina is similar in position to that in Virginia.

INTER-TRIASSIC FAULTS

These faults are grouped together because they occur wholly within the several Triassic areas as seen upon the surface, though very probably they affect the rocks underlying the Triassic basins. Some of them are merely local as the first three, namely, the Leesburg, Harrison and Belmont. Others can be traced for some distance, as they represent boundary lines between various phases of the Border Conglomerate and Bull Run shales, which contact can be explained only by a faulting in which Manassas sandstone which naturally would be in juxtaposition with the Border Conglomerate has either been upfaulted and eroded or downfaulted and concealed. These faults are detected by various means, as slicken-sides, fault breccia, conglomerate-shale contacts, or topographical features such as depressions, and by actual displacements shown by persistent lithologic beds. These faults represent only a small number as compared with those which really exist.

LEESBURG FAULT

The Leesburg fault is named from the fact that it occurs in the limestone phase of the Border Conglomerate exposed in the Leesburg lime quarry within the corporation limits of Leesburg. The strike of this fault is a few degrees east of north and the dip is approximately 56° E. The fissure varies from a few inches up to 2 feet in width and is filled with limestone breccia. Slickensides are shown especially well on the hang-wall, also secondary calcite is very common on this wall and has been deposited in thin scales or crusts. The breccia is cemented together by secondary calcite and silica with a very little ferrous iron. Broken and angular pebbles of limestone from which thin sections were made show evidence of movements.

From the slicken-sides collected from different places over the quarry there is every indication that the motion has been that involved in a reverse fault. The direction of faulting along the western border was downward motion on the hangwall in contrast to the upward motion on the hangwall in the Leesburg fault. This type of block faulting is very common in the various areas and is responsible for the duplication of the Triassic strata. Such duplication was not recognized by the early geologists in Virginia, due to lack of fossiliferous or persistent strata. It was the early custom to regard limestone conglomerate on the west as the latest Triassic formation and to consider that the strata became older toward the east. The conglomerate on the east was regarded as the basal of the series. The horizontal distance was measured along with various dips and the thickness was computed without regard to duplication of strata by faulting or to the way in which the sediments were accumulated, and with no regard to the physical environment of Triassic time. Dorsey[33] pointed out these facts in the Maryland Triassic and they apply not only to that state but to Virginia, North Carolina and all the Triassic of eastern North America, whether the sediments were accumulated under purely residual, swampy, lagoonal, or estuarine conditions.

HARRISON FAULT

The Harrison fault is exposed 1 mile east of Leesburg on the Edwards Ferry road. It is named from Harrison Island in the Potomac River which lies only a short distance north of an abandoned quarry. This quarry was used up to 20 years ago and here the limestone phase of the Border Conglomerate is shown to be resting directly but unconformably upon a dark blue limestone, the Shenandoah limestone. This limestone has been brought up from the bottom of the Triassic basin by faulting of a reverse type. The fault plane is very steep, dipping at an angle of 72° to the east. On the western side of this fault plane the only rock exposed is a few feet of Border (limestone) Conglomerate, in every way similar to that in the Leesburg limestone quarry. On the eastern side of this fault there is an exposure which is as follows:

[33]Dorsey, G. E., The stratigraphy and structure of the Triassic System in Maryland, Dissertation, Johns Hopkins University, Baltimore, Maryland, 300 pp., 1918.

Section 1 mile northeast of Leesburg, Loudoun County, Virginia

	Feet
Soil	1
Conglomerate, small pebbles and bedding planes well developed	5
Conglomerate thick bedded, poor bedding planes	10
Shenandoah limestone, very compact, dark blue color, and homogeneous throughout; exposed 5 feet	5

This fault is local and, like the Leesburg fault, can not be traced more than 100 feet. From all indications the strike is a few degrees east of north and not very different from the Leesburg fault with which in all probability it is parallel and it is certainly not a continuation.

BELMONT FAULT

The Belmont fault is exposed in the Belmont trap rock quarry on the east side of Goose Creek, north of the electric railway and 4 miles southeast of Leesburg. This fault is marked by a great abundance of black and glistening slicken-side material, which fills a fissure of a width from 15 inches up to 3½ feet. This fault is best seen on the east and west walls of the quarry, especially on the east wall. It evidently extended the entire length of the quarry, which east-west distance in the summer of 1920 was 265 feet. The dip of this fault is very steep and to the south and the strike is east and west. This is the only case of an east-west strike observed. There is no way to ascertain exactly how much motion has taken place in this fault but, judging from the abundance of slicken-side material, there has been considerable motion. In thin sections this material shows that extreme fracturing and grinding of the diabase have resulted from the movements. It is made up of the same minerals which compose the diabase and Shannon[34] has described a mineral which he referred to diabantite. A slight topographic depression is noticeable on the surface, as the fault breccia is less resistive to erosion than the unfractured diabase. As far as could be traced this fault is altogether limited to the Belmont stock.

CULPEPER FAULT

The Culpeper fault extends from a point a little north of Rappahannock River to Rapidan River and is broken for a short distance south of Culpeper by diabase. This fault passes to the east of Culpeper and close to the Western Border fault. It is the Bull Run Shale-Border Conglomerate contact in which the Manassas sandstone has been faulted and is either elevated and eroded or depressed and concealed. The shales form the hangwall and the conglomerate the footwall. Such a sharp change from the fine to medium grained shales to the very coarse conglomerate can be explained by no other means than faulting. South

[34]Shannon, Earl V., op. cit., pp. 50-51.

of Culpeper the shale-conglomerate contact is replaced by the diabase-conglomerate contact and this continues nearly to the Rapidan River where the red and gray shales appear again. Whether this diabase in contact with the Border Conglomerate represents a fault it is not possible to say, as no evidence is available. It is quite likely that it does and that the diabase came up along the fault plane; that the red shale has been eroded in some places, while the gray shale is due to alteration of the red shale by the diabase. South of Culpeper the Border Conglomerate contains a mineralized zone from its contact with the diabase and a small pit opened some years ago shows the conglomerate with small amounts of specularite, chalcopyrite, azurite and malachite in the matrix. This fault is extremely peneplained and nowhere is it possible to get the dip of the fault plane, or any fault breccia or slickensides.

RACCOON FORD FAULT

The Raccoon Ford fault represents the shale-conglomerate contact which extends along the southeastern portion of the Potomac area in Culpeper County. It parallels the Rapidan River and is approximately 5 miles in extent. The strike is northeast and the dip is 45°-50° to the southeast. The shale is mostly red but there occasionally occurs some gray shale caused from diabase dikes. Here the conglomerate is the best developed on the eastern side of the Potomac area south of Herndon, and in all its physical aspects it resembles the conglomerate forming Cedar Mountain on the western side. The shale-conglomerate contact is a very significant one and shows up well as this region is not so peneplained and is cut through by Rapidan River which flows in a northeast direction.

LIBERTY MILLS FAULT

The Liberty Mills fault extends in a northeast direction from Liberty

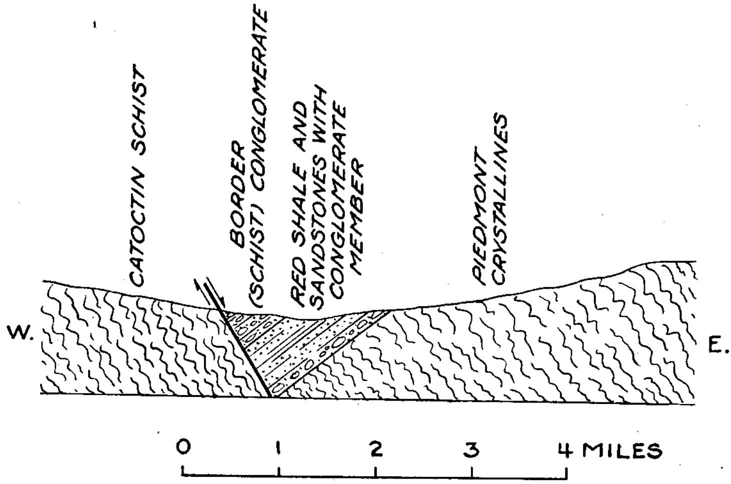


Figure 3. Cross section of Triassic through Somerset, Orange County.

Mills to the southern end of the Potomac area, a distance of from 2½ to 4 miles, and represents the contact between the red shales and the conglomerate. In some few places, however, sandstone comes in and makes the natural sequence in the strata, namely conglomerate, sandstone, and shale. This fault bears the same general relations in the southern portion of the Potomac area that the Culpeper fault bears further north and they may be parts of the same fault, though it has not been possible to trace such a fault over the intervening space.

GLENDOWER AND HOWARDSVILLE FAULTS

The Glendower fault is well exposed in the northwestern portion of the Scottsville area near Glendower where the very coarse conglomerate is in juxtaposition with the fine Bull Run shale. This fault extends in a northeastern direction over a distance of 2½ miles. In several places it shows slicken-sides and leaves topographic expression of its existence. The steep hills of the Border Conglomerate are replaced by the low hills and flat lands of the Bull Run shales, sometimes within a distance of one-fourth of a mile.

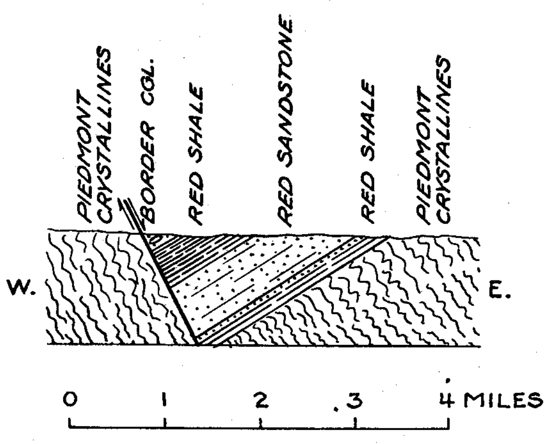


Figure 4. Cross section of Triassic through Howardsville, Albemarle County.

The Howardsville fault extends east of the town of Howardsville in the southwestern portion of the Scottsville area and its length is approximately 6 miles. Its direction of extent is the same as that of the Glendower fault, and these two faults in the Scottsville area bear the same general relations as do the Liberty Mills and Culpeper faults in the Potomac area. All four of these faults have the same strike and are in line with each other. The Howardsville fault shows in two places the development of fault breccia and slicken-sides and there is a rather abrupt change in the topography from the coarse Border Conglomerate and the fine Bull Run shale. South of Howardsville the James River has eroded the soft shale and has formed high bluffs out of the hard conglomerate. The high hills from 200 to 250 feet above the James River at Howardsville are composed of Border Conglomerate and all the low land south of the river is Bull Run shale with intercalated Manassas sandstone.

WHITE OAK MOUNTAIN FAULT

The White Oak Mountain fault occurs in the Danville area and is first seen south of Roanoke River, just across the river from Long Island Station. It extends along White Oak Mountain, sometimes on the east, sometimes on the west flank, and west of Danville it is well exposed on the summit. It is represented in two distinct ways, namely, first by the conglomerate-shale contact and secondly by a granite-gneiss and shale or conglomerate contact.

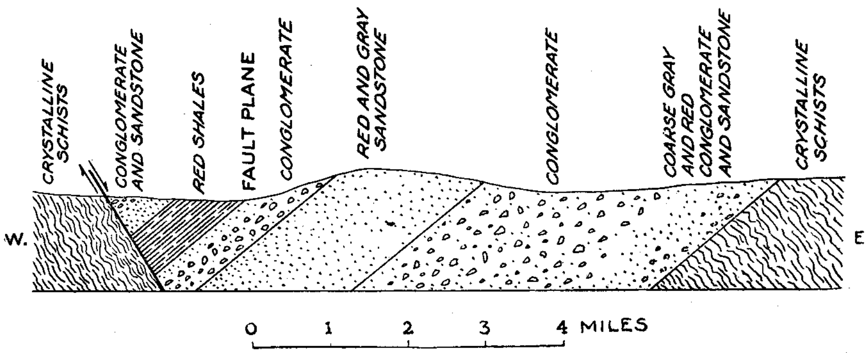


Figure 5. Cross section of Triassic across White Oak Mountain, 5 miles south of Chatham, Pittsylvania County.

It is very probable that this fault extends northeast and ties on with the small displacement in the Norfolk and Western Railway cut 2 miles southeast of Gladys. The fault has a general bearing of N. 30° E. and is easily recognized. East of Mt. Airy the fault shows slicken-sides developed on the shales and a distinct absence of sandstone. Southeast of Chatham it shows both a conglomerate-shale contact and a gneiss-conglomerate contact and considerable displacement is suggested here. White Oak Mountain is much peneplained west of Danville and along its crest granite-gneiss frequently outcrops, with Triassic conglomerate and shale both to the east and the west. Between Oak Hill Station (Wenonda P. O.), on the Danville and Western Railway, the Border Conglomerate is in immediate contact with highly indurated Bull Run shales. This fault extends for something like 30 miles and the fact that it has brought the underlying rocks of the Triassic basin to the top of White Oak Mountain is a proof of the enormous displacement. Dan River, cutting across the Triassic, has concealed the fault near the North Carolina border, and this is especially true south of the river.

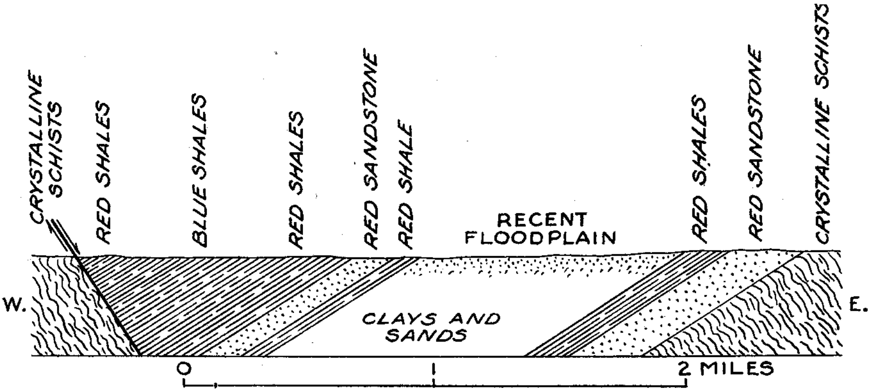


Figure 6. Cross section of Triassic along the Danville and Western Railway, Danville area.

FARMVILLE FAULT

The Farmville fault is exposed at two places northwest of Farmville in Cumberland and Buckingham counties. On the W. W. Jackson property, 1 mile northwest of Farmville, the basal Border Conglomerate has been brought to the surface, and resting upon it on the east side of the fault are Manassas sandstone and Bull Run shales. On the west side of the fault is Bull Run shale. The amount of displacement is not very great for the basin was shallow. The same relations exist north of this point and the underlying granite of the basin is brought to the surface. The strike of this fault is a few degrees east of north. The dip is steep, varying from 60° to 70°. Slickensides occur at both places. Peneplanation is more pronounced in the Farmville and Richmond areas than in the western areas, and this increases the difficulty of detecting faults and contacts. The distance between the two points of faulting is approximately 4 miles and, since the relations are similar and one is in line with the other, they were regarded as one fault.

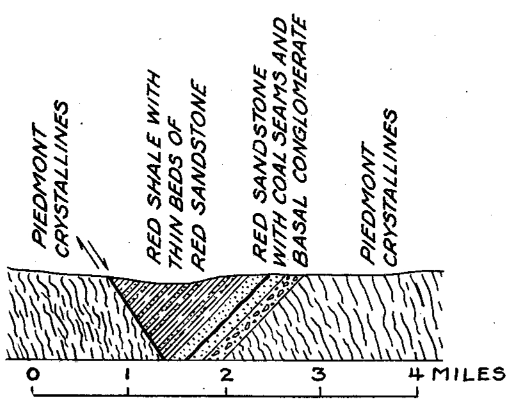


Figure 7. Cross section of the Triassic in Farmville area north of Farmville.

OTTERDALE FAULT

The Otterdale fault occurs near the central part of the Richmond area and the best exposures are on the property of Warren Morrisette 6 miles south of Otterdale and 1 mile west of Coalboro. In the first instance the basal conglomerate has been brought to the surface with the sandstone and red shales resting upon it. On the east side of the fault this three-fold series occurs but on the west side red shale outcrops. The underlying granite gneiss is exposed on the surface 6 miles south of Otterdale, and on the east side of the fault red shale is found, on the west side red sandstone. Intruding this light colored granite-gneiss and exposed along with it is a small diabase dike. Granite and granite-gneiss boulders of very large size occur for half a mile and mark the strike of the fault. It is not possible to determine either the dip or displacement of this fault.

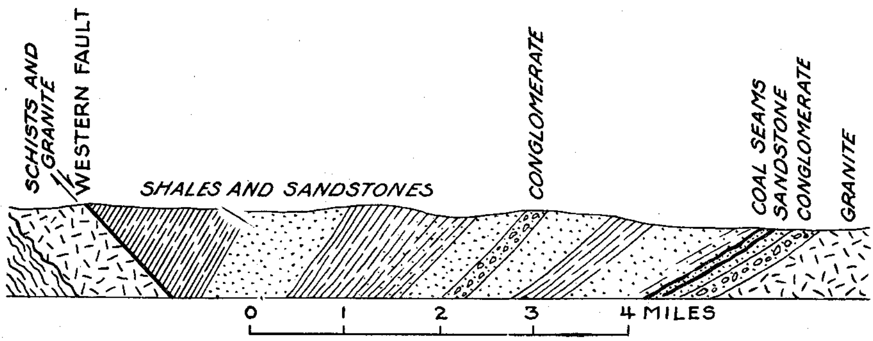


Figure 8. Cross section of the Triassic through Midlothian and Otterdale, Richmond Basin.

BOSCOBEL FAULT

The Boscobel fault is certainly the unique Triassic fault. It occurs on the western side of the Richmond basin in Goochland County as shown in and near the Boscobel stone quarries. The underlying granite and granite-gneiss of the basin have been brought up by a fault and outcrop on the north bank of James River. On the east side of this mass Manassas sandstone occurs with a little shale and outcrops all along the James River bluff and the old Chesapeake and Ohio canal down to Vinton Station on the Chesapeake and Ohio Railroad. Overlying this sandstone is the very thin bedded Bull Run shale. Red shale outcrops on the granite rocks to the west of the quarries and also to the north. The amount of displacement must be rather great here to bring up rocks underlying the basin but not as great as the displacement 6 miles south of Otterdale which is near the center of the basin. In both of the quarries east of Boscobel Station a number of small fault planes occur in the granite and granite gneiss and slicken-sides are well developed. It is not possible to measure the fault plane dip or the amount of displacement except to say that the latter is most likely equivalent to the depth of the basin at this point.

There are many localities showing fault breccia and slicken-sides. Much of both the red and the carbonaceous sandstone and shale on the many coal dumps shows slicken-sides. Faulting has taken place across the basin at many places, and in the majority of cases this has been concealed by peneplanation. Many of the older investigations for coal, both north and south of James River, report faulting as one of the serious difficulties in coal mining. From all indications the amount of displacement has been considerable and the fault dip is high. Small displacements are common to the shales.

Miss Anna I. Jonas, who has been studying faults in the Piedmont region, has traced certain ones across the Triassic areas and such faults are shown on the Potomac area coursing in east-west and northeast-southwest directions.

BEDDING PLANES

Bedding planes are rather poorly developed in the conglomerates and the smaller the pebbles the better the planes appear. The trap phase of the conglomerates shows these planes best in the quarries south and west of Culpeper. The limestone phase of the Border Conglomerate shows occasional planes north of Leesburg, especially where the boulders are not large. The conglomerates in the Farmville and Richmond areas contain smaller pebbles and boulders, and bedding planes are well developed.

Manassas sandstone and Bull Run shale show excellent bedding planes in nearly every exposure. Sandstone may be relatively thin bedded, and sometimes it is so massive that it shows few such planes. These planes may be anywhere from a fraction of an inch up to 4 feet apart. The sandstone quarried from the Portner and other quarries in the vicinity of Manassas shows bedding planes ranging from 6 inches up to 2½ feet apart. The thickest bedded sandstones occur in an abandoned quarry 1 mile south of the junction of Blue Run and Rapidan River, along White Oak Mountain south of Chatham, and on the eastern margin of the Richmond area underlying the coal measures.

Shales vary from very thin, fissile deposits to those which measure 3 inches thick. They may be very brittle and split along the bedding planes easily. The blue shales are almost slates and cleave very evenly when unweathered. Many exposures show the shales with intercalated sandstone and give the effect of wide variation in the phenomenon of bedding.

The dip of all the bedding planes is west or northwest except in those cases where faulting or intrusions have interfered. The strike of such planes varies from a few degrees west of north to a few degrees east of north. The beds may be horizontal, but no anticlinal structure is exposed anywhere. A very gentle and small syncline occurs north of Mount Pony.

JOINTING

Jointing is not confined to any particular group of the Triassic rocks and sometimes is better developed in diabase bodies than in sandstone and shale. In the sedimentary series jointing is closely tied up with the strike and dip of the beds. The prevailing direction of the major system of joint planes is the same as the strike of the beds in all the areas. This jointing is strongly pronounced in all the shales and nearly all the sandstone. There is a minor system of joint planes which extends in a northwest-southeast direction approximately at right angles to the major system. These two systems, when occurring together, make quarrying simple, as blocks can be taken out in a rectangular shape. Jointing is very sparingly developed in the conglomerates. The ideal place to observe jointing in the sedimentary series is the abandoned Southern Railway quarry 2½ miles southwest of Bristow, Prince William County. Not only is the phenomenon of jointing shown in this quarry but horizontal bedding and fossil trails are equally well shown. Occasionally one sees an oblique system of jointing which runs in a northeast-southwest direction. The joint planes of the shales persist for some distance, more markedly so than is the case in the sandstones. Some of the joint planes in the red shales are filled with secondary calcite, barite, and copper salts in very small amounts.

Jointing in the diabase bodies is better developed in the fine grained to dense varieties, but common in the coarse to medium textured rocks. The Belmont and Sterling stocks show two systems of jointing, in one system of which the strike is either a few degrees east or a few degrees west of north, and the dip is steep and ranges around 60°.

Another system of jointing occurs approximately at right angles to the above north-south system, and its average direction of extent is N. 65° W. The dip is steep and to the northeast. Shannon [35] says this east-west break is a fracture rather than a joint system, and he gives as his reason that the breaks are spaced too far apart to be a jointing system.

Both systems of joints are characterized by a very brilliant black diabantite coating and there has been some movement possibly along some of the breaks. In all probability the jointing in the rocks is the result of consolidation rather than solely of movements taking place in the underlying basin. The writer was unable to determine whether both systems were or were not of the same age.

The Mt. Pony diabase stock does not show any pronounced jointing but it is fairly well developed in the Buzzard Mountain stock. Two systems of jointing are found in the Buzzard Mountain stock, the main system running N. 15°-20° E., and the other N. 40°-50° W., each dip-

[35]Shannon, Earl V., op. cit., p. 7.

ping at comparatively steep angles. Jointing is not so well brought out here as in the stocks further north.

One excellent feature shown in the Buzzard Mountain stock, which was observed nowhere else, is masses of irregular light gray diabase in medium to dark gray rock, which may be termed "schlieren." These masses may range from a very small size up to 10 feet in length. Their irregularity is quite pronounced and boundary lines are very sharp and distinct. Thin sections across the boundaries of this schlieren show the principal difference to be a lower percentage of pyroxene and hornblende, consequently making the plagioclase feldspars higher in amount.

In the dense or aphanitic diabases or basalts jointing is more prevalent than anywhere in the igneous rocks. There are two systems of jointings, one of these parallel to the strike, the other at right angles to it. In the small dikes rectangular pieces of the diabase weather out and resemble the brown sandstone.

FORMS OF IGNEOUS ROCKS

Throughout the Virginia areas at least three forms of Triassic diabase occur, namely, stocks, dikes and sheets. It is entirely possible that the Mt. Pony and Buzzard Mountain masses instead of being stocks may be laccoliths. The writer, in company with the late Thomas L. Watson, examined the two localities during the summers of 1922 and 1923 in an effort to determine the form of these masses. The sediments show profound disturbance on the west and north flanks of Mt. Pony but there is nothing abnormal on the other portions. Around Buzzard Mountain the sediments dip to the west without an observed interruption. The conclusion reached was that without the shales and sandstones dipping away from the masses as a result of having been pushed up by the body, it could not be regarded as a laccolith in spite of the fact that it does have the form and other marks of such a body.

STOCKS

There are two stocks of enormous size in the northern portion of the Potomac area, the Belmont and Sterling stocks. The Belmont stock covers a large area, the major axis of which extends northwest between Centerville and Leesburg, and its width reaches as much as 6 miles in places. The stock is shown in the Belmont quarry on Goose Creek better than in any other locality, and can be traced over the surface by the enormous boulders and flat exposures of rocks. In the vicinity of Arcola (Gum Spring) the enormous boulders and ledges of diabase recall the Devil's Den and Little Round Top on the Gettysburg battlefield, which are Triassic diabase.

The Sterling stock is much smaller than the Belmont and is oval-shaped in its exposure with its main axis east and west. It shows the macrocrystalline texture typical of the Belmont stock with no disturbance of the shales and sandstones adjacent to it. It has produced alteration on some of the shales on the west side.

Both the Belmont and Sterling stocks show from their alteration upon the shales that they are much younger than the youngest member of the Triassic. These two bodies of diabase resemble each other in every way except in shape and size, and they leave no doubt as to the form. Pegmatites are present in both of them. They are alike affected by block faulting and help place the age of such, since their formation is later than the youngest Triassic accumulations. They do not show crescent forms as do the diabase bodies in New Jersey and the Connecticut Valley.

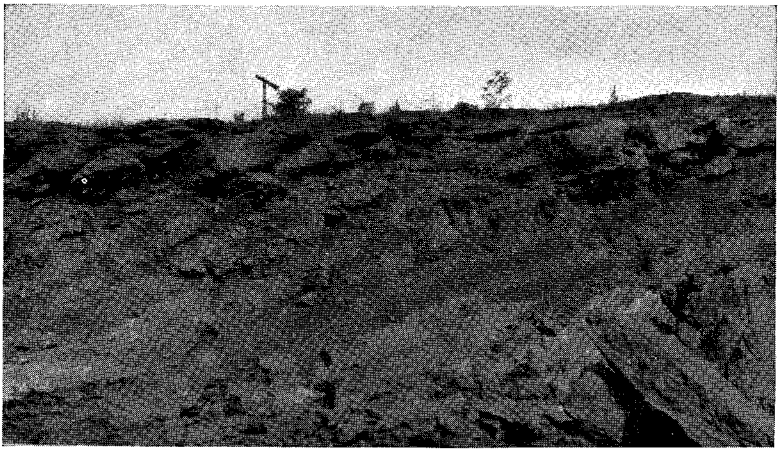
The Mt. Pony and Buzzard Mountain stocks in some way resemble the two previously named stocks, but they have far more points of contrast. Both of these stocks are oval to round in shape with their major axes running transversely in the Mt. Pony and parallel to the strike of the sedimentary rocks in the case of the Buzzard Mountain stock. The texture is fine to medium and no pegmatitic texture occurs. The masses present evidence of very different cooling conditions as well as different chemical conditions of the magma as compared with the Belmont stock.

These two forms closely resemble laccoliths in their form, texture and topographic relations. They are conical and have either been intruded towards the top of the Triassic shales and sandstone, or erosion has left them as monadnocks, or they may have been elevated as the country was being peneplained. Cedar Mountain, which lies southwest of Mt. Pony and is composed of basal Triassic conglomerate, has an elevation almost equal to Mt. Pony and as great as that of Buzzard Mountain. It is undoubtedly a product of erosion and this suggests that these two peaks may have been the result of erosion. They certainly give the impression of laccoliths and upon further investigation may prove to be of this form.

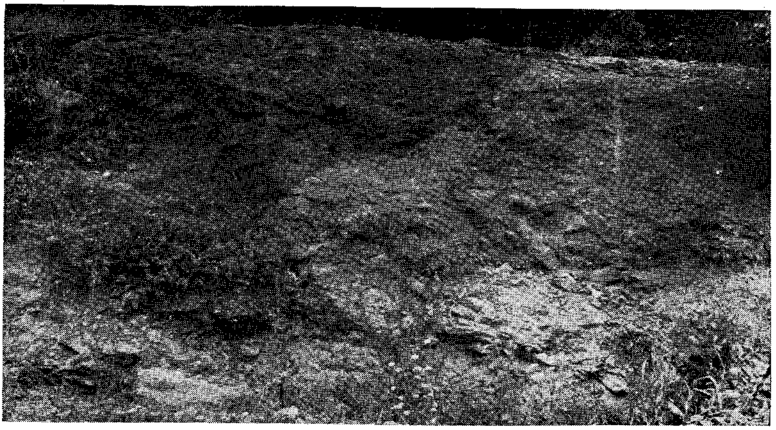
DIKES

Dikes comprise the great bulk of diabase in the Triassic areas, in fact they are the only forms of diabase seen in the Scottsville, Danville, Farmville and Richmond areas. They are usually narrow bodies and their width decreases toward the south. In the Potomac area they reach upwards of a mile in width at times but usually are less than half a mile. They can often be traced for 20 to 60 miles and may cut across or follow the general strike of the sedimentary beds. In the Farmville and Richmond areas, however, erosion and peneplanation have progressed so far that tracing the dikes is extremely difficult.

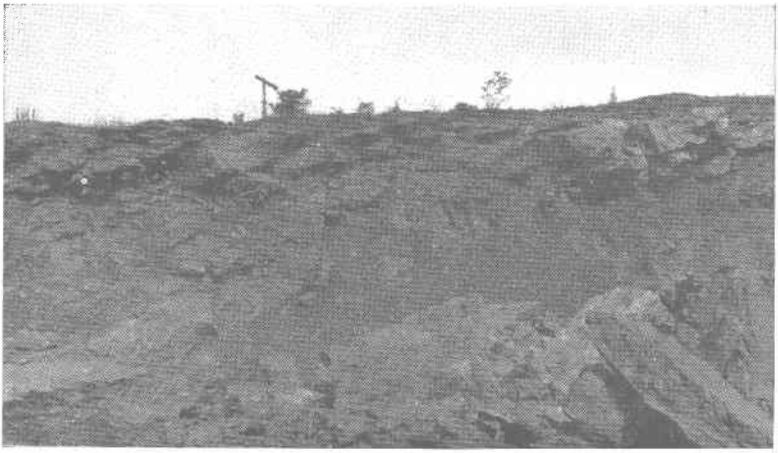
Along the Prince William-Fauquier county line three dikes occur with the Rappahannock River cutting across all of them. There are 9 dikes mapped in the Potomac area and many are too small to be mapped. Judging from surface indications of the present day, diabase intrusion appears to have been far more intense in the Potomac area than elsewhere in



A. View of the Border Conglomerate (trap phase) 1 mile southwest of Culpeper, Culpeper County, showing the development of bedding planes.



B. View of the Border Conglomerate near Scottsville, Albemarle County, showing the massive nature.



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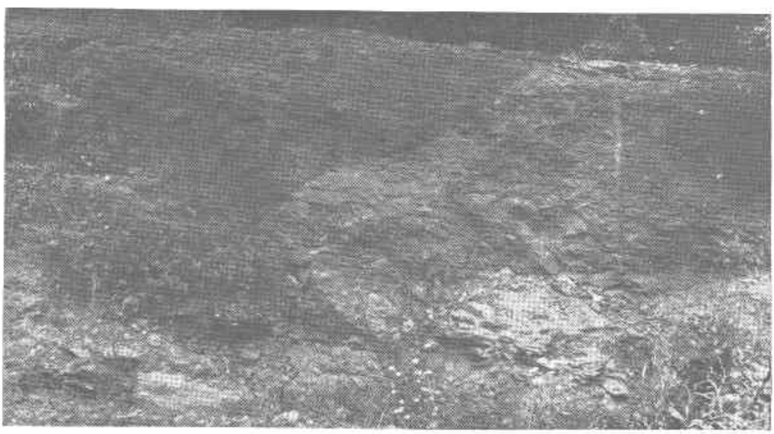

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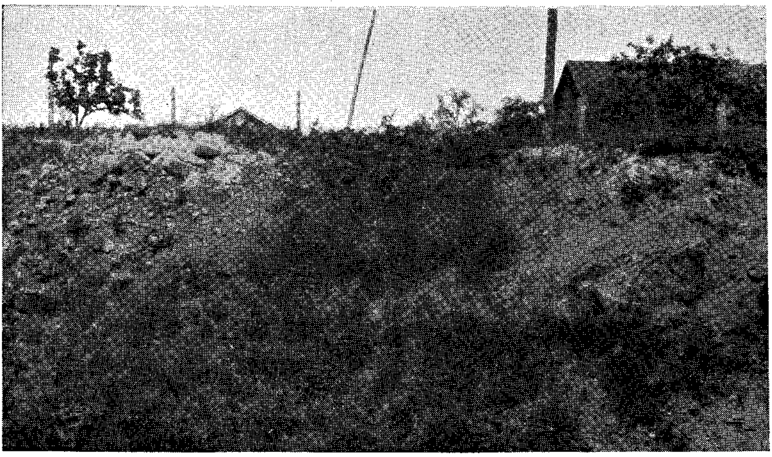
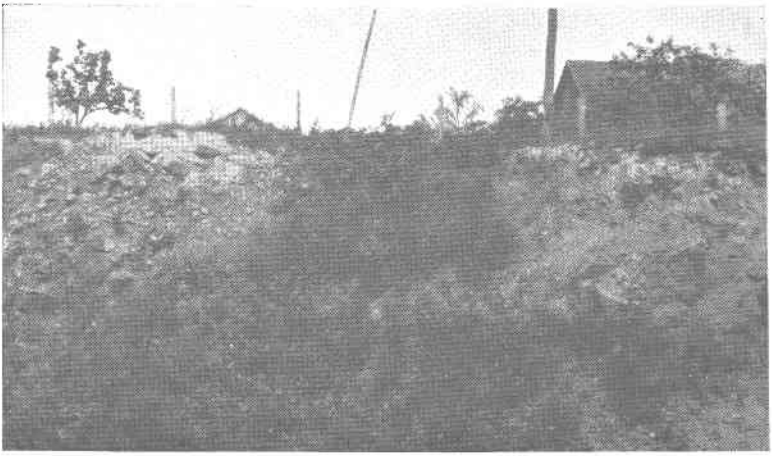


A. View showing outcrop of a small aphanitic dike in the railway cut west of Ashburn, Loudoun County.

B. View showing jointing in a diabase dike, 2 miles north of Warren, near Boiling Springs flag stop, Albemarle County.



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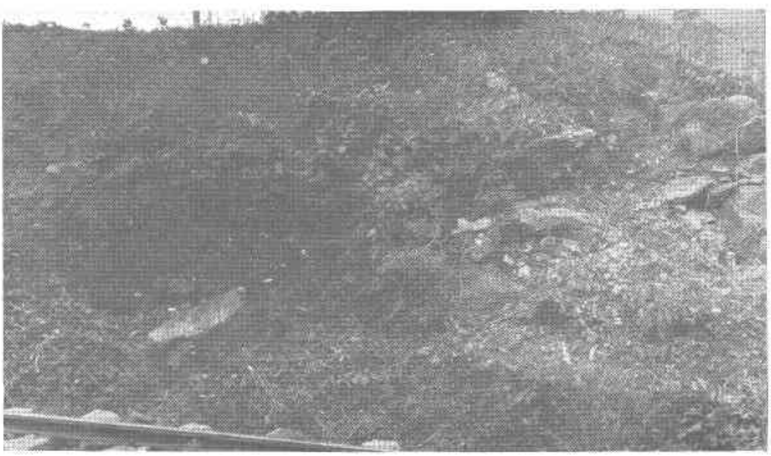


B. View showing jointing in a diabase dike, 2 miles north of Warren, near Boiling Springs flag stop, Albemarle County.

Virginia during the Triassic. No dikes have been located in the southern extension of the Potomac area or cutting the adjacent rocks nearby and only one dike cuts the Scottsville area, though there are three to the east and two to the west of this area. One long dike cuts across the Danville area into the crystalline rocks and is traceable over a distance of 60 miles; in this area there are at least four other dikes but they are small and so broken in their exposures that tracing them for anything like 5 miles is not possible. The longest and best developed dike showing on the surface in the Richmond area is less than 5 miles long. The dikes must be somewhat numerous from their effects upon the coals along the eastern border of the basin.

Everywhere the dikes are fine grained in texture and the smaller the dike the finer the texture, though some few exceptions occur. The rocks of the small dikes are called basalt. These aphanitic bodies are dark gray to dull black and have every appearance of diabase. None of the larger dikes show plagioclase or augite crystals which exceed 2 millimeters in length.

The strike of the dikes may be north, northeast, northwest or east. The only case of the latter strike is near Boiling Springs in the Scottsville area. A few of the dikes in a small portion of their extent are crescent. Sometimes dikes follow along bedding planes and separate shales, and occasionally they show conglomerates on one side and shales on the other. They have intruded all three of the Triassic sedimentary series and the adjacent rocks of both igneous and metamorphic classes.

SHEETS

Diabase sheets are the most difficult of all the forms to locate and the only one which shows for any distance is south of Mitchell Station in Culpeper County. This sheet is an intrusive one since it shows alteration upon the superjacent and subjacent shales. It is very thin and has the same dip and strike as the enclosing strata. It is fine to dense in texture and possesses jointing to a very marked degree. Some other sheets occur east of Brandy Station in Culpeper County but they do not outcrop over a very large area. The matter of diabase sheets is a very unsatisfactory problem in the Virginia Triassic, for while one is quite certain that they exist, they are, in most cases, not exposed. With conditions during Triassic time so similar from Prince Edward Island to the North Carolina-South Carolina border and the great number of extrusive and intrusive sheets common in New England and New Jersey, but poorly developed in Virginia, it is quite certain that one is justified in expecting to find them in the State and is at the same time at a very great loss to explain their scarcity.

THICKNESS OF THE TRIASSIC SYSTEM IN VIRGINIA

No little has been written regarding the thickness of the Triassic system in eastern North America. This subject received the attention of Hitchcock, Dana, and others in their study of the Triassic of the Connecticut Valley, and from their time on the matter has received the attention of those studying the field relations in New Jersey, Pennsylvania, Maryland, and Virginia. Enormous thicknesses have been assigned for the belt of red beds, some estimates reaching well above 20,000 feet.

When the methods by which such great thicknesses were derived are considered, one is not so surprised at the size of the figures; but when a thickness of from 20,000 to 34,000 feet of conglomerates, sandstone, and shale is estimated for a basin whose maximum width is only 15.6 miles, one is at a loss to understand such an estimate, inasmuch as nothing like this is going on anywhere at present. Something is fundamentally wrong with the methods that produce such figures and the error is due to a misinterpretation of the origin of the Triassic system and the part which block faulting has played in duplicating the strata. Take for example the widest cross section in the Virginia Triassic, namely, from Leesburg in Loudoun County to Herndon in Fairfax County, a distance of 15.6 miles or 82,370 feet; and take the various dips for the strata, say 10°, 20° and 25° W. for these dips, if one follows the old method of regarding the quartz phase of the Border Conglomerate at Herndon as basal and the limestone phase of the same conglomerate at Leesburg as the youngest member of the Triassic, the thicknesses for the foregoing dips are respectively 14,000, 25,000 and 34,400 feet. Certainly these estimates of dips are not extreme as the many measurements taken in the field average around 20°. Even with a 10° dip how could such a thickness as 14,000 feet have been deposited in a basin 15.6 miles wide? The question which presents itself is where are there today any basins of such widths with a depth of 14,000 feet or more. As a matter of fact, the two conglomerates, one at Herndon and the other at Leesburg, are of the same age, and the Triassic sediments which accumulated under residual conditions were deposited in narrow and shallow basins such as existed on the eastern foothills of the Appalachian Mountains during Middle and Upper Triassic time. The youngest sediments filled the middle portions of such a basin near the close of accumulation, and this fact must be considered when computing thicknesses. Evidences for terrestrial source of the Triassic sediments will be discussed under the subject of Triassic environment.

The second factor, which must be considered in the estimation of the thickness of the Triassic sediments is that of faulting. In crossing any portion of any of the Triassic belts, one or more faults extending approximately parallel with the area will be recognized. In the absence of persistent or fossiliferous strata, the problem of locating the faults becomes difficult and the tracing of them for any distance impossible. In a few regions in crossing the Potomac belt as many as four faults occur. These faults have duplicated the strata many times. In the measurement of horizontal distance, and not taking into account this duplication by faulting, the same strata are measured several times and, therefore, great thicknesses result. The error involved in not accounting for duplication by faulting, coupled with the regarding of the easternmost beds as basal and the westernmost ones the top, rolls up figures out of all reason.

With the present data there is no method by which the thickness may be had. Of course, much of the original material has been carried away in the process of peneplanation and the original thickness will always remain problematical, but if all the faults could be located and their dip and displacement known, the present day thickness could be closely estimated. It is hardly probable that the depth of the various basins which existed along the eastern foothills of the Appalachian Mountains in Triassic time were much over a thousand feet deep, if that much. Presumably highlands existed on both sides of these basins, the highest ones on the western margins. From these highlands various dynamical agents eroded, transported, and deposited the conglomerates, sandstones, and shales, so that the basins were well towards level about the close of Triassic time with the largest sediments, the conglomerates, on either side, the sandstones next towards the middle, and the finest sediments, the shales, in and near the middle of the basin. When such a basin as this was lowered on the west by normal faulting and repeatedly faulted and strata duplicated, it is not strange that the early geologists and the casual observer of today should look upon the Triassic beds as being of enormous thickness. It is extremely doubtful if the original thickness of the red beds ever reached as much as 2,000 feet and a range of 1,000 to 1,500 feet is more in harmony with conditions as they exist today and the environment of Triassic time which is interpreted from features remaining in the beds at the present time. The reader is referred to the closing portion of this report which deals with environment of Triassic time as read from fossil life and the character and distribution of the sediments.

LOCAL METAMORPHISM

The intruding diabases in all their forms of stocks, dikes, and sheets show more or less metamorphism upon the conglomerates, sandstones, and shales of the Triassic as well as upon the adjacent igneous and crystalline rocks. The limestone conglomerate in the vicinity of Leesburg shows profound alteration, due to its contact with the Belmont stock. The conglomerate, in both pebbles and matrix, has lost all its color nearest the stock, and some of the limestone has been recrystallized and contact minerals formed. East of Leesburg on Goose Creek, a short distance north of the Leesburg-Washington pike, the Belmont stock has intruded the limestone phase of the Border Conglomerate and formed pyrite, chalcopyrite, calcite, quartz, epidote, garnet and a few other minerals of the contact metamorphic class. By intrusion of the trap phase of the Border Conglomerate south of Culpeper, specularite, pyrite, chalcopyrite, calcite and other minerals of copper have been formed. Profound changes upon the intruding diabase have resulted also, as evidenced by the dense texture and fragments of the intruded rock often included with the diabase, and masses of the diabase were pushed out into the sedimentary rocks.

The stocks have caused the most spectacular and profound changes in the dip and strike of the shales and sandstones. Such evidence is seen north and west of Mt. Pony and the strike at places assumes an east-west direction and the strata dip to the north. Often the sandstones and shales have undergone a change of color and advanced considerably in brittleness. This color may be a dull gray, dove, or yellowish gray. Increased brittleness may not be accompanied by any change of color. The sandstones may be so highly indurated that they are almost quartzites and the shales border on slates.

The dikes show more vivid effects upon the sedimentary rocks than the stocks and also they themselves are more affected by alteration than are the stocks. The dikes may be parallel with the general strike of the sedimentary series or they may cut obliquely or directly transverse to the strike. They cut all three of the formations. The conglomerates, however, are the least affected of the sedimentary rocks. The sandstones and shales bear certain definite changes when traced away from the dike contacts. These changes may be any one or all of the following, namely, increased brittleness and induration, partial or complete loss of color, change in strike and dip, development of fracture, and formation of minerals.

Increased brittleness in the shales is to be observed in the majority of cases, and usually along with this change is a change in color. The distance away from the dike over which alteration extends varies somewhat, but more generally the average is around 20 feet, higher of course in case of the stocks. The change in color, that is from a red to a lighter tone, is due to the conversion of the ferric oxide which coats the grains and is scattered through the matrix into magnetite. Instead of this uniformly disseminated ferric or red oxide, there occurs in clusters or well disseminated the black iron oxide, giving a gray color to the rock. Thin sections made from specimens taken from various intervals from the altered to the original shales and sandstones show these changes.

One of the most outstanding of all dike alterations is the formation of natural coke or "carbonite" in the Richmond area. Small dikes have intruded the coal beds and the heat from these bodies of rocks has coked the coals. Quite a considerable amount of this natural coke has been mined in the Richmond area and it is known to occur in the Farmville area. The coke is porous and of low specific gravity closely resembling the product from the coke ovens.

The dikes in the majority of cases show a great change in texture, especially if they are large. The small dikes are always of an aphanitic texture and deserve the name of basalt rather than diabase. In the case of large dikes, that is those of a hundred feet or more in width, the texture of the rock on the periphery is dense and that toward the central portion is crystalline. An increase in size of grain is apparent from the periphery inward, also on the periphery vesicular structure due to the sudden cooling of the dike on flowing out into the cold sedimentary rock is often observed. It is surprising sometimes to find small dikes coarsely crystalline but this is true in the basic rocks and not so common in more acidic ones.

The dikes have had profound influence upon the adjacent rocks of the various Triassic areas and such alteration is best seen in the Danville, Farmville and Richmond areas, where granites and granite-gneisses have been intruded. The metamorphic changes are those of mineral composition and color and extend outward a comparatively short distance.

The intrusive sheets near Mitchell and Brandy stations show a change of color and increased brittleness in the sandstones and shales, and the former have been altered into a very light gray quartzite or a sandstone so highly altered that for all practical purposes it may be called a quartzite. Jointing and fractures are very prevalent and it is a difficult matter to make out the individual sand grain with the unaided eye.

ECONOMIC GEOLOGY

The mineral resources of the several Triassic areas in Virginia, except for the item of coal, are very similar to those of the entire eastern North America. There are only two kinds of material which have been developed to any extent, namely, coal and stone, and these in a rather limited way compared with the natural resources of other geological horizons in the state. There are, however, a number of metallic and non-metallic minerals in the Triassic, but these are only of scientific importance, even though some of them have been extensively investigated and unsuccessfully exploited. The coals limited to the Richmond and Farmville areas have been mined for short periods over a long stretch of time and the output has never been large. By far the most continuously exploited product of the Triassic is the stone though we have no definite record of when this development began. The same type of stone quarried prior to the Civil War is no longer quarried today, but as the use of red sandstone was discontinued diabase and various phases of the Border Conglomerate have been produced, thus giving stone a continuous period of production:

COAL

The Triassic coals of the North American continent occur in Virginia and North Carolina, and in both states they are limited to the basins lying furthest east and not to any extent in those areas near the Blue Ridge in the Piedmont section which are chiefly of residual origin. The Triassic coals in Virginia were first investigated in the Richmond Basin and from this area the first coals are said to have been mined. N. J. Nicolls in "The Story of American Coals" states that the Richmond coals were worked as early as 1750. The earliest accounts of the Virginia Triassic dealt with the coals of the Richmond Basin. McClure's map of 1817 showed the extent of the Richmond coals as then understood. Nuttall, Sternberg, Brongniart, Fontaine and Heinrich called attention to the fossil floras of the Richmond basin during the early part of the last century. In 1839 W. R. Johnson made a report in which he described the coal from near Richmond which was used in foundries in the manufacture of cannon as early as Revolutionary times. Coal was shipped from Richmond to Philadelphia and New York during the early part of the 19th century, but there is no accurate record of the total production from 1770 to 1925. The Triassic coal statistics are grouped with those of coals of the Pennsylvanian and there are no available figures which deal solely with the Richmond area, except from 1842 to 1877.

HISTORY OF MINING OF THE VIRGINIA TRIASSIC COALS

The best report of the early mining in the Richmond Basin is given by O. J. Heinrich who at one time was a superintendent of the mines at

Midlothian. Colonel Byrd reported the occurrence of coal near Richmond to the Colonial Council of Virginia on May 10, 1701. The most dependable records show that the first continuous mining was somewhere between 1770 and 1780 with no complete figures of production. An old arsenal (Belona Arsenal) on the James River, 14 miles west of Richmond, and another arsenal west of Huguenot Springs date back to Revolutionary times as well as Civil War days, and Triassic coal was used in both. Much of the coal was used locally for domestic purposes. The first period of activity may be said to extend from the earliest workings up to about 1840, prior to the mine activity of Civil War times. The output of coal prior to 1840 was probably greater than 250,000 tons.

A second period of activity began in 1842, or thereabouts, continued through the Civil War period and up until the close of the seventies when the Midlothian and Gayton mines were in their zenith of investigation and exploitation. Today the abandoned and timeworn huts, commissaries, and offices bear evidence of this. The stone and brick buildings of the Midlothian vicinity, some of which are still standing, were constructed at this time. The first period was marked by shallow workings along the eastern margin but during the second period these workings were transformed into deep shafts and inclines. Some of the drillings went downward 2,000 feet and some of the mines were over 800 feet deep. Coal mined during this period (1842-1880) was used locally and much of it shipped, and the production was far greater than that prior to 1842. It was during this second period that drilling and other investigations went on at two points north of Farmville.

The third period of active mining had its inception about 1890 and 1895, during which time the mining interests centered around Winterpock and Midlothian, Chesterfield County. During this third period the Farmville and Powhatan Railroad was built from Farmville through Winterpock to Bermuda Hundred on the James River which proved a great convenience to the mining industry. The Gayton mines north of the James River and on a branch line of the Chesapeake and Ohio Railroad, had already changed hands and closed down, as well as the mines around Manakin (Dover). No very large production was realized during this third period. Work continued until the World War which gave a slight impetus to mining in the Midlothian vicinity. The Murphy Coal Corporation of Richmond acquired considerable coal property east and south of Midlothian and began operating about 1920. During the year 1923 this company mined approximately 50,000 tons. During this third period mining has been carried on in a much more modern way than heretofore from the standpoint of ventilation and general safety conditions and no mine accidents occurred such as took place during the second period, though it must be stated that far fewer men were employed as compared with the second period. Thus the activity in the Richmond Basin naturally divides itself into three distinct periods which may be stated roughly as 1701-1840, 1842-1880, and 1885 to the present.

SIZE OF THE COAL AREA

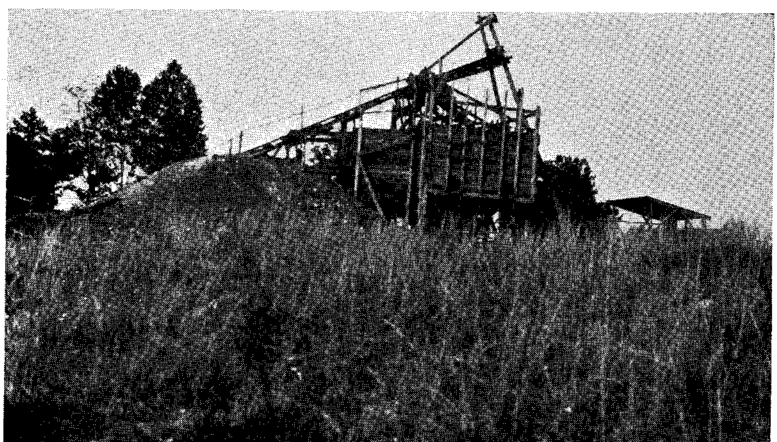
The Richmond area contains approximately 150 square miles and the Farmville area 40 square miles. There are no available data for determination of the approximate part of either of these areas which is underlain by thin or even workable seams. Such determination would require systematic drilling, and what drilling has been done so far has been limited largely to the eastern margins of both areas. Coal outcrops occur along the east side of both areas and have been mined north and south of Midlothian for a number of years. Some writers claim that the Richmond Basin is 2,500 feet deep near its center, and many of these who have examined the structural features both on the surface and in the mines think it quite probable that coal seams underlie the entire basin. This is quite possible, and at the same time variation in thickness, number of seams and impurities must be considered. The actual territory investigated in the Farmville area is about five miles in length between the two points where drilling or inclines have been made and the width is only a few hundred feet. The area over which coal is known to occur in the Richmond Basin is much larger and also far better known from drilling, shafts, and inclines.

On the eastern margin of the Richmond area mining has been done around three centers, namely, Gayton and Coalbrook north of the James River, Midlothian south of the James River, and at Winterpock approximately 10 miles south of Midlothian. Outcrops occur and pits have been opened up between these three main points of working, so that one feels with a considerable degree of certainty that the coal seams are more or less continuous north and south though subject to intense faulting in addition to the usual variation. On the western side of the Richmond Basin mining has been directed in two localities, namely around Manakin north of the James River, and north and west of Huguenot Springs south of the same river. The coal seams along the west side are deeper, due to the monoclinal folding, but faulting may have brought them nearer the surface in several cases. The western side because of the westward dip of the strata and the lack of outcrops of coal seams has induced little investigation as compared with the eastern side. Faulting has brought no coal seams to the surface or, if so, peneplanation has leveled the surface and a thick mantle of soil has concealed them.

MINING METHODS

The method of mining in the Eastern Virginia coal fields has progressed from the most primitive kind through the more improved stages. Even today at points along the eastern border of the Richmond area small local

A. The Forbes coal mine, 3 miles north of Midlothian, Chesterfield County, eastern margin of the Richmond basin. On the left of the timbers the coal bed is 3½ feet thick.



B. View of the Scott (Kennon) coal mine, three-fourths mile south of the James River, and 1 mile northwest of Huguenot Springs, Chesterfield County, showing the bin and the car track from the incline.

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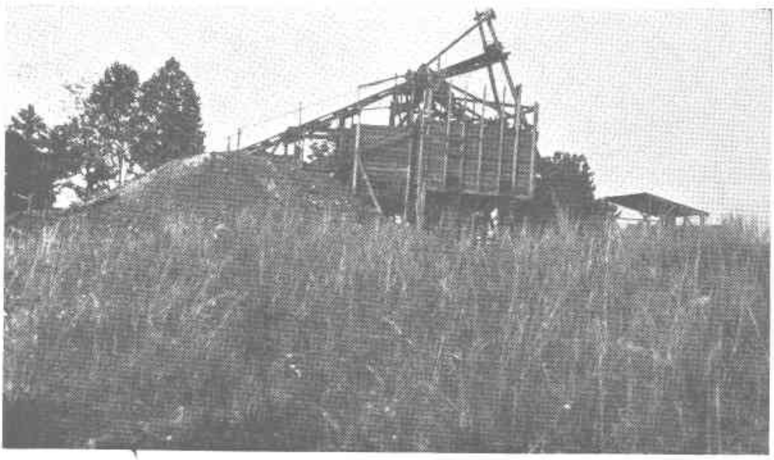

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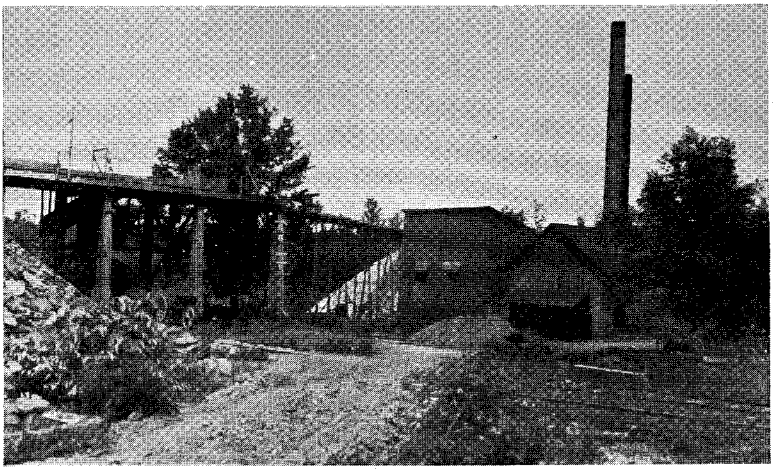
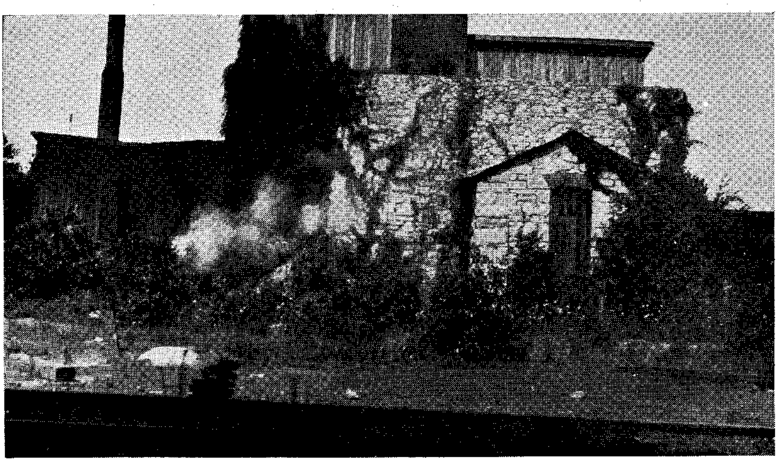
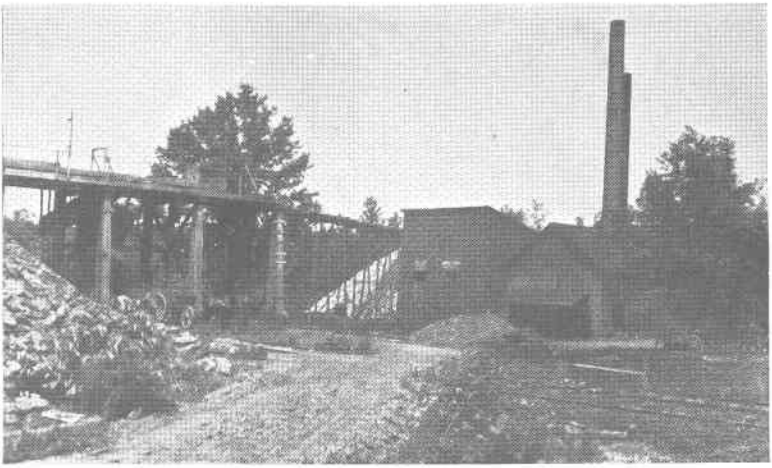


A. View of the boiler house, machine shop and overhead tracks from the incline to the dumps and storage bins of the Murphy Coal Corporation, 1 mile south of Midlothian, Chesterfield County.



B. A portion of the old stone building of the "Grove Shaft" now used as a pumping station by the Murphy Coal Corporation, 1 mile south of Midlothian, Chesterfield County.



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B. A portion of the old stone building of the "Grove Shaft" now used as a pumping station by the Murphy Coal Corporation, 1 mile south of Midlothian, Chesterfield County.

or "wagon mines" may be found, such as around Winterpock, north of Midlothian and south of the James River. The early method on the eastern margin, as typified by the workings around Midlothian, was to begin removing the coal at the outcrop and follow the bed, the incline having the same slope as the dip of the coal layer. Shafts were used later to reach the deeper coals and also because of the frequent pinching or thinning out of the beds on account of the "rolls" or buckling in the strata.

During the third period of mining activity in the first decade of this century a branch line was built from the Chesapeake and Ohio Railway northward from Gayton Junction to Gayton and extensive preparations were made to mine coal. An incline was constructed dipping at approximately 35°, and extended to a distance of 1,650 feet and on the 1,350 foot level a tunnel 900 feet long extended in an eastward direction. The incline was extended 750 feet further, thus making a total distance of 2,400 feet. A very large breaker was constructed and the mine was supplied with a fairly good ventilating apparatus such as was commonly used at that time. At the present time the Gayton-Coalbrook mines give the impression of the most elaborate preparation of any of the mines in the entire area. These mines were closed in July, 1912, but the branch line to the Chesapeake and Ohio Railway was still intact in 1923. At the old Midlothian main colliery one mile south of Midlothian the Grove shaft was sunk during the sixties and its depth is 618 feet. It is still kept open and used in case of emergency. An incline was put down 200 yards south of the old Grove shaft late in the final decade of last century and recently this incline has been extended by the Murphy Coal Corporation. In July, 1923, it measured 2,330 feet in length, starting on the surface at an angle of 19° W. and following the dip of the Triassic beds, which at times becomes 70° due to "rolls" or buckling of the strata. The direction of the incline is N. 64.5° W. and the vertical distance from the deepest working to the surface in July 1923, was 1,240 feet or 900 feet below sea level. The average of the slope is approximately 40 per cent.

The zenith of activity around Winterpock was from 1905 to 1907 and since that time the shafts have been abandoned and only a few shallow inclines are worked for local domestic use today. The equipment at the Winterpock mines was not as elaborate as that at Gayton. When the several mining localities are studied it is an outstanding fact that the point of maximum and continued interest centers around Midlothian. The production of the Midlothian mines has in the main furnished the great bulk of coal. When these mines were open they afforded excellent opportunities which are not to be had at the surface for the study of the underground structure, the relation of the natural coke to the diabase, the fossil floras, and many other problems.

STRUCTURE OF THE COAL BEDS

The structure of the sedimentary rocks of the Farmville and Richmond areas is not different from that of the other areas, although these two coal-bearing areas differ in their method of origin from those lying along the Piedmont region. The once simple structure of the beds after they were accumulated under mesophytic swamp conditions has been made progressively complex by faulting, "rolls" developed in the strata or buckling, jointing, intrusion by dikes and sheets, and erosion. The underground relations have been studied to some extent in the old shafts, inclines, and outcrops of Gayton, Manakin, Midlothian and Winterpock, and especially at Midlothian.

The fact that the basal Triassic member or the Border Conglomerate rests unconformably upon the pre-Cambrian granite and granite-gneiss is well known and the data supporting it can easily be obtained. This conglomerate blends upward into a very coarse and highly arkosic pale red sandstone. This Manassas sandstone grades into the Bull Run shales and the several coal seams are found in the sandstone, that is coals with overlying and underlying sandstone, or in the thin seams carbonaceous shales may form the roof of the coal.

The dip of all the shales, sandstones, and coal beds found in either of the coal-bearing areas is to the west. This same inclination is reported in all of the mines where underground conditions are recorded. The monoclinal dip has developed frequent buckling, or what the miner calls "rolls." As a general rule these rolls become further apart with an increase in depth. In the present incline south of Midlothian there are three such rolls. They cause the dip to flatten and steepen, giving variations in the above named incline of from 19° to 70°. This buckling is caused by the usual forces which cause folding. It offers increased difficulties to mining, though not in the same degree as is caused by faulting. Often with the rolls there has been intense fracturing of the coal, and slicken-sides phenomena are well developed.

Faulting is common over the coal areas and it is quite evident that this faulting is not the result of settling of the Triassic sediments alone but that the underlying granite is involved. The stresses originated in these underlying rocks and affected whatever may have covered the granite. Proof of this is that the faults can be traced from the Triassic beds into the granites. The great fault at Boscobel shows grounds sufficient to prove this. Some geologists claim that faulting is more prevalent along the eastern than along the western border and some hold the converse. Grounds for more faulting along the eastern side of the Richmond Basin are derived from the great number of faults seen in the mines; proofs of the opposite view are based on the frequent faulting as seen in the quarry at Boscobel and other places. There is no more reason for faulting being more frequent on one side than another and evidence goes to show that faulting has been frequent across the whole basin. The Triassic beds, no doubt, have added something to the faulting but the source of such displacements has been in the granites and granite-gneisses. The fault planes are steep wherever they are found and always dip to the east or southeast and strike approximately parallel to the north-south axis of the areas.

Faulting east of Midlothian has resulted in small detached areas of the Triassic which contain coal. The space between these small areas and the mother area does not exceed half a mile and numerous granite outcrops mark this intervening space. Even the coals of these small patches have been intruded by diabase dikes and converted into coke.

The type of faulting could not be determined, that is, whether it is normal or reverse. There is no doubt that the great fault or Border Fault on the west was a case of normal faulting. The writer was permitted during a part of one morning in July, 1923, to note the underground conditions of the Midlothian mine. From slicken-sides of one of the small faults motion was indicated as upward on the hangwall, or reverse faulting. Reverse faulting is not so well brought out in the areas lying along the Blue Ridge. The amount of displacement in the Midlothian mines is not so great, being less than 2 feet, but faulting toward the center of the area and north at Boscobel quarries involves a profound displacement, probably as much as from 250 to 400 feet or more, certainly enough to bring the granites of the basin to the surface.

Jointing is poorly developed in both the Farmville and Richmond areas. The shales and to a less degree the coal seams themselves show little jointing. The main and usually the only system developed parallels approximately the strike of the strata and is probably caused by movements which faulted the strata. Jointing is not a matter which is to be considered in mining the coal.

Core from drill hole on the property of W. W. Jackson, three-fourths mile northwest of Farmville, Virginia

No.	Description of strata.	Thickness Ft.	Ins.
1.	Surface soil, clay and gravel	2	0
2.	Sandstone	9	0
3.	Black slate	5	0
4.	Sandstone	10	0
5.	Black slate	3	0
6.	Black sandstone with a lime streak	2	0
7.	Black slate	4	0
8.	Slate	29	3
9.	*Coal Seam*	2	3
10.	Slate	1	0
11.	Black bituminous shale	3	0
12.	Slate	3	5
13.	Black sandy shale	1	0
14.	Dark sandstone	14	5
15.	Black slate	1	1
16.	*Coal Seam*	2	6
17.	Slate	0	7
18.	Argillaceous sandstone	2	2
19.	Slate	2	0
20.	*Coal Seam*	2	0
21.	Slate	1	0
22.	Sandstone	2	6
23.	Black slate	0	7
24.	*Coal Seam*	1	6
25.	Black slate and sandstone	2	6
26.	Gray sandstone conglomerate	7	0
27.	Black slate	3	0
28.	*Coal Seam*	0	7
29.	Very soft black shale	2	0
30.	Hard green calcareous slate	0	4
31.	Black slate	0	3
32.	Hard green calcareous slate	0	9
33.	Black slate	3	0
	Total depth drilled	124	8

The coal measures dip due west at an angle of about 45 degrees, and strike about due north and south.

Section at Jewett's (Coke) pit bottom, one-half mile north of Midlothian, Chesterfield County, Virginia[36]

	Ft.	In.
Whin	2	6
Hard arenaceous shale	6	0
Dark shale	1	3
Coke	2	0
Black shale	1	0
Coke	1	9
Parting	0	2
Coke	9	0
Fire clay	0	4
Thin layers of whin occasionally	..	..

Section at Carbon Hill (Edge Hill) or Gayton, north of the James River, Henrico County, Virginia[37]

	Ft.	In.
Drift and soil	(a)	(a)
Sandstone and shales	(a)	(a)
Cinder seam (burnt coal)	(a)	(a)
Trap seam	35-50	..
Sandstone and shales	(a)	(a)
Coke	3	0
Parting	(a)	(a)
Coal	3	6
Shale	(a)	(a)
Coal	(a)	(a)
Sandstone	(a)	(a)
Coal	(a)	(a)
Sandstone and shales with coal seam	(a)	(a)
Coal	9	0
Sandstone and shales with bed containing nodules of ironstone	(a)	(a)
Gneiss	(a)	(a)
Granite	(a)	(a)

(a) Thickness not given by Clifford.

A number of drill holes have been put down along the eastern edge of the Richmond area but the logs were not recorded and left available for study. In his discussion of the Richmond area Charles Lyell[38] in 1847, after spending some time examining the coals near Richmond, reports that three seams were known to exist at Dover on the western side of the basin. Also Lyell speaks of a number of other thick seams on the eastern margin. From one to five seams of coal are known to occur on the eastern margin and as a usual thing the upper seam is the thickest. All seams are subject to thinning out, opening up, buckling,

[36]Clifford, William, Richmond coal field, Virginia: Geol. Soc. Manchester, Trans., vol. 19, pp. 326-353, 1888.
[37]Clifford, William, Richmond coal field, Virginia: Geol. Soc. Manchester, Trans., vol. 20, pp. 247-256, 1889.
[38]Lyell, Sir Charles, On the structure and the probable age of the coal field of the James River, near Richmond, Virginia: Quart. Jour. Geol. Soc. London, Trans., vol. III, pp. 262-264, 1847.

and faulting. A sandstone roof is the common one, although shale is found at times. The most recent workings[39] of the Murphy Coal Corporation in the Midlothian mines show that, after driving the incline over a 60-foot roll and bringing it to a distance of 2,330 feet, three coal seams were encountered, some of which had been pinched out by the roll. The bottom coal seam, known as the "A" seam, consists of 16 inches of coal and 12 inches of slate; the seam next above, or seam "B", consists of 24 to 36 inches of coal and 18 to 24 inches of slate; the top or "C" seam consists of from 52 to 58 inches of coal with a slate roof.

Section on the Bailey's Hill property, near Midlothian, Chesterfield County, Virginia[40]

	Ft.	In.
Hard dark-gray sandstone	3	7
Hard bluish-gray sandstone	4	0
Bluish-gray clay slate	2	3
Black slate	2	0
Gray argillaceous sandstone (jointed)	6	2
Gray slate and indurated shale (very jointed)	4	10
Top seam of coal	5 – 6	4
Top seam of slate, often interstratified with inferior bony coal	5 – 6	4
Clean good coal	3 – 4	0
Dark slate	0	1 – 2
Rich coal, highly bituminous	9.8 – 12	0
Sulphur band	0	1 – 7
Coal	2	7
Dark slate	0	1½
Good clean coal (bottom coal of main seam)	5	7
Light-gray slate (gypsiferous)	0	9
Coal	1	6
Gray slate band	0	2
Coal	6	0
Slate (gray)	1	6
Coal ... 5 inches; Gray slate ... 4 "; Hard gray sandstone (floor) ... 3 "	1	0

This 60-foot roll is the most serious one encountered by the Murphy Coal Corporation. After driving through this roll several working places have been opened. The thickness of the "C" seam varies from 26 to 84 inches. The bottom of the old Grove shaft is in one of the small detached areas east of the main basin and the coal rises westward for 250 feet and then follows the main dip of the basin. On top of this roll the "C" seam was 26 inches thick. The "C" seam is on the average 48 inches thick down to 2,200 feet where it becomes involved in the 60-foot roll.

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[39]Personal communication from Manager S. Dixon of the Price Hill Colliery Company, Price Hill, West Virginia, March 21, 1925.

[40]Heinrich, Oswald, J., The Midlothian colliery, Virginia: Amer. Inst. Min. Eng., Trans., vol. 1, p. 347, 1871-73.

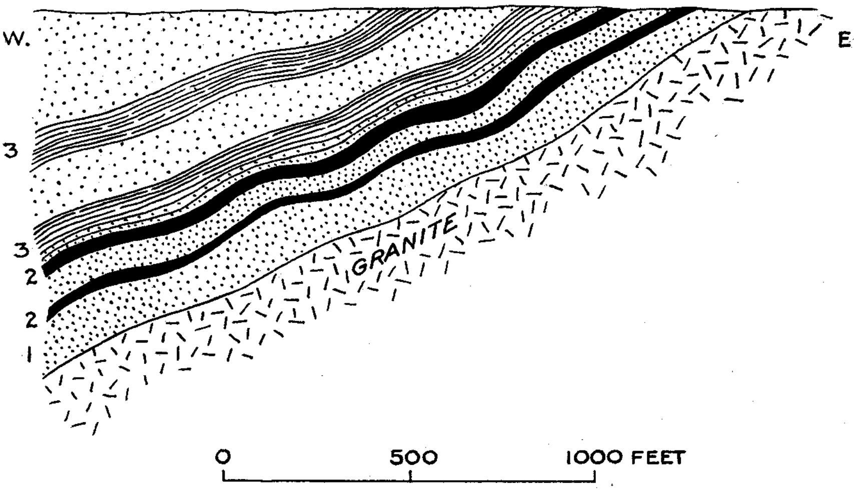


Figure 9. Structure along eastern edge of Richmond Basin, 1 mile south of Midlothian.
(1) Sandstone; (2) Coal; (3) Shale.

In the abandoned shafts north of Midlothian and in the workings around Gayton and Winterpock from one to five seams have been reported, two of which have been worked. One seam was sampled at Carbon Hill mine 1 mile from Gayton in 1912 and analyses of coal from this seam are given in this report.

The matter of diabase dikes offers no particularly serious problem to mining. Such dikes have not been reported by the Murphy Coal Corporation in the recent workings south of Midlothian. Dikes have been found north of Midlothian and around Gayton and the old workings must have encountered them. As a usual thing all of the dikes of the Richmond and Farmville areas are narrow compared with those of the Triassic areas north of the James River. The dikes which have been seen in the old workings cut the coal and sandstone at very steep angles, at times as much as 75°. All of the surface rocks of diabase composition show a fine to dense texture indicative of their small size as dikes.

DISTRIBUTION OF MINES

The following distribution of mines includes nearly all of those of which there are records. This list is not exhaustive and many small openings have been made for local supplies, possibly with no record made. The main mines are distributed around Gayton and Manakin, north of the James River, and around Midlothian and Winterpock, south of the James. All of these mines with their several shafts have gone through many hands during the three periods of mining activity.

The openings which were producing during the summer of 1923 were as follows:

(1) Forbes mine, 3 miles north of Midlothian—Coal mined during the summer and fall months for local use.

(2) Kennon (Scott) mine, 1½ miles northeast of Huguenot Springs—Coal mined during fall months for local use, averaging 150 tons annually.

(3) Murphy Coal Corporation, Midlothian—The only opening shipping any coal.

(4) Rudd mine, one-half mile east of Winterpock—Operated during summer and fall months by Mr. A. A. Rudd solely for local use, averaging from 100 to 200 tons annually.

The following list gives the names of some of the mines which were operated during the second period of activity (1842-1880) and some of which were continued into the present period:

(1) Gayton vicinity:

Carbon Hill (Edge Hill)
Coalbrook
Coke Pit No. 1
Coke Pit No. 2
H. J. Cook mine

(2) Manakin vicinity (Dover):

Anderson's Pit
Aspin Wall
Coalbrookdale
Crouches
Deep River
Dover Pit
Randolph
Waterloo

(3) Huguenot Springs vicinity:

Finney
Norwood
Old Dominion
Sallis
Scott
Spencer
Trabue

(4) Midlothian vicinity:

Aetna (Willis Pit)
Blackheath
Boiling
Buck and Cunliffe pits
Burfoot

- Diamond Hill
- Forbes
- Gowrie shaft
- Greenhole
- Groves
- Jewett (Coke)
- Maidenhead Pit
- Mills and Reed Creek shaft
- Ross and Curry pits
- Salle
- Stone Henge
- Union (Greenhole) mines
- Woolridge

(5) Winterpock vicinity:

- Bright Hope shaft
- Coxe (Clover Hill)
- Hall
- Hill
- Jaw Bone
- Park Hill
- Raccoon shaft
- Vaden

PRODUCTION OF RICHMOND BASIN COAL

The following table gives statistics of annual production in the Richmond Coal Basin from 1822 to 1877. It has not been possible to obtain accurate statistics of production for the years 1878-1922. There has been some production for local supplies by the owners during these years and this at the present time is averaging less than 1,000 short tons annually. It is known that the mines around Midlothian and Winterpock produced some coal during 1880-1900 and Midlothian has been active at several short periods since that time. The Midlothian mines at present are closed. The only one of the old localities which is absolutely closed, even without a wagon mine, is the Manakin or Dover. The production of the Midlothian mines is used locally and shipped to Richmond over the Southern Railway. A spur track has been built from the Midlothian mines to the main line of the Danville-Richmond Division of the Southern and connects at Midlothian.

Annual production of coal in the Richmond Coal Basin from 1822 to 1877, as reported by Oswald J. Heinrich[41]

Year	Short tons
1822–1842	1,925,000.00
1843	95,605.57
1844	115,312.83
1845	134,602.79
1846	124,668.91
1847	136,421.79
1848	120,747.36
1849	133,801.36
1850	138,017.16
1851	136,523.14
1852	106,686.74
1853	101,725.66
1854	132,554.10
1855	125,977.00
1856	106,150.26
1857	114,826.30
1858	113,734.34
1859	106,337.71
1860	112,472.88
1861	94,697.01
1862	115,494.69
1863	112,067.68
1864	111,742.07
1865	73,729.61
1866	70,911.89
1867	90,810.19
1868	96,183.73
1869	115,563.51
1870	90,199.06
1871	101,931.62
1872	95,972.96
1873	101,504.31
1874	81,851.20
1875	88,706.25
1876	57,181.64
1877	67,907.29
Total	5,647,620.61
1923[a] (Approx.)	50,000.00
Total available production from 1822 to 1877 and including 1923	5,697,620.61

a 1923 production by the Murphy Coal Corporation, according to their statement of March 21, 1925.

[41]Heinrich, Oswald J., The Mesozoic formations in Virginia: Amer. Inst. Min. Eng., Trans., vol. 6, 1877-78, p. 271.

Shipments of the Richmond Basin Coal 1843-1877[42]

Short tons shipped via various means of transportation:	
Richmond, Fredericksburg and Potomac R. R.	138,362.80
James River and Kanawha Canal	793,918.00
Richmond and Danville R. R.	750,217.81
Clover Hill and Richmond and Potomac R. R.	1,287,369.41
Miscellaneous transportation by wagons	502,027.00
Total shipments 1843-1877	3,471,895.02
Used at mines (estimate of 7 per cent of production)	250,725.59
Total production 1843-1877	3,722,620.61

ANALYSES OF COAL FROM THE RICHMOND BASIN

There are a fairly large number of analyses of Triassic coals from the Richmond Basin dating back into the forties of last century. Many of these earlier analyses were made before the days of refined methods of getting the volatile and fixed carbon, sulphur, ash, and the B. t. u., and hence we are somewhat at a loss in comparing them with some of the more recent ones. The earliest analyses were made about the year 1843 by Walter R. Johnson of Philadelphia and were published in "Preliminary Report of Experiments on the Evaporative Power and other Properties of American Coals," 28th Congress, 1st Session, Washington, 1844. The letter of transmittal is dated November 28, 1843. Eleven analyses were made from samples collected from the Richmond Basin, which represented good work for that day, and which compare favorably with those of a later time. Five other analyses were later made by Johnson, bringing the total up to 16. These analyses are numbered in the table from 10-25, inclusive.

W. B. Rogers reported 20 chemical analyses in various reports of the Virginia Geological Survey and these include serial numbers 28-45 in the table of bituminous coal analyses on page 108 and serial numbers 7 and 8 in the table of coke analyses on page 109. Many of these analyses were made about the time of Johnson's and probably mean little for comparison. There are only four recent chemical analyses available and these are Nos. 6, 7, and 47 of bituminous coal and No. 3 of coke analyses furnished through the kindness of M. R. Campbell, Geologist of the United States Geological Survey. Three of these were made from samples collected November, 1912, by H. I. Smith. Several analyses have been made of the natural coke and these will be found by reference to serial numbers 1-10 in the table of coke analyses on page 109. Only three samples were analyzed for the carbon, hydrogen, oxygen, and B. t. u. The most recent analysis was made about 1912.

[42] Heinrich, Oswald J., Amer. Inst. Min. Eng., Trans., vol. 6, 1877-78, p. 271.

Analyses of Bituminous Coal from the Richmond Basin

No.	Analyst	Location of Mine or Pit	Moisture	Volatile Matter	Fixed Carbon	Ash	Sulphur
1.	Alexander, J. H.	Midlothian	....	31.60	61.10	7.10	....
2.	Andrews, G. W.	Coxe Mine (Clover Hill)	....	38.50	55.00	6.50	....
3.	"	Richmond coal	....	32.00	59.25	8.75	....
4.	Clemson, T. G.	Willis Pit (Aetna Shaft)	....	28.80	66.60	4.60	....
5.	"	Anderson Pit (Dover)	....	26.00	64.20	9.80	....
[a]6.	Fieldner, A. C.	Carbon Hill, near Gayton	2.81	25.70	62.47	9.02	1.43
[a]7.	"	" " " "	2.11	23.58	56.95	17.36	2.16
8.	Heinrich, O. J.	" " upper seam	1.40	20.60	60.80	17.20	....
9.	"	" " 2nd seam	0.40	18.60	71.00	10.00	....
10.	Johnson, W. R.	Coxe Mine, (Clover Hill)	1.34	30.98	56.83	10.13	0.51
11.	"	Creek Company Shaft	1.45	26.79	60.30	8.57	2.89
12.	"	Midlothian average coal	2.46	29.74	53.01	14.74	0.06
13.	"	" New Shaft	0.67	31.21	56.40	9.44	2.29
14.	"	" screened coal	1.79	34.30	54.06	9.66	0.20
15.	"	" 900-ft. Shaft	1.17	27.28	61.08	10.47	....
16.	"	Chesterfield Mining Co.	1.90	28.72	58.79	8.63	1.96
17.	"	Carbon Hill average coal	1.79	23.96	59.98	14.28	....
18.	"	Tippecanoe Pit	1.84	33.79	54.62	9.37	0.38
19.	"	Cranch Low Shaft, av. 4 spec.	....	23.96	67.32	8.72	....
20.	"	Scotts (Kennon) Pit	....	33.70	60.86	5.44	....
21.	"	Waterloo Shaft	....	26.80	55.20	18.00	....
22.	"	Deep Run Pit	....	26.16	39.84	5.00	....
23.	"	" " " av. 40 spec.	....	21.57	67.96	10.47	....
24.	"	Midlothian	1.01	28.74	56.11	14.14	2.38
25.	"	Barr's Deep Run Mine	1.79	19.78	67.96	10.48	....
26.	McCreath, A. S.	Midlothian, Grove Shaft Scr.	1.03	38.23	54.27	6.47	1.52
27.	"	Midlothian average	1.05	36.49	46.70	15.76	2.23
28.	Rogers, W. B.	Coxe Mine (Clover Hill)	....	29.12	65.52	5.36	....
29.	"	Stone Henge	....	36.50	58.70	4.80	....
30.	"	Mill and Reed Creek Shaft	....	38.60	57.80	3.60	....
31.	"	Greenhole Shaft	....	31.17	67.83	2.00	....
32.	"	Maidenhead Shaft	....	32.83	63.97	3.20	....
33.	"	Old English Shaft	....	35.82	53.36	10.82	....
34.	"	" " middle bench	....	28.40	66.50	5.10	....
35.	"	" " top bench	....	28.40	61.68	9.52	....
36.	"	Powhatan Pits	....	32.32	59.87	7.80	....
37.	"	Anderson's Pit (Dover)	....	23.80	66.78	4.92	....
38.	"	T. M. Randolph Pit	....	30.50	66.15	3.35	....
39.	"	Coalbrookdale	....	29.00	66.48	4.52	....
40.	"	" Seam No. 1	....	24.00	70.80	5.20	....
41.	"	" " " 2	....	22.83	54.97	22.20	....
42.	"	" " " 3	....	24.70	65.50	9.80	....
43.	"	" " " 4	....	21.33	56.07	22.60	....
44.	"	Cranches Upper Seam	....	30.00	64.60	5.40	....
45.	"	Engine Shaft	....	37.65	62.35	2.80	....
46.	Silliman & Hubbard	Midlothian coal	2.00	31.62	58.26	7.67	....
[b]47.	U. S. Geol. Survey	Richmond Basin	2.80	25.70	62.50	9.00	1.40

a Furnished by the U. S. Geological Survey; also published in Bureau of Mines Bulletin, No. 85, 1914, p. 106.
b U. S. Geological Survey, Prof. Paper 100-A, p. 32.

Analyses of the Richmond, Virginia, Natural Coke[43]

No.	Analyst	Location of Mine or Pit	Moisture	Volatile Matter	Fixed Carbon	Ash	Sulphur
1.	Bailey, A. F.	Chesterfield County	....	17.00	68.00	15.00	....
2.	Clemson, T. G.	Chesterfield County	....	10.70	83.30	6.00	....
a3.	Fieldner, A. C.	Gayton, Henrico County	2.54	16.28	70.24	10.54	1.31
4.	Heinrich, O. J.	Carbon Hill	1.57	9.64	79.93	8.86	....
5.	Johnson, W. R.	Carbon Hill	1.12	11.98	75.08	11.83	....
6.	Riggs, R. B.	Midlothian "Natural Coke"	1.66	13.65	63.17	12.86	4.70
7.	Rogers, W. B.	Chesterfield Natural Coke	....	9.98	80.30	9.72	....
8.	"	Chesterfield Natural Coke	....	16.00	70.00	14.00	....
9.	Wallace, W.	Carbon Hill, Gayton	1.56	14.26	81.61	2.24	0.33
10.	Wurtz, Henry	Richmond Basin Coal	0.44	14.08	77.17	8.31	....

a Furnished by the U. S. Geological Survey; also published in Bureau of Mines Bulletin, No. 85, 1914, p. 106.

Table showing ranges of Triassic coal and coke of the Richmond Basin

Constituents	Maximum Range		Minimum Range		Average	
	Bit. Coal	Coke	Bit. Coal	Coke	Bit. Coal	Coke
Moisture	2.81	2.54	0.40	0.44	1.62	1.48
Volatile matter	38.60	17.00	18.60	9.64	28.95	13.36
Fixed carbon	71.00	81.61	39.84	63.17	60.39	74.88
Ash	22.60	15.00	2.00	2.24	9.14	9.94
Sulphur	2.38	4.70	0.06	0.33	1.49	2.11

[43] Fieldner, A. C., U. S. Bureau of Mines, Bulletin No. 85, 1914, p. 106.

The following table[44] gives the most recent analyses of the three samples of bituminous coal and one of coke.

Analyses of coal and coke

	No. in Anal. Table	Air Dried Loss	Moisture	Volatile Matter	Fixed Carbon	Ash	Sulphur	Hydrogen	Carbon	Nitrogen	Oxygen	Calories	B. t. u.	$\frac{FC}{VM}$
Bit. Table	6	1.9	2.81	25.70	62.47	9.02	1.43	4.90	76.55	1.81	6.29	7496	13493	2.41
Bit. Table	7	1.4	2.11	23.58	56.95	17.36	2.16	4.44	69.22	1.59	5.23	6778	12200	2.47
Coke Table	3	1.9	2.54	16.28	70.24	10.94	1.31	....	....	....	....	....	....	4.32
Bit. Table	47	.....	2.80	25.70	62.50	9.00	1.40	....	....	....	....	....	23490	2.43

[44]Fieldner, A. C., Analyses of Coal, Bureau of Mines, Bull. 85, pp. 106, 332, 333.

Section from which No. 7 analysis was taken[a]

B—Bed in carbon Hill Mine, Henrico County
Roof, "Draw slate"

	Feet	Inches
Coal, hard	1	0
Shale	0	1
Coal streaked with shale	0	6
Shale	0	½
Coal, very friable	1	0
Shale	0	½
Coal	0	11
Shale	0	1
Coal	1	3
Floor Clay		
Thickness of bed	4	11
Thickness of coal sampled	4	9

a Shale not included in specimen for analysis.

The moisture content is not abnormally high in any of the Richmond coals and the limits are from 0.40 to 2.81 per cent. The volatile matter like the fixed carbon has a wide range. The older analyses were most probably made from coal not representative of the beds. Analyses shown in the table by serial numbers 6, 7, and 47 were from samples collected after approved methods, and for this reason the older analyses can not be relied upon. Very few sulphur tests were made, only 15 out of the 57 analyses, and sulphur is one of the principal impurities in the coals of the basin. Whether or not the shale partings were included in the specimens for analysis is an important item in ash, volatile matter and the fixed carbon content. There is not so much variation in the fixed carbon and volatile matter as might be expected when the conditions of the area are considered, that is, the conditions under which the coal floras grew and formed into coal. The Farmville basin coal is quite similar to the Richmond coal in all its chemical properties.

Four analyses[45] were made by the United States Geological Survey from specimens of Triassic coal taken from the North Carolina areas, three specimens from the easternmost areas and one from the Dan River area. The analyses are as follows:

Analysis of coal from Triassis areas of North Carolina
(F. W. CLARK, *Analyst.*)

Constituents	Eastern Areas Upper Layer	Middle Layer	Lower Layer	Western Areas	Average
Volatile matter	24.48	24.22	23.94	17.99	22.66
Fixed carbon	72.44	67.86	66.37	55.47	65.54
Ash	3.08	7.92	9.69	26.16	11.71
Sulphur	0.99	1.42	3.32	5.56	2.82
Moisture	....	....	....	0.38	....

[45] U. S. Geol. Survey, Bull. 42, 1887, p. 146, F. W. Clark, Analyst.

The analyses of the North Carolina coal do not agree so closely with those of the Richmond area but they are very similar in their physical properties. The North Carolina coal has not been sampled in as many localities as has the Richmond coal.

PHYSICAL PROPERTIES OF THE COALS

The Richmond coal is chiefly a bituminous variety and, as such, it shows a very black color and a brilliant luster. Bedding is well developed and laminated structure is quite pronounced. Joint planes are developed at right angles to the bedding planes, causing the coal to break into cubical and rectangular blocks. Fractures are abundant and are often filled with pyrite (FeS_2). Shale partings are more common to the thin seams of coal. In general the physical features of both the Farmville and Richmond coals are quite similar to those of the Pennsylvanian coals of southwestern Virginia.

Specific gravity is well under 2. It has not been recorded for many of the analyses. The following table shows 11 specific gravity tests made near the middle of the last century by W. R. Johnson.

Specific gravity of Richmond Basin Coal

Serial No. in table of chemical analyses	Specific gravity
10	1.285
11	1.319
12	1.294
13	1.325
14	1.283
15	1.487
16	1.289
17	1.451
18	1.346
24	1.390
25	1.382
General average	1.346

The foregoing estimates are practically correct for the coals. From samples collected the writer had specific gravity tests made, which are approximate. These samples were taken from four mines or pits, three of which were in operation at the time of sampling, July, 1923.

Recent tests of specific gravity

Location of mine or pit	Specific gravity	Average
New opening south of Grove Shaft, one mile south of Midlothian	1.362	
Forbes pit, three miles north of Midlothian	1.292	
		1.332
Kennon (Scott) pit, two miles northeast of Huguenot Springs	1.318	
C. A. Rudd pit, one-half mile east of Winterpock P. O.	1.355	

Hardness is a somewhat variable feature in any coal, and the amount of shale and many other factors modify this feature in the Richmond coals. The fracture is cubical except in the natural coke which is irregular. The slaty portion of the coal is rather dull but the workable portions are a bright black. Thin sections of the coal show plant tissues with fairly well preserved cells.

Thin laminae varying in color intensity often occur in the coals. As a rule, the very black and highly lustrous laminae show less plant structure. Bits of plant stems, leaves, and roots occur in the coal and especially in the carbonaceous shales which occasionally are partings in the coal and often serve as the roof.

IMPURITIES

The principal impurities of the Triassic coals in Virginia are pyrite and shale or slate. Pyrite occurs in small masses, though sometimes it is disseminated through the coal. It is usually to be found in the fractures or joint planes in scales. It presents a light straw yellow. It is so abundant in some of the small seams that it becomes extremely unpleasant when the coal is used in grates and in kitchen stoves. Washing the coal would eliminate much of this pyrite, especially that of a flaky nature. The shale partings are often so thin as to make mechanical separations impractical. Those partings encountered in the mines of the Midlothian region are thick enough to permit the slate to be separated by hand and are not a serious difficulty. The top or "C" seam of the Midlothian mines, as reported by the Murphy Coal Corporation, is from 52 to 58 inches thick with no shale partings, but it has a shale roof.

THE NATURAL COKE

The fact that natural coke occurs in several of the old pits in the Richmond coal basin has placed this basin in a somewhat unique position. This coke, as previously stated, owes its origin to the intrusion of diabase dikes and sheets. During the recent field work in the basin none of the old coke pits were available for study, but from the descriptions of others and from specimens taken at time of operation in these pits, conditions are fairly well understood. Similar natural coke also occurs in a number of the pits of the Deep River Triassic area in North Carolina and at present is found in the pits now opened up near Egypt. Specimens from the Carolina pits show diabase and coke adhering to each other and often masses of coke will be included in the diabase and the converse is equally true.

Natural coke has been referred to as "mineral charcoal" and "carbonite." Numerous writers have described natural coke in Virginia and the principal references are from Coryell, Heinrich, Hotchkiss, Hunt, W. R. Johnson, Raymond, H. D. Rogers, W. B. Rogers, Shaler and Woodworth, Stevens, and Wurtz, whose articles are listed in the bibliography accompanying this report.

Carbonite is termed by Oswald J. Heinrich[46] a semi-bituminous coal in all probability and it contains varying amounts of impurities. For all practical purposes this may be regarded as natural coke. In color this coke is generally medium gray to grayish black. Its specific gravity ranges around 1.320-1.345. An analysis of the coke is given in a preceding table but may be given here with an analysis of natural coke from New Mexico. The coke analyses of the Richmond Basin are as follows:

Analyses of natural coke from the Richmond Basin and a comparative analysis of natural coke from New Mexico

Location of mine or pit	Moisture	Volatile Matter	Fixed Carbon	Ash	Sulphur
Chesterfield County	....	17.00	68.00	15.00	....
Chesterfield County	....	10.70	83.30	6.00	....
Gayton, Henrico County	2.54	16.28	70.24	10.54	1.31
Carbon Hill near Gayton	1.57	9.64	79.93	8.86	Trace
Carbon Hill	1.12	11.98	75.08	11.83	....
Midlothian	1.66	13.65	63.17	12.86	4.70
Chesterfield County	....	9.98	80.30	9.72	....
Gayton	1.56	14.26	81.61	2.24	0.33
Richmond Basin	0.44	14.08	77.17	8.31	....
Average of Richmond coke	1.48	13.06	75.42	9.48	2.11±
"Natural Coke", Purgatory, N. M.		16.87	74.18	8.95	....

The coke is porous and is not unlike synthetic coke. It does not weather as readily as the coal. Fragments can be picked up around Carbon Hill and other pits which have been lying on the surface from 25 to 40 years and these are a light to medium gray color and are unchanged in all their properties. The distance outward from the diabase intrusives to which this coking process has taken place varies. At best the thickness of the coke is not great. At the Carbon Hill pits the coke would sometimes attain as much at 2¼ feet or more in thickness. Thicknesses up to 4 2/5 feet have been reported by the Midlothian owners for the pits north of that town. To say the least, natural coke is a problem of great interest in the Richmond and Farmville basins, though from the data available at present its occurrence in the latter basin is of much less importance.

MACHINERY USED IN COAL MINING IN THE RICHMOND BASIN

The machinery used in the Richmond coal mines represents several types from the most primitive to the type commonly used about 1900.

[46]Heinrich, O. J., The Mesozoic formation in Virginia: Amer. Inst. Min. Eng., Trans., vol. 6, pp. 243-244, 1877-78.

There is no record of just what machinery was in use about 1700 and up to 1750. Mines during that period followed the coal seam from the surface and the coal was removed by small cars on wooden tracks. Later when shafts were put down the coal was hoisted by buckets on a cable or rope attached to a revolving drum or windlass. This primitive method held with the smaller mines for some time. In the larger enterprises around Midlothian, such as the Midlothian Coal Mining Company which was organized in 1836, boilers were used to develop power for hoisting and other purposes. According to Heinrich,[47] the prospecting went on about 1836 and later consisted in sinking five shafts near Midlothian. The shafts have the following distances to coals:

Length of incline and depth of coal

	Length of incline Feet	Depth of coal Feet
Old pump shaft	777	716
Middle shaft	625	612
Wood shaft	625	250–300
Grove shaft	622	485
Shaft No. 5	1015 and bored 322 feet lower—no coal.	

The early boilers used for hoisting and pumping the mines were of the Cornish type, varying from 60 to 500 horse-power. The coal was mined with picks and loaded by hand, and all this rendered production slow. Cheap labor made such work possible then. The great western coal fields were not open, there were no railroads and all of the coal was shipped over the James River and used for iron foundries in Richmond, Philadelphia, New York, and Boston.

Machinery modern for the time was introduced shortly after the Civil War. The equipment of the Midlothian Company, according to reports, was as follows:[48] Allison and Bannan steam pump 6 inch diameter, 6½ inch steam cylinder and 4½ inch plunger; an engine for hoisting, double cylinder, link motion, 24 inch cylinder, 5 foot stroke of about 130 horse-power; fan engine; four boilers and buildings for the various engines, blacksmiths, fan house, grading bins, etc.

About 1900, more improved machinery was introduced and may be seen at Gayton, which was abandoned about 1912 and is now in a state of dilapidation. When these mines closed in July, 1912, the following equipment and buildings were in use: Ventilation fan 9 feet in diameter, set on a substantial concrete base and well cased in concrete and metal; three 120 and two 200 horse-power boilers; a very large breaker building, three story and well equipped; boiler and engine buildings, now torn away; machine shop; storage bins; well cased incline, reported 2,400 feet total depth; spur track from the Chesapeake

[47]Heinrich, O. J., The Midlothian, Virginia, colliery in 1876: Amer. Inst. Min. Eng., Trans., vol. 4, pp. 309-310, 1875-76.
[48]Heinrich, O. J., op. cit., pp. 314-315.

and Ohio Railway leaving the main line at Gayton Junction; and numerous houses for workmen, commissary buildings, and stables. The enormous dumps give evidence of the work which went on around Gayton.

Machinery of about the same type was used around Winterpock up to the time when mining operations ceased and a number of old boilers, wire cable, deserted houses, and waste heaps mark the scene of the once great activity of its day.

The equipment in use at the present time by the Murphy Coal Corporation, 1 mile south of Midlothian at the old Grove shaft, is as follows: Two boilers of about 250 horse-power each for hoisting and pumping, high power pumps, double tracked incline, a number of 1-ton cars, tipple of 200 feet in length, one large bin, engine and boiler houses, and an office building, all of which are located 200 yards south of the old Grove shaft. At the old Grove shaft, which is still used for emergency, there is a large boiler pump and hoisting machinery. These mines are accommodated by a spur track from the Southern Railway. Modern equipment is in use underground.

At the present time the entire Richmond basin is quiet and shows no indication of immediate activity. The pits are still worked for local fuel during the fall. During the winter of 1925 the mines of the Murphy Coal Corporation were still being pumped, indicating a temporary cessation of activity. Labor has been unusually high since 1916 and with the difficulties of the basin the price of coal has not justified much mining or investigation. The Farmville basin has been quiet for years and no investigation is in progress. Just what the Triassic coal will mean in the future will depend largely upon the method of working it, as compared with the older coal mines it seems to present quite different problems. A frail sandstone roof in many cases compels bracing, which is slow and expensive. The great advantage of the field is its nearness to market, thus avoiding the long freight hauls, such as those of the Norfolk and Western, the Chesapeake and Ohio and the Virginian railways. With a rise in the price of coal and the improved methods of mining which will lessen danger and increase production at low costs, the field may assume some importance at some time in the future, though how remote this may be is mere conjecture at present.

STONE

The stone of the Triassic period which is used for a number of purposes, consists of the Manassas sandstone, the limestone and trap phases of the Border Conglomerate, and igneous rock or diabase. These various uses so far have been for building, for road metal, ballast, concrete filler, and for agricultural lime.

BUILDING STONE

Two varieties of Triassic rock have been used for building purposes, namely red (Manassas) sandstone and diabase. There is no record of the date at which the first quarries were opened in either of these stones or when the first shipments were made. Sandstone was the first worked and is found in buildings 150 years old or older around Aldie in Loudoun County and Manassas in Prince William County.

SANDSTONE

The red sandstone has been quarried in a number of places but the main quarries are confined chiefly to the Potomac and Scottsville areas. The famous old home of President James Monroe near Aldie, Loudoun County, has red sandstone for walks, for some of the foundation stone, and also for some of the out buildings. The famous "Stone House", the only building in that section antedating the battle of Bull Run, is built of red sandstone, as is the old stone bridge 1 mile east of the "Stone House." Many of the older residences near the sandstone quarries have foundations of sandstone.

The red sandstone is similar to the red sandstone of the Connecticut Valley, New Jersey, Pennsylvania, and Maryland in general appearance. When quarried at the proper time of the year and placed in horizontal position in building, its length of service is as great as the ordinary sandstone. Its bedding planes and habit of jointing often make it possible to quarry rectangular blocks with very little effort. The quarries rarely have more than 2 to 4 feet of soil overburden. Some few of the quarries have red (Bull Run) shales intercalated with the sandstone and this hindered the quarrying to some extent. The sandstone never has a steep dip in any of the quarries and it ranges from practically horizontal to a dip of from 15° to 20°.

Location of quarries.—The location of quarries in the Manassas sandstone and of other quarries in the Triassic area is as follows:

Manassas sandstone quarries

Potomac Area:

(1) Portner quarry—1 mile north of Manassas Court House and on the edge of the town, Prince William County.

(2) Bull Run quarry—2½ miles north of Manassas near Bull Run, Prince William County.

(3) Brentsville quarry—One-half mile east of Brentsville, the old county seat of Prince William County previous to moving the seat of the county court to Manassas.

(4) Aldie quarry—3½ miles east of Aldie, Loudoun County.

(5) Greenwich quarry—East of Greenwich on the east side of Broad Run, Prince William County.

(6) Southern Railway quarry—Along the east side of the Southern Railway, 2 miles southwest of Bristow, Prince William County.

(7) State quarry—1 mile east of Stevensburg and 5½ miles southeast of Culpeper, Culpeper County.

(8) Newman quarry—1¼ miles east of Liberty Mills on Blue Run, Orange County.

Scottsville Area:

(9) Howardsville quarries, two different openings, 1 mile east of Howardsville, south side of James River, Buckingham County.

(10) Midway Mills quarry—At Midway Mills, north side of James River, Nelson County.

Danville Area:

(11) State quarry—5 miles south of Chatham on the Chatham-Danville highway near the summit of White Oak Mountain, Pittsylvania County.

Farmville Area:

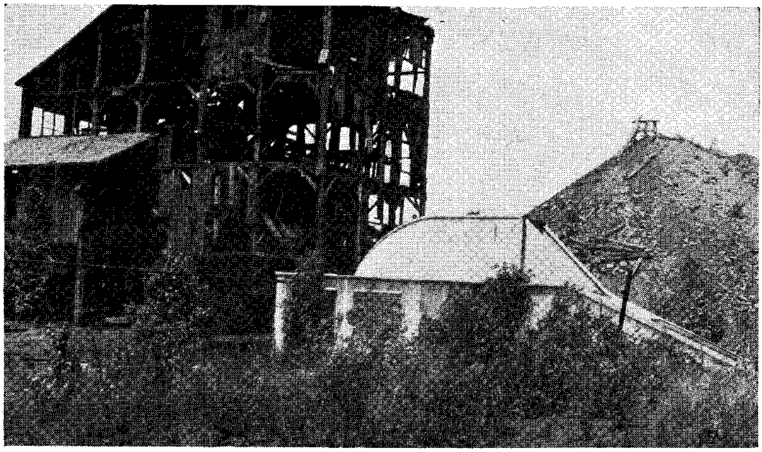
(12) Farmville quarry—1 mile northwest of Farmville on the property of W. W. Jackson.

Richmond Area:

(13) Boscobel quarries—Two quarries just east of Boscobel, on the Chesapeake and Ohio Railway, Goochland County. This is not a Triassic sandstone but is inside the area.

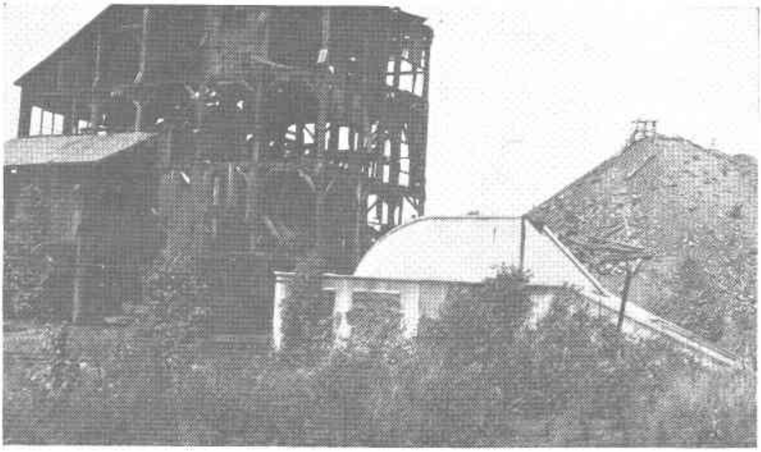
The quarries of the Potomac area were the earliest opened in the Virginia Triassic. Stone has been shipped from the Manassas quarries to various places. The Portner and other quarries around the town of Manassas were begun before the Civil War days and stone for building was shipped to Washington, Baltimore, and Richmond. There are a number of smaller quarries around Manassas, but they have been abandoned so long that the people have no records of them. The bridge over Bull Run, 1 mile east of the famous "Stone House" on Bull Run Battlefield, is built of the red sandstone, which must have come from some nearby quarry. The bridge is on the Warrenton-Fairfax pike and was built shortly after the Civil War. It has two of the most graceful arches of any bridge structure in the country and the sandstone shows evidence of being an excellent building stone.

The Court House, Portner Tower, and many private homes of Manassas and the vicinity are built of the sandstone. The Manassas quarries were closed about 35 or 40 years ago. North of Manassas the old boiler and engine house is still standing and the quarry ledges are still exposed. The Brentsville and Aldie quarries have not been operated for 45 years. The Greenwich quarry was operated to get rock for the buttresses of the bridge nearby and for the foundations of various houses in the neighborhood. The Southern Railway quarry was never successful because of the tremendous amount of shale, the



A. View of the abandoned tipple, concrete ventilation building, and the mine dump at Gayton, Goochland County.

B. View of the Boscobel quarry (east quarry) operated in granite-gneiss and within the Triassic of the Richmond Basin, just north of the James River, Goochland County.



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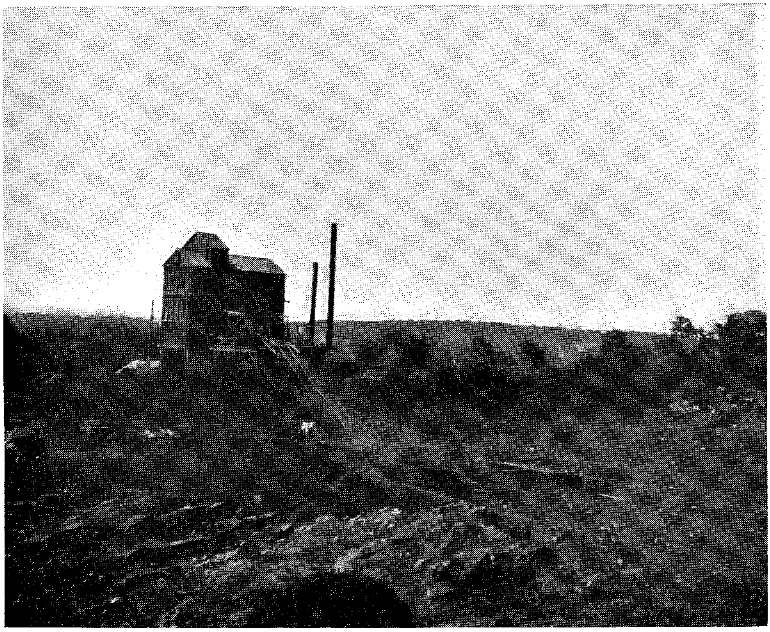
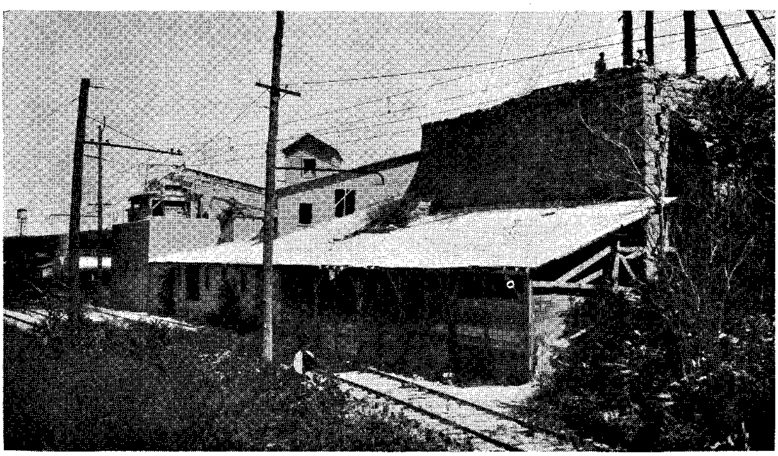
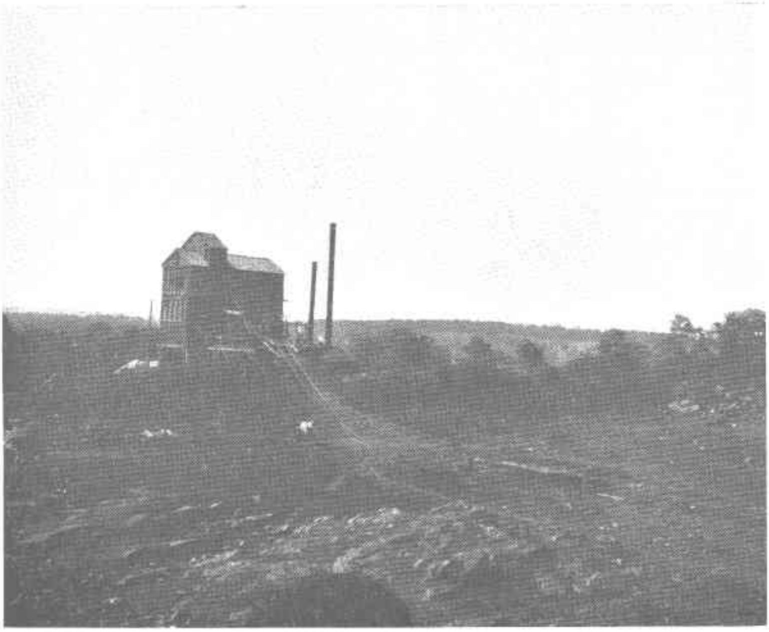


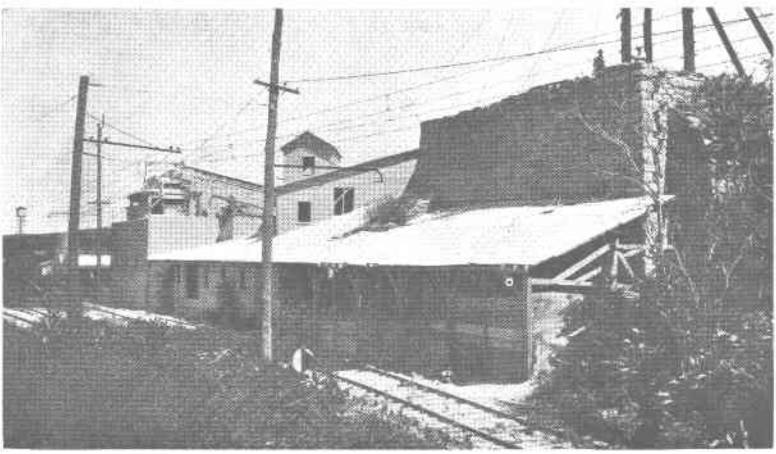
A. View of the crusher, storage buildings and power plant of the Belmont Trap quarry, 4 miles southeast of Leesburg, Loudoun County. (Photographed by Thomas L. Watson.)



B. View of the crusher and kiln buildings of the Leesburg Lime Company, Inc., Leesburg, Loudoun County.



A. View of the crusher, storage buildings and power plant of the Belmont Trap quarry, 4 miles southeast of Leesburg, Loudoun County. (Photographed by Thomas L. Watson.)



B. View of the crusher and kiln buildings of the Leesburg Lime Company, Inc., Leesburg, Loudoun County.

softness of the sandstone, and the use to which it was applied, namely, to ballast. The State Quarry for road building, east of Stevensburg in Culpeper County, was opened in 1922 and has furnished very good stone. This sandstone lies on the north side of Mt. Pony and has become much indurated by the Mt. Pony stock or laccolith and is a stone very resistive to wear.

The Newman quarry in the Potomac area is small and the stone has been used only in a very local way. The Newman residence, tower, and gate entrance near Montpelier are built from the sandstone from this quarry. The quarry has been abandoned for over 25 years.

The quarries around Howardsville have been used for local purposes, such as foundation work and gate entrances. The quarry at Midway Mills has produced a considerable amount of stone. The Norfolk and Western Railway station at Bedford City is built of sandstone from this quarry, as is part of the Federal Court building at Abingdon, and many uses are made of it in Lynchburg and Richmond. None of the quarries in the Scottsville area have been worked for the past 25 years.

The State quarry south of Chatham in Pittsylvania County was opened up for road building in 1921 and has not been used for building stone. No building stone has been used from the Triassic in the Danville area for there are no suitable sandstones except at the above mentioned quarry. In this quarry both the Manassas sandstone and the Border Conglomerate are used and there is a complete gradation from the sandstone into the conglomerate. The sandstone is grayish red to red and the conglomerate is white to gray and very arkosic.

The Farmville quarry is very small and has furnished stone for local purposes. The sandstone used overlies the conglomerate and contains thin seams of shale and coal and is cut across by dikes of diabase. The foundation stone of the Farmville town reservoir is about the only stone taken from this quarry and is of fairly good grade.

The Boscobel quarries of the Richmond area along the bluffs north of James River at Boscobel are not in Triassic rocks but in granite and granite-gneiss which have been brought up to the surface by a fault. On both the east and west sides of these quarries the red sandstones and shales are exposed. These metamorphosed igneous rocks are the foundation members of the entire Richmond basin. The rock quarried is not used for building stone and will be discussed under ballast.

The most desirable sandstone used for building purposes has come from the Aldie, Manassas, and Midway Mills quarries. These sandstones are a medium to fine grained texture on the average, although some of them may be rather coarse. Experience has proved that the coarse sandstone does not give satisfaction when placed in a building, as after a few years it crumbles. The very fine grained sandstones have proved equally unsatisfactory, as they scale, especially if they are placed with their bedding planes in vertical or inclined position. The best building stones are bright red on freshly quarried surfaces but after long exposure assume a dull brownish red. The Manassas stone is especially free from the nodules and concretions common to many of the sandstones along the eastern border of the Triassic. Possibly the best building stone of the red sandstones is that of the State quarry near Stevensburg. This sandstone is highly indurated and offers much more resistance to breaking than the stone examined in any of the other quarries.

The red sandstone was once a rather popular building stone but it reached its zenith shortly after the Civil War when it was replaced by granites, gray sandstones and limestones, all stones of a lighter color. Not only have the red sandstone quarries of Virginia undergone decline and been abandoned, but the same wave of unpopularity has affected the red sandstones of the Connecticut Valley.

Manufacture of cement on an extensive scale, the ease with which it is handled and its low cost have crowded out building stone and many quarries over the country are abandoned. Just whether there will be a swing back to the use of building stone remains to be seen. From the standpoint of time cement is not as well tested as building stone and it is questionable whether it will stand the test of time as well as stone. It appears now that, with the probable improvement in cement which will come with a better understanding of its physical and chemical characteristics brought about by routine experimentation, building stone will not have the demand it once had and its future will remain eclipsed by cement.

DIABASE

Diabase has been used to a very small extent for building stone. The main reason for its limited use in this respect is the general lack of popularity of building stone in the face of concrete plus the fact that the quarries now in operation were not very active at the time when building stones were popular. Only two quarries, the Belmont Trap quarry of Loudoun County and the Buena Granite Company of Culpeper County, have opened up in diabase, and both of these are located in the Potomac area.

Diabase takes a very high, beautiful and lasting polish and makes an excellent building stone. It possesses great crushing strength, about equal to that of granite and syenite. It is fully as difficult to quarry as granite, though in some of the Virginia localities it possesses joint planes which render it possible to take out blocks with less effort than in some of the massive deposits which have no such planes.

It has been used locally around the quarries and throughout the region of dikes for foundation stone and has been shipped to Washington for the same purpose. Several residences at Leesburg are built of diabase and this has proved to be as satisfactory a stone as could be had, but the fact that it is as costly as granite and is a dark color makes it undesirable. Stone of medium grained texture is the most desirable for building stone and the fine to dense rocks will never be popular. Medium grained rock, when it contains a large amount of feldspar and less pyroxene and other dark constituents which give it a distinctly light gray color, is about as desirable as granite, and this variety is often referred to by quarrymen as "salt and pepper" stone.

ROAD METAL

Diabase is the best kind of Triassic rock used for road metal and no rock has better qualifications for this purpose. It is somewhat difficult to crush but is sufficiently satisfactory to fully justify its use.

There are but three good sized quarries opened in diabase. The only one in operation is the Belmont Trap Rock quarry and, as the principal bulk of stone is used for road metal, it will be described here and mentioned under the other headings of use, namely concrete filler and railroad ballast.

Belmont Trap Rock Quarry.—The Belmont Trap Rock quarry was opened approximately 45 years ago and is situated on the east side of and contiguous to Goose Creek 4 miles southeast of Leesburg, Loudoun County. It is accommodated by the Washington and Old Dominion Railroad, an electric line extending from Washington City to Bluemont. Its water needs are well provided for by Goose Creek which is about 50 feet lower than the quarry, and being so much lower the quarry is not troubled by the water problem.

This quarry was opened first about 1880 and was handled by several managers until 1910 when it passed to the management of the present owner, Mr. C. M. Lawrence of Herndon, Virginia. This quarry has been operated continuously since 1910 and has realized a steady and progressively increasing output of stone. The quarry was operated by the railroad at one time and during this period the chief use of the output was for building stone. Its chief uses today are concrete filler and road metal and to a less extent railroad ballast.

The average output per day during the summers of 1920 and 1921 was approximately 200 to 250 net tons. The demand was greater than the mechanical equipment could handle and as a result the company was far behind with orders. Labor up to that time had been rather satisfactory and had given no serious trouble. The great bulk of the rock was used in road building and shipped to Washington, Alexandria and Fairfax.

The quarry equipment in use up to the summers of 1922 and 1923 was as follows: Two boilers, 40 and 80 horse power respectively; one

100 horse power engine; one air compressor 10-10, requiring 40 horse power Ingersoll-Wrenn engine; one screen 18 feet by 40 inches; one 54 foot elevator; one No. 6 Gates (Gyratory) crusher; one 13 inch by 24 inch Buchanan crusher for screenings; and two Ingersoll-Wrenn drills. Also there were several hundred feet of steel rail track and a large number of small cars. The stone as taken from the crusher was loaded into cars and shipped.

The amount of overburden is relatively small, usually consisting of soil up to 2½ feet in thickness. The rock is drilled at wide intervals and great masses are shot down by dynamite and broken up to smaller sizes by sledges. This is loaded into the quarry cars and drawn up a 120-foot incline to the top of the main crusher and screen building. Here the rock enters the crusher. On leaving the first crusher it is screened and the larger fragments are directed into a smaller crusher and finally to the storage bins. The bins load cars by gravity and thus lessen the cost of handling the material.

The stone is rather hard and tough to crush and this causes a great amount of wear in crusher jaws. These jaws are built of the best grade of molybdenum steel and have to be replaced on the average of twice per month. There are two types of diabase crushed in the Belmont quarry, the coarse and the medium textured, and the coarser the texture the easier is the crushing process.

The physical and mineralogic characteristics of this stone have already been described under the subject of stratigraphy. Its minerals in the main are plagioclase feldspars and pyroxenes of monocline class and they break in the crushing process, leaving an extremely angular rock well suited for binding in road beds and interlocking in concrete. The French coefficient of wear is around 15, the hardness 18.5, and the toughness 16.0. The per cent of wear varies around 2.8-3.0. Its cementing power is unsurpassed by any rock in the state.

The diabase reserve in the Belmont Trap Rock quarry and vicinity is enormous. The quarry lies in a belt toward the eastern edge which extends in a northwest-southeast direction for 10-15 miles and is from 2 to 4 miles wide. It is the great Belmont Stock. No drill has ever tested the depth of the diabase but the surface conditions indicate a great amount. This type of rock is unexcelled along the lines for which it is used and the future of the quarrying is quite encouraging.

Buzzard Mountain Quarry.—The most recent quarry for ballast is situated on Buzzard Mountain, 1¼ miles east of Buena and 3½ miles northeast of Rapidan Station. The rock is medium to fine grained diabase. This quarry was opened in 1919, superintended by Mr. Lamond of Washington, and operated by the Southern Railroad. The amount of rock quarried must have been approximately 1,000-1,500 cubic yards. The quarry was idle in 1921 but the machinery was still on the ground.

During 1926 the Buena quarry was opened again for the production of dimensional stone by Everett B. Ainsley, under the name of the Buena Granite Company. There are two varieties of diabase in this quarry, a light gray and a dark gray, and the rock is sold under the trade name of granite. It has been quarried in other sections of the Triassic area, as for instance, near Gettysburg, Pennsylvania, where it is known as "Gettysburg granite." A recent analysis of the Buena diabase is listed on page 56 and older analyses on page 57.

The Buena diabase has a very pleasing color when polished. The ratio of plagioclase feldspar or light colored minerals to the augite and other dark colored minerals determines the tone of gray in the rock. It takes a beautiful and lasting polish and meets all the requirements for building stone. The United States Department of Agriculture reported the following test upon diabase:

Analysis of Buena Granite, Culpeper, Virginia

	Per cent
Per cent of wear	3.2
Hardness	19.3
Toughness	12.0
Weight per cu. ft. in lbs.	191.0
Per cent absorption	0.17
Crushing strength (lbs. per sq. in.)	37,550

	Per cent
Essential Minerals:	
Plagioclase—Silicate of alumina, lime and soda	49.2
Augite—Silicate of alumina, magnesia and iron	47.8
Accessory Minerals:	
Magnetite—Magnetic oxide of iron	1.2
Biotite—Hydrous silicate of alumina, iron, magnesia and potash	0.4
Secondary Minerals:	
Kaolin—Hydrous silicate of alumina	1.4
	100.0

The rock is rather tough and on account of having few or no joint planes parallel is expensive to quarry. For purposes requiring this particular tone of gray the rock is as desirable as could be obtained, since its polish, beauty, wear, and crushing strength are satisfactory. As a monumental stone the dark gray variety has a distinct advantage over other light colored stones, such as granite, in that the dark color does not glare in the sunlight and the lettering shows up as a very light gray, giving an excellent contrast. The stone is excellent for use as markers along a highway, as will be readily recognized by one familiar with its qualities.

The equipment consists of an engine and boiler of around 120 horse power, a large capacity crusher, cylindrical screen, storage bins, and water tank. There is from three-quarters to a mile of spur track with a fairly good grade from Buena to the quarry. The machinery has been protected and is in fair shape. The reason for closing this diabase quarry was the difficulty in crushing the stone.

Buzzard Mountain consists of two peaks and the quarry is situated on the west side near the base of the western peak. The summits of the peaks are from 550 to 660 feet above sea level and 150 to 200 feet above the level of the surrounding country. These peaks are composed exclusively of diabase. The western and northern slopes are gentle but the southeastern and eastern sides are very precipitous and show great boulders of diabase which have vertical faces of 25 to 60 feet. The mountain is covered with a fine growth of trees and nowhere in the world are better examples shown of the profound influence of organisms on weathering. In these rocks are numerous fissures and joint planes and ingrowing tree roots are continually increasing the size of the fissures. Everywhere the diabase is covered with liverworts and lichens that are instrumental in the process of weathering.

The physical features of the Buzzard Mountain diabase have already been described and a recent chemical analysis given under igneous rocks. The rock is of a uniform and fine to medium texture and breaks with the same ease in all directions. It is tough and must give high crushing and abrasion tests. From all appearances it is as satisfactory as the Belmont diabase. Its fineness of grain may have something to do with the difficulty in crushing it.

The amount of material available on the two peaks at Buzzard Mountain is enormous. The mountain, or ridge more properly speaking, is a little over a mile long in a northeast direction and less than half a mile wide, somewhat like a dumb-bell in shape, and the average height is 150 feet, which gives an idea of its size.

Another small road quarry was opened up during the summer of 1922 on Little River, 8½ miles south of Leesburg on the main Aldie-Leesburg pike. This rock is of a finer texture than the Belmont rock but it is an excellent rock. The stone has been used to build the new stretch of road from Aldie to Fairfax along the old Fairfax pike.

A small quarry was operated 12-15 years ago 1 mile east of Aldie. This rock was a fine-grained to a dense basalt and proved to be a fairly good stone. The production of this quarry was quite large and the stone was used to build the road beween Aldie and Middleburg. Some of the machinery, such as the sizing screens and boiler, is still at the quarry. In 1922 a trap quarry was opened for production of road metal about 4 miles north of Aldie.

The amount of diabase available in the Potomac area is sufficient to build all the roads needed in that section. Most of the diabase is limited to this area anyway. There are 4 large stocks and at least 12 good size dikes. The Sterling and Mt. Pony stocks have never been opened up and the Buzzard Mountain stock has but one quarry and that is idle at present. South of the Belmont Trap Rock Quarry along Goose Creek and then through the region of Arcola (Gum Spring) the surface gives evidence of a great stock of diabase. It is to be regretted that this rock is not available in those sections of the state where either inferior rock must be used or high freight rates paid on rock from a distance.

Limestone Phase of the Border Conglomerate.—The limestone, conglomerate is used in a limited way for road building. Both quarries in this conglomerate are located in Loudoun County. The main limestone quarry of the county is that of the Leesburg Lime Company, Inc., but inasmuch as the great bulk of its rock is used for other purposes than road metal the quarry will be described later.

The main quarry for road metal and producing only road metal was opened about 1919, 2 miles north of Lucketts and the stone was used by the State Highway Commission to furnish the road metal for the construction of the macadam pike between Leesburg and Point of Rocks. This quarry is in a flat exposure with very few large conglomerate boulders. The type of conglomerate has been described previously but, in brief, it is one of the two classes of the limestone conglomerate phase. The two phases are the red or ferric iron matrix and the white to gray matrix. This quarry north of Lucketts is the red matrix. The pebbles of limestone vary from very small to great dimensions and are chiefly limestone in composition, derived from the Shenandoah limestone.

The conglomerate is broken up by blasting and reduced to sizes small enough for the crusher. After passing the crusher it goes to the sizing screen, is there graded, and then stored in bins. The rock is rather difficult to crush as the shape of the rounded pebbles, although they range around 3 (Moh Scale) in hardness, increases the crushing difficulty. The rock makes a fairly good road metal but it does not bind as well as the diabase because so many rounded pebbles smaller than the crusher size escape crushing and remain rounded, and much of the crushed material has curved sides. This rounding detracts, it seems, from the binding of the pebbles. The finely crushed material is excellent for top surfaces, and with asphalt it makes as good a surface as can be made from the limestone. This quarry north of Lucketts was only of a temporary character and is closed at present. The conglomerate will not make good agricultural lime on account of the high iron content.

Trap Phase of the Border Conglomerate.—The trap phase of the Border Conglomerate has been used more extensively for road metal than the limestone phase. Three quarries have been opened up by the state near the town of Culpeper. The oldest quarry, now little used, was opened about 1912; it is situated 1 mile due southwest of Culpeper on the main Culpeper-Charlottesville pike. The second quarry to be opened is about 1.8 miles south of Culpeper on the east side of the Southern Railway; this quarry was opened in 1919 and was abandoned in 1922. The third quarry, opened about 1923, west of the Southern Railway and 1.5 miles south of Culpeper, is in operation at present and shipping crushed stone.

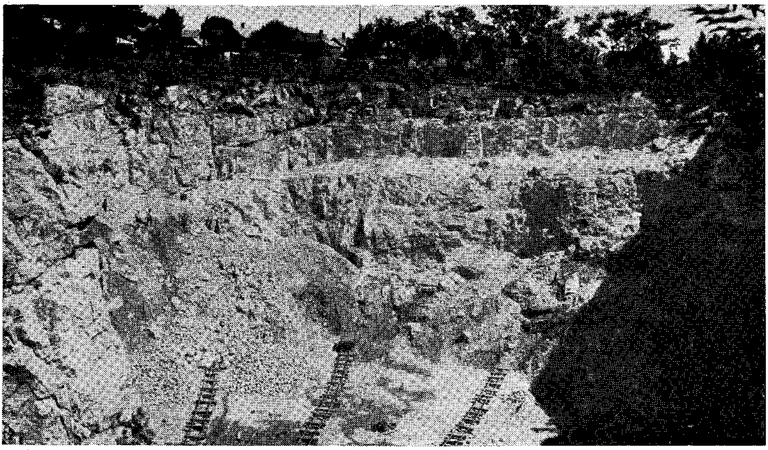
The character of the trap phase of the Border Conglomerate is in many respects similar to the limestone phase except in chemical composition and hardness. Along the western border of the Triassic basin in the vicinity of what is now Culpeper the pre-Cambrian trap and metamorphosed rocks were available to form the basal conglomerate, just as around and to the north of Leesburg limestone was available and three phases of conglomerate were formed under the same set of conditions, only of different material. Rounding of pebbles, ferric iron forming in the cement, and many other things went on under the strictly residual environment.

The conglomerate is blasted from the formation and reduced by sledge hammers to sizes small enough for the crusher. After passing through the crusher it is graded by the revolving sizer and dumped into bins. The same trouble of the small round pebbles is encountered but this is not as noticeable as in the coarser grades of the limestone conglomerate. The stone binds well and for water bound macadam roads it equals basalt and diabase. The amount removed from the first quarry exceeds that mentioned above taken from the second quarry. Until recently the stone was used exclusively in Culpeper County.

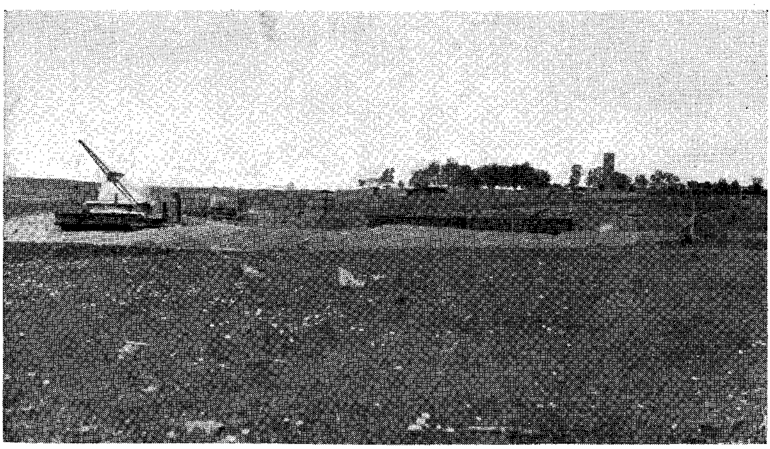
The equipment consists of crusher, air drills, one boiler and engine, sizer and storage bins. The conglomerate occurs along hill sides and has up to 3 feet of overburden. The weathered zone is not very thick and very little rock has to be lost. This trap phase is the best suited of all the conglomerate for use as road metal. It is the nearest rock of good grade to this section and it has a good future.

Arkose Phase of the Border Conglomerate.—The arkose phase of the Border Conglomerate has been used slightly for a road metal. Small quarries in this kind of stone have been worked south of Oatlands and east of Aldie. The stone makes a very good road metal but its use has been very small. Close to this stone are outcrops of red sandstone and further east red shale comes in, giving the entire Triassic sequence.

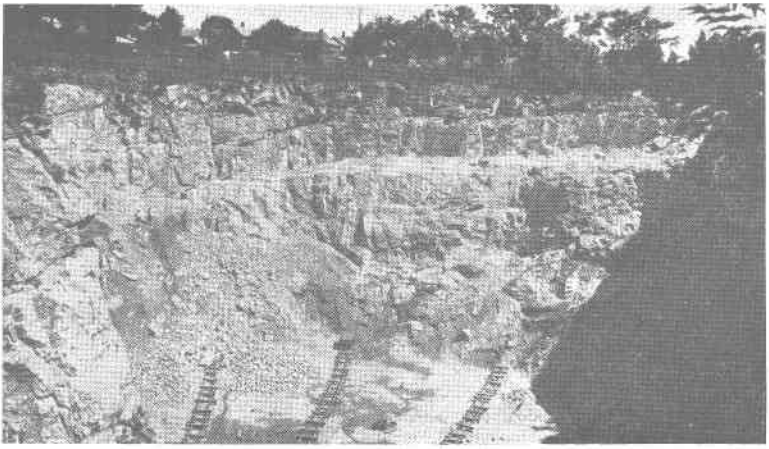
Schist Phase of the Border Conglomerate.—A small quarry has been opened since 1919 in the schist conglomerate, 1½ miles north of



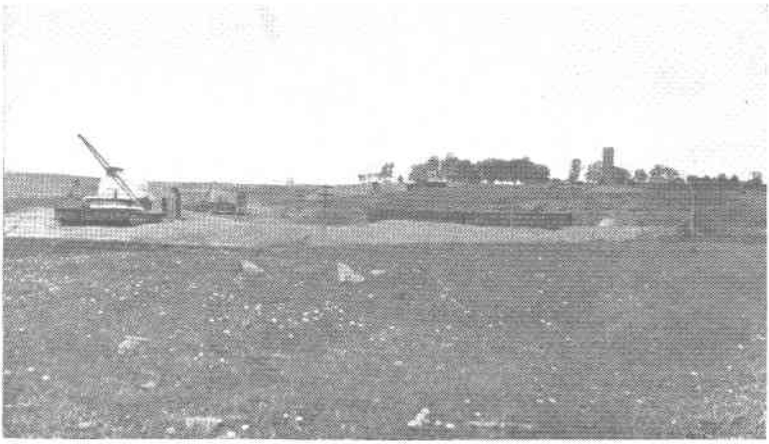
A. View of the Leesburg Lime Company's quarry operating in the Border Conglomerate (limestone phase) on the east side of Leesburg, Loudoun County.



B. View of the quarry operating in the Border Conglomerate (trap phase) 1¼ miles south of Culpeper, Culpeper County.

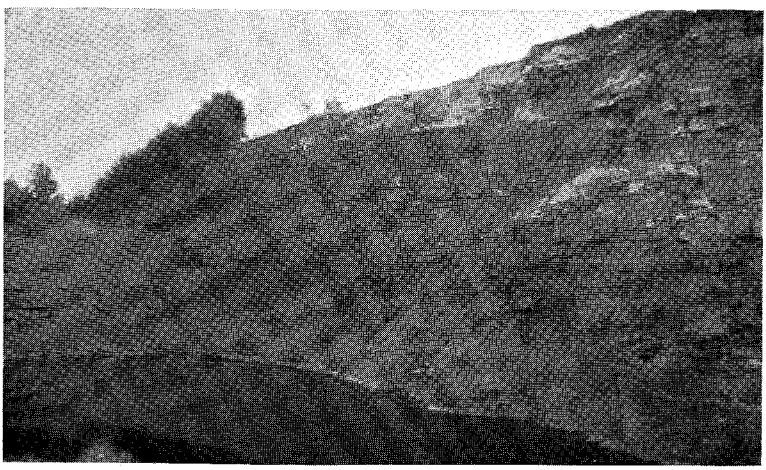


A. View of the Leesburg Lime Company's quarry operating in the Border Conglomerate (limestone phase) on the east side of Leesburg, Loudoun County.



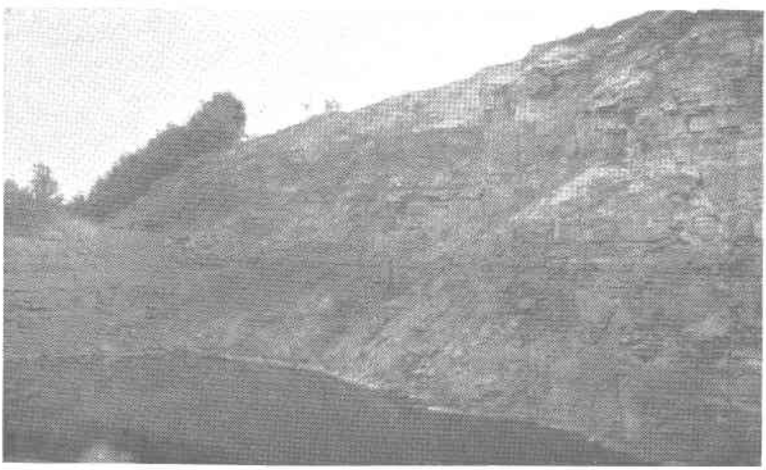
B. View of the quarry operating in the Border Conglomerate (trap phase) 1¼ miles south of Culpeper, Culpeper County.

A. View of the north wall or side of the Belmont Trap quarry showing jointing in an east-west direction. (Photographed by Thomas L. Watson.)



B. View of an abandoned quarry in the red sandstone and shale, 2½ miles southwest of Bristow, Prince William County, opened up by the Southern Railway.

A. View of the north wall or side of the Belmont Trap quarry showing jointing in an east-west direction. (Photographed by Thomas L. Watson.)



B. View of an abandoned quarry in the red sandstone and shale, 2½ miles southwest of Bristow, Prince William County, opened up by the Southern Railway.

Herndon. This stone does not make a very resistive road metal compared to the diabase and trap and limestone conglomerate, but it is the best rock near Herndon. The quarry was not active during any of the field season. It will never have much demand because of the enormous amount of diabase a few miles west at Sterling and the Belmont Trap Rock Quarry.

Sandstone for Road Metal.—The Manassas sandstone has been used in the last 10 years for road construction. As a general rule the sandstone is not indurated to a sufficiently high degree to be suitable for a road metal and it is only in a few cases of metamorphism that it can be used. Three quarries have been opened in the sandstone, two in the Potomac and one in the Danville area. Nowhere else in the entire Triassic does any sandstone occur which would meet the requirements of a road metal except on the eastern edge of the Richmond area underlying and associated with the coals, but the abundance of granite in this region completely eliminates the sandstone. The first quarry opened up for road metal is one-half mile east of Brandy Station. The sandstone is well jointed and has been altered almost into a quartzite. It was used about 1918 for road construction near Brandy Station. It possesses good wearing qualities and binds well. The quarry was out of commission in the summer of 1922 but the State was preparing to quarry stone to build a road from Brandy Station to the Culpeper-Fauquier line, the Rappahannock River near Remington. The stone is very brittle, crushes rather easily, and altogether is quite satisfactory. It carries little overburden in this section and the dip is approximately 12° N. E.

The second quarry to be opened is the White Oak Mountain quarry, 5 miles south of Chatham. The stone was used in the Chatham-Danville pike and is partly a red and gray conglomerate and a fairly coarse textured sandstone of red, grayish red, and gray colors. The sandstone is highly indurated and is probably the best sandstone in the Triassic for road metal. It is thick bedded with little or no jointing. The usual machinery which the Highway Commission has adopted was being used in the quarry during the summer of 1922. This is the nearest road metal to Chatham. The diabase dikes are narrow and not well exposed in this vicinity nor are they sufficiently well exposed for quarries in any of the areas south of the Rapidan River.

The latest quarry was opened during 1922, 1 mile east of Stevensburg and the rock was used on the Culpeper-Stevensburg road. The sandstone is a deep to light red color and highly altered, presumably by the Mt. Pony diabase body which lies south of the sandstone. The sandstone dips 10° N. W. and strikes N. 60° E., very different from the strike and dip of the red sandstone and shale a short distance west. The stone is difficult to crush and reports claim it is excellent in abrasion and binding tests. The quarry, like all road quarries, is temporary in its operation.

The Bull Run shale has been used in one instance south of Manassas, but without success. The shale is soft and soon disintegrates, causing mud in winter and wet weather and dust in dry weather. Mixed with a proper amount of sand, it might be used but its length of service would not be very long. The blue shale which occurs west and northwest of Cascade would make a fairly good road metal since it will not disintegrate as easily as the red shale.

AGRICULTURAL LIME

There is only one source for agricultural lime in the Triassic and this is the limestone phase of the Border Conglomerate. Only one quarry is producing such limestone at the present time and this is the Leesburg Lime Company, Inc. This quarry was opened in 1888 as the Leesburg Lime Quarry Company. It is in operation the entire year and produces stone for agricultural purposes, both raw and burnt, also for macadam and concrete purposes. Approximately 70 per cent of the lime is burned.

The machinery used at the present time in this quarry is as follows:

1 hoisting engine
2 Austin gyratory crushers, No. 2 and No. 5
1 Sturdevant open door grinder
1 jaw crusher
1 Sturdevant separator
2 boilers—60 H.P.
2 steam drills
1 horizontal steam engine—50 H.P.
1 air compressor
5 pot kilns, capacity 12 tons each per day.

The quarry in 1920 was rectangular in opening, 350 x 300 feet at surface, 285 x 275 feet at bottom, and the average depth was approximately 106 feet. The old quarry a few hundred feet to the east of the present quarry was opened in 1884 by Colonel E. V. White. The initial output was about 200 bushels as compared with about 125,000 bushels in 1919. Originally the lime was sold on a guaranty basis and proved very satisfactory.

The rock runs high in lime content with little magnesia, iron, alumina and silica. When burned the small amounts of iron, alumina and silica form a clinker of silicates, which must be ground. There is a great demand for the burnt lime as it is an excellent quality and the only limestone in this section east of Catoctin Mountain.

The conglomerate is very consolidated and weighs approximately 2,600 pounds per cubic yard. The conglomerate for burning is passed through the crusher and then charged with coke into kilns heated by coal. Thirteen tons of coke burn 25 tons of the conglomerate. There is a great thickness of limestone conglomerate adjacent to this quarry. The depth of the town well at Leesburg is 360 feet and it does not penetrate the limestone conglomerate. No core drilling has been done in this section, hence the depth of the conglomerate is unknown. The quarry is not more than one-half to three-quarters of a mile east of the great Border Fault, the western limit of the Triassic belt.

A chemical analysis made in 1904 will be found under the stratigraphic description of the limestone phase of the Border Conglomerate. An analysis made since 1920 has been furnished by the Leesburg Lime Company, Inc., which is as follows:

Analysis of limestone conglomerate at Leesburg

	Per cent
Calcium carbonate ($CaCO_3$)	65
Magnesium carbonate ($MgCO_3$)	20
Silica (SiO_2)	10
Iron oxides (FeO and Fe_2O_3) Alumina (Al_2O_3)	5
	100

The quarry is running full time and is usually behind with orders, especially in the farming and road building season. The average annual production for the past few years, as reported by the company, is as follows:

Average annual production of Leesburg Lime Company, Inc., 1918-1921

	Tons	Per cent
Agricultural ground burnt lime	2,000	47.6
Agricultural burnt lime, run of kiln	500	11.9
For road construction	1,500	35.7
For concrete	200	4.8
	4,200	100.00

The entire production is disposed of by shipping over the Washington and Old Dominion Railway (Electric) to Alexandria, Virginia, and to other points, as Bluemont, Fredericksburg, and Manassas. A small per cent of the output is used locally.

The burned lime meets all the requirements of a good lime and builds up the soil quickly. Excellent results have been realized from application of the finely ground raw lime. The results are naturally slower than in the case of the burnt lime but equally as desirable with many crops.

The so-called "Potomac" marble or "calico rock" has been quarried at intervals near Point of Rocks, Maryland for something over a century and a quarter but these quarries have not been operated for about 30 years. The rock was first noted by B. H. Latrobe[49] who selected it for columns in the National Capitol. It would seem from Latrobe's account that the quarries from which the stone was taken were located in Loudoun County, Virginia and in Montgomery County, Maryland.

The conglomerate takes an excellent polish and the variously colored limestone pebbles make an odd and attractive pattern. These pebbles give a great deal of trouble in the process of polishing by breaking out and leaving cavities which have to be filled in with the dislocated material, or more often by colored wax and cement. It is not likely that the quarries will be opened again as the demand for this stone is small and the difficulty and expense of preparing it for market are excessive.

STONE FOR RAILROAD BALLAST

At the present time little if any stone is being quarried from the Triassic rocks for railroad ballast. There is a great abundance of stone which meets the requirements of ballast, but it is too expensive at present day prices. The diabase, the limestone and trap phases of the Border Conglomerate, and the highly indurated sandstones, such as those north of Mt. Pony and south of Chatham, meet all the requirements of railroad ballast. The diabase is the superior stone for ballast and a quarry was opened some years ago on Buzzard Mountain. Some of the diabase produced by the Belmont Trap Rock Company at Belmont has been used for ballast. No doubt much material has been used of which there is no record. Sandstone has been used to a slight extent from a quarry near Bristow. The two ballast stone quarries opened during the present century will be described below.

Sandstone has been quarried in only one locality for railroad ballast. This was known as the Southern Railway quarry located 2½ miles southwest of Bristow, Prince William County, 200 yards east of the main line of the Southern Railway. This quarry was abandoned in 1916.

The length of the quarry is 560 feet, the width 56 feet, and the greatest depth 167 feet. The red Manassas sandstone is intercalated with the Bull Run Shales. The sandstone is of fairly good grade but the shale became so abundant that the rock used on the railroad disintegrated so rapidly it was no longer satisfactory. The strata are practically horizontal, though as much as an 8° W. dip occurs nearby

[49]Latrobe, B. H., Sen. Doc. 14th Congr., 2nd Sess. No. 101, pp. 3 and 6; Md. Geol. Surv., vol. 2, 1898, pp. 187-193.

and the strike is about N. 25° E. There is some blue shale which is highly indurated and this is the best material for ballast of all the shales and sandstones.

Of course sandstone forms the bed of railroads in a number of places though it was not quarried specifically for that purpose, but used only because the railroad was built through it. Such is the case at a number of places between Bull Run where it is crossed by the Southern Railroad and Rapidan Station, through the Scottsville area on the Southern Railway, through the Danville area both along the Norfolk and Western and Southern railways, and in the Richmond area, particularly between Vinita and Boscobel on the Chesapeake and Ohio Railway. The ordinary sandstone is not suitable for ballast but such altered sandstone as that in the State quarries north of Mt. Pony and south of Chatham would probably be very satisfactory.

STONE FOR CONCRETE

A comparatively small amount of the stone quarried from the Triassic has been used for concrete filler. The amount, however, is increasing, especially with the construction of concrete roads and the rapid and recent drift toward concrete buildings.

The Triassic diabase wherever it is found in the belts and in an unweathered condition meets all the demands for concrete purposes. Its toughness interferes greatly with its being easily prepared. When crushed it breaks with a very sharp outline and its high crushing strength makes it rather a desirable concrete filler. Its color being dark may be unfavorable, but all other properties make it a desirable stone. The Belmont Trap Rock Company is very close to Washington and the rock can be shipped in at a very low rate. Other quarries can be opened near the main line of the Southern Railway, as at Catlett, Remington, and near Rapidan and Culpeper, where there are almost unlimited supplies of diabase.

BLUE SHALE

Blue shale is found at several places in the Triassic, but the two localities where it occurs in large enough amounts to be economically important are near Cascade, Pittsylvania County on the Carolina border, and three miles east of Cascade and one mile east of Leaksville Junction along the Danville and Western Railroad.

The blue shale in the Danville area is very highly indurated and is about the most resistive rock of the whole Triassic sedimentary formations. Just northwest of Cascade it has been used for the construction of a dam on Cascade Creek and has proved very satisfactory for this purpose. So far, this is about the only use of the blue shale except for foundation work in many private homes near where it outcrops.

The blue shale strikes N. 36° E. and dips 28° N.W. near Cascade and this shale belt is about 2 miles wide. The shale is very brittle, well laminated, and of homogeneous texture. It splits evenly and would be rather easy to quarry.

RED CLAY FOR BRICK

In several localities clay resulting directly or indirectly from the weathering of Triassic shales has been used in the manufacture of brick. This clay is of Recent age but often its origin can be traced directly to the Triassic shales, so that in a way it may be regarded as being directly related to the Triassic.

The only clay of this nature at present used for the manufacture of brick is that taken from the old flood plain of the Dan River, 1 mile north of the river and 2 miles west of Oak Hill Station or Wenonda Post Office. The clay is a fairly homogeneous mixture with an occasional sand impurity and is a very deep red in color. It is taken from the pit and shipped to Danville for the manufacture of brick. This has been done for some years and the pits were fairly active during the summer of 1922. The brick is used for the most part for local purposes.

MINERALS OF SCIENTIFIC INTEREST

The minerals of the Triassic which are of scientific interest are barite and several minerals of copper and iron. Several attempts have been made to mine these minerals and a small output has been realized in some of the localities. There is no accurate record of production of the barite or the other minerals but, due to exhaustion of the present commercial deposits, advance of mining methods, and a possible increase in prices, some of these minerals may be of economic importance in the future.

BARITE

Barite ($BaSO_4$) has been found in a number of places as fracture fillings of the red and blue Bull Run shales. The principal place where it may be seen on the surface is 2 miles south of Manassas in the old shale quarry where road material was used some years ago to construct the Manassas-Milford Mills road. The fissures filled with barite in this exposure are nowhere over three-quarters of an inch wide and there is no indication on the surface which would lead one to infer that there is a commercial deposit of barite in this neighborhood. Another surface indication with somewhat the same features as the occurrence above mentioned is 3 miles southeast of Bealeton in Fauquier County.

Barite has been mined from Triassic shales in only one locality, namely, 4 miles southeast of Catlett near the southeastern edge of Prince William County. At the time field work was done for this report, the workings were abandoned and the shaft and all buildings were fallen and dilapidated. According to Watson[50] these mines were opened as early as 1845 and in all probability represent the oldest workings of barite in the State. At different times since 1845 these mines have been operated both by open cuts and by shaft. They were worked just before the Civil War, then next in 1880, in the nineties, and in 1903. This property, which is known as the St. Stephens mine, belongs to Mr. Walton of Vienna, Fairfax County.

The original shaft in the 1903 workings was about 8 feet square and there were three shafts on the property, the deepest one a little over 100 feet. The red shale and brecciated calcareous shale with the fissures of barite are not very difficult to mine. Some of the fissures were reported to be 2-8 feet wide, but their width, length, and direction were subject to much variation, especially the first two features.

The underground conditions could not be seen but the nearest outcroppings of shale three-quarters of a mile south of the old St. Stephens shaft show a strike of N. 33° E. and dip of 12° N.W., and the shales an eighth of a mile north and toward Catlett have a strike of N. 33° E. and a dip of 13° N.W. The old dump shows specimens of red and blue shale with brecciated calcareous shale, all containing many baritiferous fissures. There is no record of the directions of the fissures or whether there is one or more than one system.

Several small diabase dikes occur between the St. Stevens mine and the Southern Railway 5 miles west, but no dikes are connected with the barite deposits as far as is known. In the Manassas region no dikes are found in the red shales bearing the barite. Nothing could be gathered as to the direct origin of these fissure fillings. The specimens found on the dumps showed crystalline barite with occasional calcite and the shales often contain small cubes of pyrite disseminated through them. It is not improbable that these fissures were filled by shallow waters rather than by deep thermal waters. The fissures were the result of settling of the Triassic beds or the faulting of the rocks of the Triassic system. Fissuring is common everywhere in the Triassic but the barite filling is limited to the eastern margin and what relation this location has to the deposits is not understood. The associated limestone, which is reported to increase in depth, is highly metamorphosed and is very probably an extension of the belt of crystalline limestone which occurs at various points in the Pied-

[50]Watson, Thomas L., Mineral resources of Virginia, 1907, pp. 308-9.

mont region and is the contact member of the red sandstone and shales along the eastern border of the Scottsville area at Warminster and to the east of Howardsville.

An output of 1,500 tons of barite was reported in 1903. The mines were closed somewhere about 1910 and all of the machinery has been removed. The total production has not been large and at the present cost of operating the mines could not make a profit on the ore.

COPPER AND IRON MINERALS

Copper and iron minerals are found in a number of places in the Triassic, chiefly in the Potomac area and north of the James River. The lack both of barite and copper and iron minerals is noted especially in those areas south of the James River and at the same time there is an equal scarcity of diabase dikes and total absence of stocks and sheets.

The associated copper and iron minerals are about the same wherever found in the Triassic and they are contained in the Border Conglomerate, the Manassas sandstone and the Bull Run red and blue shale. The copper minerals consist of chalcopyrite ($CuFeS$), malachite ($CuCO_3.Cu(OH)_2$), and azurite ($2CuCO_3.Cu(OH)_2$), and the iron minerals of pyrite (FeS_2) and hematite (Fe_2O_3) which coats and colors the constituents of the red sandstones and colors the matrix of the red shales and so many of the conglomerates. Specularite, a variety of hematite, is also present.

There are five localities where one or more of the above named copper and iron minerals occur, which are as follows:

(1) On the west side of Goose Creek, 1 mile north of the Leesburg-Washington pike, Loudoun County.
(2) A few hundred feet southeast of the old Court House yard at Brentsville, Prince William County.
(3) Two and one-quarter miles southeast of Bealeton and 100 yards north of the public road, Fauquier County.
(4) Four and one-half miles east of Stevensburg, near Batna, Culpeper County.
(5) Two and one-half miles south of Culpeper, on the west side of the Southern Railway and distant from it 75 feet, Culpeper County.
(6) Three-quarters of a mile west of Somerset and also to the north of Somerset, Orange County.

The Goose Creek locality is the main one along this creek where prospecting has been done. Here are found chalcopyrite and azurite associated with pyrite and specularite. These minerals occur in the Border Conglomerate near their faulted contact with red shales and also near a stock or a dike of diabase. What little reference there is to these minerals along Goose Creek assigns them to the red shale. The old pits and shaft excavation material now found on the dumps show the chalcopyrite and associated minerals formed in the conglomerate fissures, as well as in the fissures of red shale and occasionally in red sandstone. The gangue minerals are calcite, quartz and epidote.

The shaft was put down somewhere around 1880 and is entirely fallen in now and all buildings are gone. Something like 40 barrels of the "copper-bearing rock," as it was called, were shipped but the matter never went beyond the stage of investigation. The minerals are too scarce and are often sparsely disseminated through the rock in such a way as to make the mining of them impossible.

The Brentsville locality 3 miles southeast of Manassas shows malacite and azurite associated in the red shales. This is near the eastern border of the Triassic and no diabase dikes are to be found. The copper minerals occur in small fissures and color the rock blue to green. No prospecting has been reported here and the amount of mineral matter in the shale is quite low. The colors in the shale are easily noticeable along the roadside. An old sandstone quarry is nearby and the same copper minerals are reported there.

The third mineral locality, southeast of Bealeton, was investigated in 1840, several times since, and last in 1916. The property belongs to C. C. Miller and is 2¼ miles southeast of Bealeton and not very distant from the eastern Triassic contact. At present the shallow shaft has partly fallen in and is filled with water. The minerals are crystalline pyrite and calcite and amorphous chalcopyrite. These minerals occur in a very blue and hard calcareous shale either in fissures or disseminated through the shale. This locality is about 5 miles west of the eastern contact of the Triassic with the old crystalline rocks and between two diabase dikes of considerable size.

The fourth locality near Batna shows copper stains in the red sandstone and shales. The chief minerals are chalcopyrite, pyrite and azurite. Efforts have been made at several times to develop the copper but nothing has been done in the last 40 years. The minerals are very small fissure fillings disseminated in very small amounts and the surface conditions offer no reasons whatever for any deposits of commercial value.

The fifth mineralized locality is in the trap phase of the Border Conglomerate along the Southern Railway, 2½ miles south of Culpeper. A small and shallow pit was put down at this point about 10 years ago and shows clearly a mineralized zone in the conglomerate. The Mt. Pony diabase body is not very far to the east of the pit. The minerals are specularite, azurite and malachite, with the first predominating. The minerals occur in the matrix of the conglomerate and very few fractures are found. When fracturing occurred the trap pebbles broke around at their contact with their matrix and not across the pebble. Nothing further than investigation has been done at this locality and the material is of mineralogical importance only.

The sixth and last of the mineralized localities, near Somerset, is a red sandstone with some little shale and small amounts of chalcopyrite and pyrite disseminated through it. The masses sometimes are as much as 2 centimeters in length. There is no indication of any igneous rock close by. Prospecting went on here about 80 years ago but very little is known about it by the oldest people living in the community.

The origin of the barite and the copper and iron minerals, from their mode of occurrence and position along the eastern margin of the basin, except the Goose Creek locality, their filling, fractures or dissemination through the rocks, etc., is due to the same causes. There are insufficient data on the underground relations to settle the question. None of these minerals give any sign of promise sufficient to encourage investigation at the present day.

MINERAL SPRINGS

Very few springs of any kind occur in the Triassic areas but the ground water level is everywhere shallow, coming nearer the surface in the far eastern areas than in those areas lying near the Blue Ridge. Almost all the water for domestic use is from wells and, in some of the larger towns, from streams.

Only two mineral springs of any note occur in the Triassic. One is the Berry Hill Mineral Spring near Elkwood, Culpeper County, and the other the Huguenot Springs in Powhatan County. The former is in the Potomac area and the latter in the Richmond area. A third spring may be considered by some as belonging within the Triassic but is just outside the limits of the Farmville area; this spring which is in Prince Edward County is known as the Farmville Lithia Spring.

The Berry Hill Spring near Elkton is a chalybeate water and has been used for many years. Its patronage has been fairly large and the water has been shipped to Washington. The Huguenot Springs, three in number, are only 17 miles west of Richmond. They were used until recently as a summer resort and a number of cottages are still in use. The water is sulphur and chalybeate and is very strong from the sulphuretted hydrogen. It has been used for over 100 years but at present no water is shipped from the springs. The majority of Virginia's mineral springs are in the mountainous section of the State, west of the Blue Ridge.

PALEONTOLOGY OF THE VIRGINIA TRIASSIC AREAS

HISTORICAL REVIEW OF TRIASSIC FOSSILS

The study of fossil remains in the Virginia Triassic began early in the 19th century. The earliest investigations in Virginia were made by William B. Rogers [50] who reported some of the fossil flora and fauna as early as 1840 and 1842. Rogers's work was quite a step forward in his period and he evidently devoted considerable time to studying the conditions around the Richmond Basin. He, like many others after him who were interested in Triassic geology in Virginia, was especially attracted to the Richmond Basin because of its coal possibilities and also the opportunities furnished by its pits and shafts to see the underground structural relations and to collect fossil floras.

Sir Charles Lyell [51] visited the Richmond area and in 1847 made a report in which he discussed the several phases of the Richmond Basin which appealed to the geologists of that day. He discussed the structure, thickness, and composition of the Triassic coal, the natural coke and its origin, the trap dikes, and, most of all, the fossils and the probable age of the beds.

William B. Rogers assigned the coal plants to the Lower Oölite series of the Jurassic. Charles Lyell came to the same conclusion after visiting the basin, collecting his own specimens, and making a study of them with the aid of Charles J. F. Bunbury. When Lyell visited the basin a number of shafts were open and he had better opportunity to get first hand information than has been possible much of the time since. Bunbury [52] studied and described 15 fossil plants which Lyell collected and he concluded his remarks as follows:

> On the whole, then, as far as the evidence from vegetable remains is concerned, we may say with tolerable confidence that the Richmond coal-field belongs either to the triassic or to the jurassic series; and it might be referred with almost equal plausibility to either. At any rate, there can hardly be a doubt that it is of later date than the true coal-measures. All over the continent of North America, from Nova Scotia to Alabama, wherever the great carboniferous system has been examined, it has been found to be characterized by a most remarkable similarity, and almost a uniformity, in its vegetable productions. Here, on the other hand, we find an assemblage of plants, of which all that occur in a determinable or intelligible state differ essentially from those of the carboniferous system, and of which some are identical with, and others closely resemble, European fossils of the secondary series.

There are several other references to the fossils and the age of the

[50] Rogers, William B., On the age of the coal rocks of eastern Virginia: Report of 1st-3d meetings Assoc. Amer. Geol. and Nat., pp. 298-316, 1840-42.

[51] Lyell, Sir Charles, On the structure and probable age of the coal field of the James River near Richmond, Virginia: Quart. Jour. Geol. Soc., London, vol. 3. pp. 261-280, 1847.

[52] Bunbury, Charles J. F., Descriptions of fossil plants from the coal-field near Richmond, Virginia: Quart. Jour. Geol. Soc. London, vol. 3, pp. 281-288, 1847.

Richmond Basin coals. These are more or less reviews of the works of Rogers and Lyell, but the most important mention made of the fossils after some considerable study in the field was by Oswald J. Heinrich [53] in which he sums up what had been done and adds to it things found in his own work.

In 1883 William Maury Fontaine [54] published his monograph on the older Mesozoic floras of Virginia, which dealt almost exclusively with the coal plants of the Richmond area. This work was the result of large collections of plants made over a long range of years and established a landmark in the Triassic literature of North America. Fontaine opens the discussion with a brief description of the various Triassic areas of the State, gives a systematic description of the many plants (42 species), discusses the floras of the North Carolina Triassic (Deep River) area, and then after comparison of the North American forms with those of Europe concludes his remarks as to the age indicated by the Virginia and North Carolina floras as follows:

> European authors, and especially Schimper, often call attention to the strong resemblance between the Rhaetic and Lower Jurassic floras, the likeness to the flora of the Lower Oölite of England being especially striking. In accordance with this fact, the presence of a marked Jurassic element in the flora of these Mesozoic beds, both in North Carolina and Virginia, is of itself an evidence that they can not be older than Rhaetic. We are, then, I think, entitled to consider that the older Mesozoic flora of North Carolina and Virginia is most probably Rhaetic in age, and certainly not older.
>
> Some authors hold that the Rhaetic beds form the uppermost of the Triassic strata. Others think that they are transition beds, having more affinity with the Lower Lias. The latter view will, I think, be justified by a study of the flora, and I have, in this memoir, assumed its correctness.

The next important contribution made on Triassic fossils and the age of the Richmond Basin was by Stür [55] in which he found the flora to indicate Keuper rather than Rhaetic age as suggested by Fontaine and Liassic as suggested by Lyell and Bunbury.

Zeiller [56] late in the eighties assigned the age of the Richmond coal beds to the Keuper, in agreement with Stür, and he did this by a comparison of the Richmond plants figured and described by Fontaine and Bunbury with those of Europe which are Keuper in age.

The next important contribution on the Richmond Basin was that of Shaler and Woodworth,[57] dealing more especially with the stratigraphy and structure but adding some new data to the general store of Triassic

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[53] Heinrich, Oswald J., The Mesozoic formation in Virginia: Amer. Inst. Min. Eng. Trans., vol. 6, pp. 227-274. Triassic Fossils, pp. 264-266.

[54] Fontaine, William Maury, Older Mesozoic flora of Virginia: U. S. Geol. Survey Monograph VI, 144 pp., 54 pls., 1883.

[55] Stür, D., Die Lunzer (Lettenkohlen) Flora in der "Older Mesozoic beds of the coal field of eastern Virginia": Verhandl. der K. K. Reichs, Band 10, ss. 203-217, 1888.

[56] Zeiller, René, Sur la présence dans la Grés Bigarré des Voges de l'Acrostichides rhombofolins, Fontaine: Soc. Géol. de France Bull., tome 21, p. 693, 1888.

[57] Shaler, N. S. and Woodworth, J. B., Geology of the Richmond Basin, Virginia: U. S. Geol. Survey Nineteenth Ann. Rept., pt. 2 pp. 385-515, 1899. Fossils of the Triassic, pp. 430-435.

knowledge. Appended to this work is a brief contribution of Knowlton [58] on some of the silicified wood in the basin.

In 1900 Lester F. Ward [59] published a treatise on the Mesozoic flora of the United States in which he sums up all the literature in any way dealing with the older Mesozoic flora of Virginia, along with other areas of the United States. This is an excellent summary. The views of Lyell, Stür, Shaler and Woodworth are outlined and discussed in this work and the survey is quite comprehensive up to that time. Ward's work was of about the same general character as I. C. Russell's Newark System, published in 1892 in a bulletin by the United States Geological Survey, except that the latter review summed up the literature and arranged it in excellent form and dealt with the location and extent of the Triassic areas in eastern North America.

The most recent reference to the Virginia Triassic was by Edward W. Berry [60] in 1916 in which he regards the Richmond coal plants as being Keuper in age according to views of Stür, Ward, and Zeiller and not Rhaetic as claimed by Fontaine. Nathorst in a personal communication agreed in placing the Richmond flora in the Keuper. Berry mentioned that it is a problem whether the entire thickness of all the red beds along the Atlantic Plain can be regarded as Keuper or not. He stated that, from a study of the fossil fish of the eastern American Triassic by Eastman,[61] it was established that the American forms closely parallel the Besano and Raibl beds of the Alpine Keuper. The general conclusion reached in 1916 by Berry and others was that in general the beds from New England to the North Carolina-South Carolina line were late Triassic, though there was doubt about all of the red beds belonging to this age. The writer during four years' work on the Virginia Triassic has collected certain data which are presented on pages 143-146, and will tend to correlate all six of the Virginia areas and show them to be of the same age.

The aforesaid geologists, namely, W. B. Rogers, Lyell, Bunbury, Heinrich, Fontaine, Stür, Zeiller, Shaler and Woodworth, Ward, and Berry are the main writers on the plants and probable age of the Virginia red beds. There are a number of other references of less note and these will be found in the bibliography which is appended to this report. The clash of opinion as to whether the plants of the Richmond Basin are Rhaetic or Keuper has about been settled. The problem of the land and water relations, while settled in some localities, certainly does not solve the situation by saying these relations were the same over all eastern North America during the Triassic. This matter will be discussed in the latter portion of this report.

[58] Op. cit., Appendix, Report on some fossil wood from the Richmond Basin, Virginia, pp. 515-519.

[59] Ward, Lester F., Status of the Mesozoic floras of the United States: U. S. Geol. Survey, Twentieth Ann. Rept., pt. 2, pp. 211-748. Triassic of Virginia, pp. 257-266.

[60] Berry, Edward W., The age of the plant-bearing shales of the Richmond coal field: Amer. Jour. Sci., vol. 34, pp. 224-225.

[61] Eastman, Charles R., Triassic fishes of Connecticut: State Geol. and Nat. Hist. Survey Bull. 18, 75 pp., 8 figs., 11 pls., 1911.

FOSSIL FLORA AND FAUNA OF THE VIRGINIA TRIASSIC

The earliest systematic grouping of Triassic fossils was made by W. B. Rogers in 1840-42, and the following forms were mentioned by him in an effort to place the age of the "Secondary Sandstone of the Richmond Basin."

Fossil flora:

Calamites arenaceous
C. planicostatus
Equisetum arundiniforme
E. columnare
Lycopodites uncifolius
Pecopteris munsteri
P obtusifolia
P. whitbyensis
Taeniopteris magnifoliae
Zamites obtusifolius
Z. whitbyensis

Fossil fauna:

Posidonia (Estheria, two species)
Scales of fish—Catopleris genus probably
Teeth, probably saurian.

The following forms were collected by Oswald J. Heinrich during the seventies of last century and were determined prior to 1878 by C. E. Hall of the University of Pennsylvania:

Fossil flora:

Calamites suckowii
Equisetum gamnigianus (Close to E. Mizeri)
E. mongratii (Calamites arenaceus)
E. munsteri
E. rogersi (in part)
E. tubercles
Schizoneura meriana
Cones of coniferous trees

Fossil fauna:

Beledon or Clepsysarurs tooth
Coprolites
Cythere
Dictyiopyge
Estheria minuta
E. ovata
Tetragonolepsis (whole and fragmentary specimens)

Lyell collected in person a number of fossil fauna from the Richmond Basin, and a number of fine forms were presented him while visiting there. He named several of the forms and was in doubt with regard to others. The forms identified by him were described in the *Quarterly Journal of the Geological Society of London* and are as follows:

Bivalve forms resembling Cyclas, also Posidonomya minuta
Bivalve forms resembling Astarte
Tetragonolepis, a homocercal fish
Dictyopyge macrura (Catopteris macrurus of Redfield)
Dictyopyge another species.

Lyell submitted the Richmond Coal Basin plants to Charles J. F. Bunbury for identification and description and the latter in an article immediately following the one of Charles Lyell gives the following forms with two plates of figures:

Taeniopteris magnifolia
Neuropteris linnaefolia
Pecopteris sp.
P. whitbiensis (P. tennis of Brongniart)
P. (Aspidites) bullata
Filicites fimbriatus
Equisetum columnare
Calamites arenaceus
C. ? sp. may be arenaceus
Zamites obtusifolius
Z. gramineus
Sigillaria ? or lepidodendron ?
Knorria sp.
An unidentified specimen poorly preserved.

The most elaborate treatise on the Triassic plants of the Richmond Basin during the latter part of the 19th century was by Fontainue whose monograph has been previously referred to. He described a number of forms, and some of the older ones of Rogers and Bunbury he considered to be of the same species and thus combined a number of these. His list of 44 forms, with the locality of each, is given below.

Fossil plants from the Older Mesozoic of Virginia[62]

Genus and species	Locality
Equisetum Rogersi (Probably includes E. arendiniforme of Rogers, and the casts described as Calamites arenaceus.)	General in Richmond area
Schizoneura sp.	Clover Hill (Winterpock)
S. Virginiensis, n. s.	Clover Hill
Macrotaeniopteris magnifolia	Common to the basin
M. crassinervis	Clover Hill
Acrostichides linnaefolius	?
A. rhombifolius	Carbon Hill, Gowry and Clover Hill
A. rhombifolius var, rarinervis[a]	Clover Hill
A. microphyllus, n. s.	Clover Hill
A. densifolius, n. s.	Clover Hill
Mertensides bullatus	Carbon Hill, Clover Hill, and Midlothian

[62] Fontaine, W. M., The older Mesozoic flora of Virginia: U. S. Geol. Survey Monograph VI, pp. 92-93.

Fossil plants from the Older Mesozoic of Virginia

Genus and species	Locality
M. distans, n. s.	Clover Hill
Asterocarpus Virginiensis, n. s.	Widely distributed over the basin
A. Virginiensis obtusiloba[a]	Clover Hill
A. platyrachis, n. s.	Clover Hill
A. penticarpa, n. s.	Clover Hill
Pecopteris rarinervis, n. s.	Manakin, Carbon Hill
Cladophlebis subfalcata, n. s.	Manakin
C. auriculata, n. s.	Carbon Hill
C. ovata, n. s.	Clover Hill
C. microphylla, n. s.	Clover Hill
C. pseudowhitbiensis, n. s.	Clover Hill
C. rotundiloba, n. s. ?	Near Hanover Junction
Lonchopteris Virginiensis, n. s.	Manakin, Clover Hill
Clathropteris platyphylla, var. expansa	Clover Hill
Pseudodanaeopsis reticulata, n. s.	Clover Hill, Carbon Hill, Midlothian
P. nervosa, n. s.	Clover Hill
Sagenopteris rhoifolia ?	Clover Hill
Dicranopteris sp.	Clover Hill
Pterophyllum inaequale, n. s.	Clover Hill
P. affine	Midlothian
P. decussatum	Cumberland (Farmville) area
Ctenophyllum taxinum	Midlothian
C. truncatum, n. s.	Clover Hill
C. braunianum	At most plant localities
C. grandifolium, n. s.	Clover Hill
C. giganteum, n. s.	Clover Hill
Podozamites Emmonsi	Clover Hill
P. tenuistriatus	Cumberland area and Carbon Hill, Midlothian, Clover Hill and Deep Run
Sphenozamites Rogersianus, n. s.	Clover Hill
Cycadites tenuinervis, n. s.	Hanover County
Zamiostrobus Virginiensis, n. s.	Near Midlothian
Baiera multifida, n. s.	Clover Hill and Carbon Hill
Cheirolepis munsteri	Cumberland area

From the localities mentioned above, Carbon Hill and Clover Hill hold first places because very numerous openings had been made there and material was abundant. During Lyell's visit the most elaborate workings were around the Midlothian vicinity.

F. H. Knowlton described two species of the silicified Araucarioxylon genus in the report of Shaler and Woodworth published in 1899 and this addition brings the number of Virginia Triassic forms up to 46, counting the 44 described by Fontaine, though the latter writer

[a] Described but not included by Fontaine in his table, thus making only 42 forms shown in his table.

only mentioned 42 in his table. The two forms described and figured by Knowlton are:

Araucarioxylon virginianum
A. woodworthi

Shaler and Woodworth were primarily interested in the structure and lithology of the Richmond Basin in their report of 1899 and devoted very little time to the fossil flora and fauna, except for correlations. The forms mentioned by them are as follows:

Fossil plants:

Cycad stem impressions
Cycad fruit, zamiastrobus
Seed vessel determined by Knowlton as Cardiocarpon.

Fossil faunas:

Fish scales of ganoid type
Batrachian footprints
Annelid burrows
Estheria ovata
Araucarioxylon

In 1900 Lester F. Ward collected all the various fossil floras and faunas mentioned in the literature together with those he collected at the time of his trip to the Richmond area in June, 1890. This number includes all described by the writers prior to 1900 and those mentioned by him and not included by the older accounts are as follows:

Acrostichites tennifolius (Emm.) Font.
A. tennifolius rarinerois (Font.) Ward.
A. falcatus obtusifolius (Font.) Ward.
Cladophlebis rarinervis, Font.
Ctenophyllum braunianum abbreviatum (Fr. Braun) Schimp.
C. braunianum augustum (Fr. Braun) Schimp.
Podozamites longifolius, Emm.
Pseudodanaeopsis plana (Emm.) Font.
P. obliqua (Emm.) Font.
Sagenopteris nilsoniana (Brongn.) Ward.
Schizoneura planicostata (Rogers) Font.

FOSSIL FORMS COLLECTED 1920-1923

During the four summers of work upon the Triassic of the State, a number of fossils were collected but, compared with some of the older horizons, there is a great scarcity. The great bulk of fossils in the Virginia Triassic occur in the Richmond and Farmville areas, and faunas and all traces of the same are scarce everywhere. In each of the five areas, however, there are traces of life, although in most cases these are not abundant. The fossils of each area collected from 1920 to 1923 are as follows:

Potomac area—

Fossil floras:

Palissya diffusa Emmons
Stems of conifers poorly preserved

Fossil faunas:

Fossil trails
Dinosaur tracks in northwest portion of Potomac area

Scottsville area—

Fossil floras:

Conifer stem fragments

Fossil faunas:

Trails

Danville area—

Fossil floras:

Araucarioxylon sp.
Conifer stem and cone fragments

Fossil faunas:

Trails

Farmville area—

Fossil floras:

Various fronds, pinnules and stem fragments of the typical mesophytic floras of the coal swamps
Araucarioxylon sp.

Fossil faunas:

Trails

Richmond area—

Fossil floras:

Fronds, pinnules, stems and cones of the typical coal plants described by Fontaine
Araucarioxylon sp.

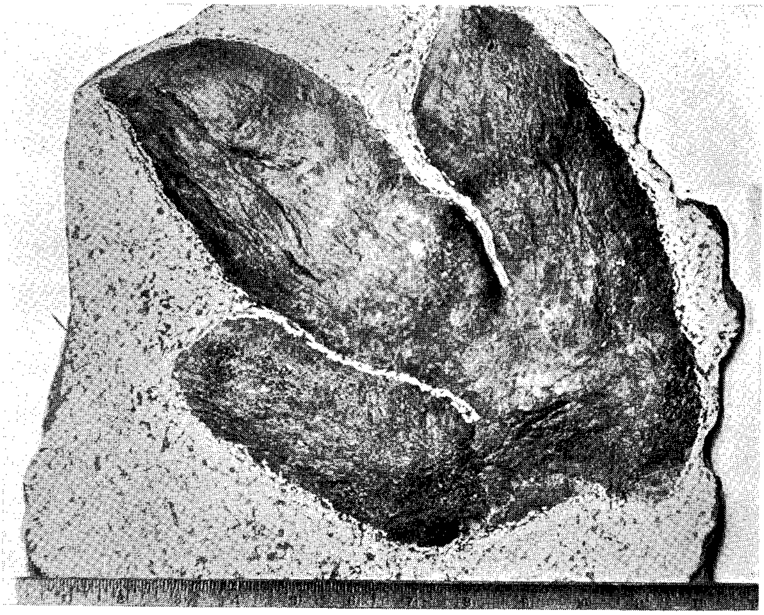
Fossil faunas:

Estheria ovata
Few fish scales
Trails

The Potomac area yields only a few fossils and most of them are unsatisfactory because of their poor preservation and fragmentary condition. The following localities have yielded plant fossils:

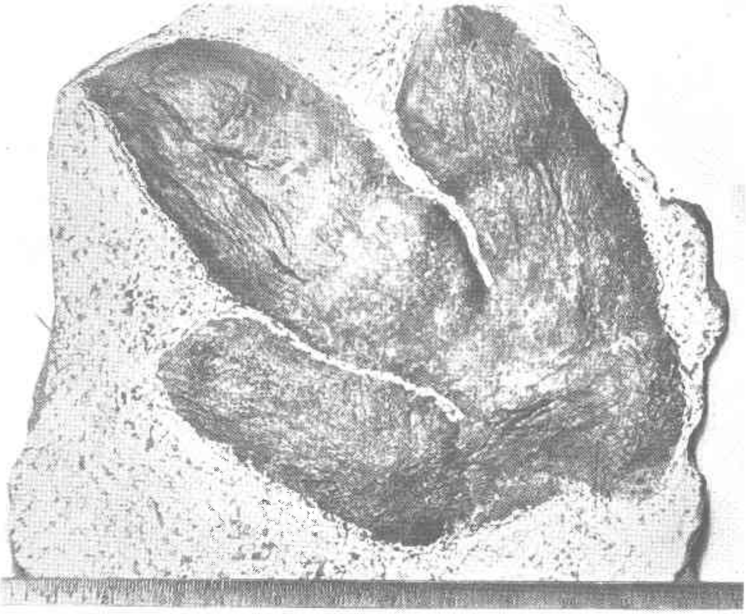
(1) Johnson property, 1 mile east of Manassas.
Palissya diffusa (Emmons) chief form.

(2) Bull Run Quarry, 2½ miles north of Manassas.
Conifer fragments.

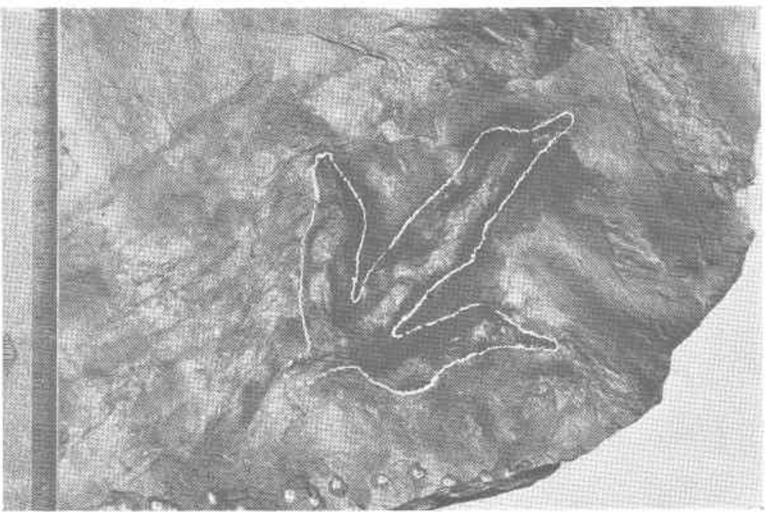


A. Dinosaur track in red shaly sandstone, from near Aldie, Loudoun County, and near the western Triassic contact.

B. Dinosaur track in thinly laminated red shale from same locality as 31, A.



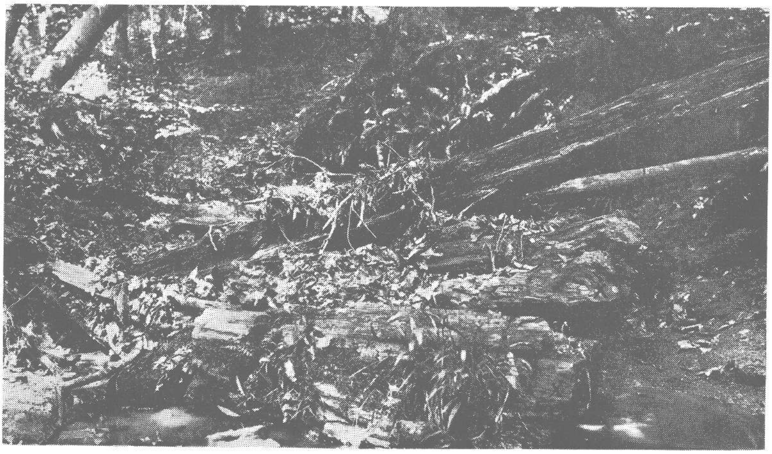
A. Dinosaur track in red shaly sandstone, from near Aldie, Loudoun County, and near the western Triassic contact.



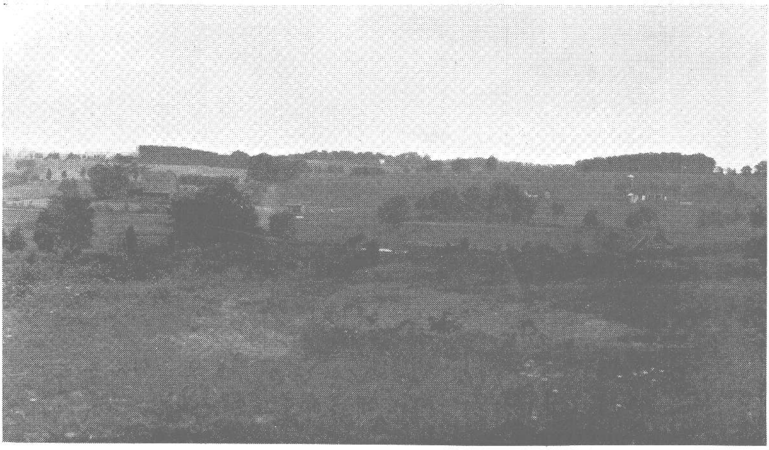
B. Dinosaur track in thinly laminated red shale from same locality as 31, A.

A. View of petrified tree trunks of Araucarioxylon sp. in a small branch 1½ miles west of Otterdale, Chesterfield County.

B. View of Bull Run shale topography on the Bull Run Battlefield. The shale in this locality shows fairly abundant "fossil trails."



A. View of petrified tree trunks of Araucarioxylon sp. in a small branch 1½ miles west of Otterdale, Chesterfield County.



B. View of Bull Run shale topography on the Bull Run Battlefield. The shale in this locality shows fairly abundant "fossil trails."

(3) Bull Run Battlefield, south of Cross-roads, 3 miles west of Manassas.
Plant stems.

(4) On Hoppen Run, 5½ miles south of Bealeton.
Conifer fragments and a few pinnae.

The Joseph Johnson property, one mile east of Manassas is the only locality for Palissya diffusa Emmons. This fossil form was determined by E. W. Berry of Johns Hopkins University. The leaves are small and show scarcely any venation. The stems are broken and badly preserved. A few small cones occur but these are crushed. The plants are found in clay lenses on the Johnson property and near the eastern edge of the Potomac Basin.

The clay lenses, several in number, are a dove color, but some are light yellow and light gray. They are contained in a very fine grained sandstone of red color which is underlain by an arkosic red conglomerate. The lenses are not more than half a mile from the Triassic-Piedmont contact. Usually these clay lenses are 2-3½ feet thick and are as much as 60 feet long. In nearly every case where they are found plants are also found. They perhaps represent ponds or stagnant water bodies in the Triassic basin along which the plants grew, and the leaves falling into the water were covered up by the silt washed in by rains and blown in by winds.

According to Berry, these coniferous fragments suggest nothing of a mesophytic swamp vegetation such as is characteristic of the coal regions in the Richmond area and also in the Deep River area of North Carolina. The Palissya diffusa has been described from the North Carolina Triassic by Emmons[63] and from Pennsylvania by Brown.[64] It has coriaceous leaves. Its conditions of preservation suggest its having lain for some time upon the ground and its final deposition in small temporary bodies of water.

Palissya diffusa was first described by Emmons in 1856 as a Walchia and the following are the various references, also the generic and specific terms for the form:

Walchia diffusus Emmons, N. C. Geol. Surv. Bull., Rept. of the Midland Counties of North Carolina, 1856, p. 333, Pl. III, fig. 2; American Geology, Pt. 6, 1857, p. 105, pl. III, fig. 2.

Walchia gracile Emmons, American Geology, Pt. 6, 1857, p. 108, fig. 75.

Cheirolepsis munsteri (Schenk) Schimper. Fontaine, U. S. Geol. Surv., Mon. VI, 1883, p. 108, Pl. L, fig. 3; U. S. National Museum, Proc., vol. 13, 1890, p. 284.

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[63] Emmons, Ebenezer, Geological report of the Midland counties of North Carolina: North Carolina Geol. Survey Bull., p. 333, pl. 3, fig. 2, 1856; American Geology, pt. 6, p. 105, pl. 3, fig. 2, 1857.

[64] Brown, Amos P., New cycads and conifers from the Triassic of Pennsylvania. Acad. Nat. Sci. Philadelphia Proc., vol. 63, p. 19, pl. II, 1911.

—— Newberry, J. S., U. S. Geol. Surv., Mon. XIV, 1888, p. 90, Pl. XXII, figs. 4 and 4a.

Palissya diffusa (Emmons), Brown, A. P.: Acad. Nat. Sci., Phila., vol. 63, 1911, p. 19, Pl. III.

This form as originally described by Emmons[65] is as follows:

Stem and branches thickly covered with small lanceolate leaves, clasping at the base; larger upon the main stem than branches; branches numerous, and irregular, often elongated, leafy.

This species is quite abundant at Ellington's in the blue slate. It does not occur in the carboniferous slates at all. There is one in this lower formation, however, which is only seen in fragments, but I believe it is quite different. It has been referred to.

Palissya diffusa occurs in the Triassic of Virginia, North Carolina, Pennsylvania, New Jersey, questionably in Massachusetts and Connecticut, and in New Mexico. It is significant that it is found no where in the eastern United States associated with the carbonaceous shales except with those of continental origin such as the red and blue shales and clay lenses of the shales and sandstones. This form is evidently what Lester F. Ward found during his trip through the Virginia Triassic while he was looking over the red sandstone quarries near Brentsville, the old County seat of Prince William County.

The other three localities mentioned above show fragments of plant stems, some of which evidently belong to the Equistales group. At times these stems are as much as 7 inches long and some show occasional nodes. The diameter may attain as much as from 5 to 6 millimeters. The fragments having nodes show very fine parallel striae which are often crushed out in the flattened forms. These plants owe their poor preservation to the continental environment which is clearly reflected in them. They are found almost always in the sandstones and must have been subjected to much decay prior to their being incorporated in the sediments. The more delicate parts evidently decayed or were disintegrated by being blown about over the surface.

FAUNAS OF THE VARIOUS AREAS

The Potomac area yields many fossil trail specimens and the best localities for collecting them are as follows: Three miles east of Leesburg on the Potomac River bluffs; three-quarters of a mile south of Ashburn on the north side of Beaver Run; near Ryan on the public highway; west of Ashburn in the Old Dominion Railway cut; at the cross-roads on Bull Run battlefield 4 miles west of Manassas; east of Buckland on the north side of Broad Run; and 1 mile east of Batna.

The so-called "fossil trails" are interpreted by geologists in different ways. Some of the older writers, such as Nathorst, regarded them as

[65] Emmons, Ebenezer, op. cit., p. 333, 1856.

of purely mechanical origin. On the other hand, others of the older geologists regarded them as due to organic causes and attributed them to plants, thus giving such markings the generic term "Fucoides." Walcott and others have shown that many of these so-called "Fucoides" are trails of crustaceans and other crawling forms. Such trails as are found throughout the Triassic of Virginia likewise occur in the red shales and sandstones of the Connecticut Valley, New Jersey, Pennsylvania, Maryland and North Carolina.

In Virginia the "fossil trails" are always confined to the red shales. They are straight to sinuous lines, smooth and convex upward. They are single and in no cases show any tendency whatever toward branching, as would be the case were they plant remains. The very red and thin bedded shales do not show any trails but they are limited to the thicker bedded shales of a dull red color and a more muddy nature.

A note appeared in the November 23, 1923, issue of *Science* regarding the occurrence of dinosaur tracks near Aldie, Loudoun County, Virginia. This find was due to Frank Littleton, who noted the tracks in some of the red shaly sandstone blocks around his house. Littleton opened up a quarry about three-fourths of a mile north of his home and took out some of these slabs. The material is a thin to medium laminated shaly sandstone and dips at about 25° W. Certain layers show abundant mica, and sun cracks, rain drop impressions, and ripple marks are common.

The tracks are fairly numerous and range from a fraction of an inch to several inches in length. The smallest ones measured were about one-third of an inch long, and one of the largest measured was 16 inches long and 12½ inches wide at the maximum spread. Some of the tracks are well preserved, as they were formed in the sand and afterwards mud washed upon them. Tracks made in the muds ran together or closed in after the foot was removed and have not been so well preserved. In several cases the tips of the toes are quite well indicated. So far no skeleton remains have been found.

Fossil trails are found in each of the areas, inclusive of the outliers of the Farmville and Richmond basins. It is quite noticeable that they are less frequent in the areas south of the James River and least frequent of all in the two coal-bearing areas. The trails represent in all probability the tracks made by the small forms which after rains in Triassic times crawled about over the red muds in search of food.

FLORAS OF THE VARIOUS AREAS

The Scottsville area yields nothing of any importance or differing from that found in the Potomac area. There are some conifer stems and numerous fossil trails. These two forms are found north of Somerset and just north of Barboursville.

The Danville area contains about the same type of conifers as the above named areas and a few trails, but in addition there are three localities where specimens of Araucarioxylon may be picked up in large numbers. The largest of these areas is 10 miles northwest of Danville on the Danville-Rocky Mount road on the property of Robertson Brothers. The second largest occurrence is 10 miles southwest of Danville and 2 miles southeast of Hall's Corner on the Horton property. The third locality is 8½ miles west of Danville near Lebanon (negro) Church.

In all the localities of the Danville area where the Araucarioxylon is found, it occurs scattered over the surface and is not found in place. Some of the fragments measured 22 inches long and had a 14 inch radius, though the average size is 3-4 inches in diameter. Many of the specimens show the wood twisted and also knot structures. Light and dark colored areas run lengthwise in the specimens, probably of a fibro-vascular bundle structure. In all the megascopic aspects the Araucarioxylon specimens of the Danville area resemble those of the Farmville and Richmond areas and only thin sections will reveal the structures.

The Farmville area has quite a different assemblage of fossils compared to the areas previously mentioned. It closely resembles the Richmond area, and these two had a mesophytic swamp environment during Triassic time while the four western areas were of continental nature. Thirty years or more have elapsed since the coal pits north of Farmville were open and now it is no longer possible to procure fresh specimens of any great variety.

On the property of W. W. Jackson, one mile northwest of Farmville, a number of Araucarioxylon fragments similar to those of the Danville and Richmond areas occur. At several other places in this area they are found but always on the surface and never in place.

The coal plants are contained in black carbonaceous shales overlying the coal or in thin bedded and fine grained sandstone which overlies the Border Conglomerate. These fossil plants consist of flattened stems of Equisetum variety, large pinnules and fronds of ferns, and a few cones. They are poorly preserved and have been exposed so long that they are extremely fragile. Very few outcrops showing plants are to be found in the entire area and only north of the Norfolk and Western Railroad. Near Ca Ira a few conifer fragments are found in the red sandstone.

The Richmond area has offered excellent opportunities in times past when various pits and shafts were open for collecting material. In the last 10 years only one of the old workings has been in operation. The fresh material from the recent underground workings of the Murphy Coal Corporation 1 mile south of Midlothian has yielded some very beautiful plant fossils. The variety is not very large but the forms are well preserved. The most abundant forms are pinnules and fronds of ferns with a few stems and cones. The best material occurs in the black shales or slates but much of the fern material in the sandstone is well preserved. From the old accounts both Carbon Hill and Clover Hill workings have yielded much material.

The Araucarioxylon fragments in the Richmond area are most abundant 1 mile west of Otterdale near the center of the area. Here there are large fragments and logs of this genus, which measure over 12 feet long and a little over 16 inches in diameter. In its physical properties the Araucarioxylon is not unlike that of the other areas in any respect. It was found in this same locality by Shaler and Woodworth late in the nineties of last century. F. H. Knowlton identified two species, namely Araucarioxylon virginianum and A. woodwortheni. The Araucarioxylon occurs in place in the Manassas sandstone west of Otterdale which lies above the coal beds.

A few shales near Vinita show the small Estheria ovata and this was the only place where they were found. The forms are about 2-3 millimeters in size, often smaller, and rather difficult to find. A few fish scales occur with the Estheria in this exposure but in lower beds. A few weathered specimens on the old dumps at Gayton and Carbon Hill show fish scales.

The many pits open at the time of Lyell's visit and during the seventies and late last century are now so filled that they are difficult to locate. Outcrops are so rare and so poor when found that they yield nothing. The day of collecting in the Triassic coal areas is past for no longer are prospectors interested in drilling or in sinking shafts. Fontaine probably collected the best material as to variety and preservation that can ever be collected again and it compares with the North Carolina collection of Ebenezer Emmons which remained lost for so many years and was found some years past in the museum of Williams College, Williamstown, Massachusetts. Fontaine's type specimens are now at the United States National Museum. In the light of present day data, a study and rearrangement of them would bring out something more definite as to the environment of the Triassic. A study of the sediments and structure has certainly brought new light to bear on the physical conditions which prevailed during the Triassic time. The Farmville and Richmond areas were typical mesophytic swamps while the three other areas lying to the west and near the eastern limits of the Appalachian system were continental and represent old valley or basin fillings under a warm and moist climate and a luxuriant vegetation.

REASONS FOR THE RELATIVE SCARCITY OF FOSSIL FORMS

The absence of abundant fossils in the various areas to the west all through Virginia, Maryland and Pennsylvania has often been referred to as adequate evidence for semi-arid or desert conditions. There are sufficient fossils to disprove this view without asking the question why, if these red beds of shales, sandstones and conglomerates represent arid or semi-arid conditions, all the great deserts of the world of the present day are not red.

Plant fragments are found at various points over the Potomac and Scottsville areas and silicified wood (Araucarioxylon) in the Danville area, showing that Triassic time was not arid. Plants and reptile tracks have been found in New Jersey and Pennsylvania southward into the Potomac area and in the Richmond and Deep River (North Carolina) areas to the south. Since a fairly large vegetation grew in these places, it is hardly possible that desert conditions or even semi-arid conditions could have held in the areas of Virginia north of James River and in Maryland. These red beds are indicative of warm or temperate climate, normal rainfall, and an abundant vegetation. The problem is why the scarcity of plant and animal life if conditions were not arid. To understand the situation more fully a better knowledge of the land and water conditions of Triassic times is needed—a problem which is discussed somewhat at length in the conclusion. It must be remembered that up to the present there is not a fossil known in the Virginia Triassic which is of marine environment. We must recall the great stretch of territory along the eastern side of the Appalachian Mountains during Triassic time which had a great many depressions with no lagoons in Virginia, but narrow depressions with highlands on each side through which streams helped accumulate sediments. In these small valleys the weathered material accumulated by agents which were continental, such as rain, winds, streams, organisms, and the action of daily and probably seasonal changes in temperature. Under conditions of this kind one can not expect forms to be preserved in any considerable number. Where leaves fall and are buried under muds and in a way are protected they stand a fair chance of being fossilized. In places where they may be blown about over the ground and are acted upon by agents of destruction and decay they have no chance to be preserved. So, as will be shown later, the scarcity and even absence of some of the abundant floras and faunas are due to the unfavorable conditions for fossilization in Triassic time and not to the absence of life or to any agent or agents which may have destroyed the forms after their incorporation into the sediments.

ENVIRONMENT OF TRIASSIC TIME

PHYSICAL CONDITIONS AND THEIR INTERPRETATION

The problem of studying the various formations and interpreting them is not always an easy problem. The sediments are an expression of the age in which they were formed and from them the geologist reads the climate, humidity, plant and animal life, the land and water relations, etc. There are several facts which suggest the conditions that existed during Triassic time. The lack of systematic core drilling is a serious drawback to the interpretation of the environment, especially in a region where there are no high river bluffs and gorges.

One of the first important problems is that of temperature, and toward the solution of this there are several lines of approach. The prevailing temperature during the Triassic in the vicinity of Richmond and Farmville was such that the coal floras could grow, as is seen from the coal measures. The various species have been named under the heading of Paleontology, all of which indicate at least a temperate environment and possibly bordering on a subtropical. This flora was a mesophytic one, composed of ferns, fern-like plants, cycads and conifers and may have been subjected to the action of frost, thus living in a temperate climate. The fact that Palissya diffusa is found in the Potomac area and to the north of Virginia in Bucks County, Pennsylvania, as well as in the Deep River area of North Carolina, is an indication of a somewhat temperate to subtropical temperature. Plants of the type found fossilized must have had a fairly warm climate, very similar in every respect to that which existed during Pennsylvanian time from New York to Alabama.

Another feature of the Triassic which indicates the temperature is the red color of the several sediments, particularly the shale and sandstone. That the red color is not the result of aridity will be left for later discussion. As has been shown with regard to the present day residual conditions, this red color is not suggestive of aridity but of warm, moist climate in the higher latitudes. Such conditions as these exist in Georgia at the present time and the red soils are forming to fill the valleys and depressions.

The third feature indicative of a mild climate is the reptile remains and tracks found in northern Virginia, Pennsylvania and New England. Some have been reported from the Potomac area and in several instances from the Richmond area. It is hardly probable that these forms could have lived under conditions of lower temperatures than temperate, and probably a higher temperature was prevalent. So, in conclusion, everything points to a temperature of a mild nature, probably very similar to that of southern Georgia today, a temperature which perhaps had seasons. These seasons were not necessarily as marked as the seasons of the present day over the same area. The mountains and lowlands were altogether different then and the air currents were probably among the great controlling factors in this climate.

The humidity problem has offered quite a few entanglements because of an idea that the red beds have been regarded as adequate evidence for aridity. Much of the early literature dealt with the arid nature of the beds and no one asked the question why all or at least some of our great deserts which are forming today are not red. With a better understanding of the principles of sedimentation the drift of opinion has been toward the other extreme.

The coal areas in Virginia and North Carolina certainly had a rather normal rainfall, and this applies also to the Danville area where numerous fragments of Araucarioxylon are found. Likewise the various trails found in the red shales are evidence in favor of muds, and the shales themselves do not suggest arid conditions. These muds were formed in the basin during rains as they are formed today in valleys, and also along the floodplains of streams in period of overflow. The various crustaceans and worms crawled over these muds in search of food and left their trails and these trails are found in every area throughout the State.

Besides the above occurrence, there are numerous ripple marks, sun cracks and rain prints. The ripple marks are developed in the sandstones and are the symmetrical types common to water. Sun cracks occur in the muds and sandstones of fine texture. The shales of the three northern areas show best the rain prints.

Certain of the conglomerates show oriented pebbles suggesting streams. The streams probably flowed parallel with the major axis of the areas, or they may have flowed transversely. They were probably small as they were the early streams shortly after the formation of the Appalachian Mountains in a country where the topography was young. So vegetation, trails, ripple marks and other features point to a rather normal rainfall over the Triassic areas, probably not far distant from that of the present time. With the high Appalachian Mountains on the west of the basins, high lands to a less degree on the east, and swampy areas toward the present Atlantic Ocean, there was not so much difference from today in the temperature and humidity, but there was a marked difference in the vegetation as the cycads and fern-like plants were in predominance, giving a very marked picture of the land conditions.

The vegetation has been outlined in the section dealing with fossil plants. The extreme scarcity of plant fossils in the Potomac, and their apparent absence in the Scottsville area has led many to suppose an arid environment. That plant life existed in every one of the areas can not be doubted. Only the hardest forms, such as certain of the conifers fossilized in some of these areas. In the valleys where accumulation was going on, with the coarsest material forming on the bottom and sides of the basin and the finer sediments filling in towards the middle, there was very little opportunity for vegetation to be preserved. Leaves, limbs, and trees themselves when blown over by storms or broken down in old age, had no chance to fossilize. Anywhere that a small pond may have occurred leaves, cones and stems might collect, be covered with silts, clays, and be preserved, just as we see the process going on under continental conditions at present. In these frequent temporary water basins there was little chance for fossilization because decay due to bacteria was more likely than preservation.

The matter was altogether different in the case of the coal swamps of the Farmville and Richmond areas, for here grew the sphagnum-like plants and other floras which generated organic acids, preserved the plant fragments, and did not allow them to disintegrate. The days of the great Pecopteris and Glossopteris plants were gone and only the smaller members or representatives of this mighty type remained. Instead there grew the great cycads, large and small conifers, and numerous ferns. The general vegetation was just as dissimilar to that of the Devonian and Carboniferous as it would be if compared with the vegetation of the Tertiary and Recent.

The Araucarioxylon trees must have been of considerable size judging from the fragments found in the Richmond area. Their habitat suggests a rather damp soil, not swampy but perhaps more like that of the sycamore and willow trees of today. The leaves of this species are not preserved since it did not grow in a swamp.

Animal remains are extremely scarce but occur frequently enough to warrant the statement that there was life. These animals left their tracks and trails after rains when they went in search of food over the mud flats and alluvial fans. When they died in this continental environment their tissues were devoured by others or decayed before silts and sands could cover them. Unfavorable conditions are more largely responsible for the scarcity of fossil fauna than is anything else. Reptile tracks are known to be present in one of the areas and they are found much more extensively in Pennsylvania, New Jersey, and the Connecticut Valley.

The streams probably contained fresh water molluscs and fish but the best preserved fish occur in the sandstones and shales of the Triassic swamp regions. The predominant animals of the region were doubtless reptiles and amphibia. The reptiles thrived upon the vegetable matter and many were probably carnivorous. The size of some of their tracks in the rocks of the Potomac and Richmond areas would indicate great bulk, and this is borne out by the length of the stride as well as by the length of the track.

The presence of streams is indicated by mudstones, ripple marks, sun cracks, and oriented pebbles in the conglomerate. There is nothing at the present time to indicate the directions of these streams. They were probably short, narrow, and relatively straight in a country lately elevated and in topographic youth. Streams were one of the very important agents in filling up these basins. They carried into the various basins the reworked materials of the older Paleozoic and the pre-Paleozoic rocks and formed the sandstones and shales. The larger constituents could not have been transported as they are intermingled with the small pebbles. They are formed *in situ,* but much of the cementing material was carried in by traction and by suspension.

ACCUMULATION OF SEDIMENTS

The sediments during Middle to Upper Triassic time were accumulated in long or short basins, all of which were narrow. Their width was a little greater than at present since faulting and erosion have narrowed them. The northernmost of these areas was Prince Edward Island, which was relatively short and narrow. Next, to the south, was the Connecticut Valley area covering parts of Massachusetts and Connecticut and ending abruptly at present near New Haven. The next large area begins in New York and extends over New Jersey, Pennsylvania and Maryland and ends about 1 mile south of Barboursville, Virginia, called by many names, the most common of which is the New York-Virginia area. The basins in Virginia are very similar to those in North Carolina and these two states differ from all others in having two distinct types of areas. These two types are: (1) The areas lying just east of the Blue Ridge and (2) those far to the east within the Piedmont which are coal-bearing. The cause for the two kinds of areas is to be found in the origin of the sediments and the types of the basins.

The three Triassic areas of Virginia lying nearest to the Appalachians, namely, the Potomac, Scottsville, and Danville, are very similar in lithology, fossil remains, general direction of extent, and all general features. The Farmville and Richmond areas differ from the above named areas in that they are coal-bearing, show numerous plant and animal fossils and lie far to the east, surrounded altogether by igneous and metamorphic rocks.

These basins were formed after the close of Permian time by the growth of the Appalachian Mountain system. Just what transpired during Lower Triassic or Bunter time is not very clear; either no accumulations or contemporaneous erosion may account for absence of deposits of this time. The plants clearly point to an age certainly not earlier than late Muschelkalk time and most probably Keuper. Along the west these depressions were gradually filled with sediments under conditions wholly continental, as shown by the plants, but to the east swamps existed in which grew a representative flora that gave rise to the coal measures. Neither set of these basins was deep when the method of filling is considered together with the width, a point brought out under the discussion on structure.

At one time there was some discussion as to the former extent of the Triassic areas, one idea being that the basins were always separate more or less as they are at present, and this view was termed by Russell[66] "the local-basin hypothesis." The other view was that these basins were formerly connected and were later separated by erosion. This was termed by the same author "the broad-terrane hypothesis." The advocates of this local-basin idea were Dawson, Newberry, Dana, Davis, Le Conte, Emerson and others; advocates of the broad-terrane hypothesis were H. D. Rogers, Kerr, Lesley, Heinrich and Russell.

The facts in the field seem to favor the local basin idea, certainly in Virginia. It is true that the three western areas in Virginia lie in line with each other but the distance between them is quite an important figure. The greatest distance between any of these three areas is between the Scottsville and Danville areas, which is approximately 40 miles. If these two areas were connected at one time and later separated by erosion, it is a rather singular fact that all the red sediments have been so completely removed from this intervening space. There is no evidence that the Richmond and Farmville areas were ever connected. It seems far more reasonable to consider that the basins were local after their formation rather than continuous from Prince Edward Island to the North Carolina-South Carolina border, a distance of approximately 600 miles.

The arguments advanced by Russell[67] for the continuity of all the Triassic areas are as follows: (1) The stratigraphic incompleteness of all areas; (2) the presence of marginal faults which form either the eastern or western limits of the area; and (3) the great amount of erosion since the close of Triassic time.

The stratigraphic incompleteness supposes a water-lain deposit, such as did not take place. There are conglomerates on both sides of the Virginia areas except in places where they have been eroded or concealed by faulting. If the continental origin is to be accepted, the first objection does not apply. The presence of marginal faults proves nothing at all with regard to the continuity of the basins,—no more than the Triassic dikes extending from one area to another over the

[66] Russell, I. C., The Newark System, U. S. Geol. Survey Bull. 85, p. 101, 1892.
[67] Idem, pp. 104-106.

intervening spaces. As for the last argument, the writer certainly fails to see how the Richmond and Farmville areas could have been connected with the Danville and other areas and each show so much in the way of dissimilarity in lithology and fossil content.

That there were highlands adjacent to each side of the various basins at the time of Triassic accumulation is suggested by the arrangement and the composition of the sediments. The highlands on the eastern portion of all the areas were composed chiefly of metamorphosed rocks, whose main source was igneous, with a small part of sedimentary rocks. Granite in relatively large amounts also occurred. The highlands on the western portion of the area in a limited way were sedimentary, but mostly metamorphic and sedimentary rocks.

From the schists, gneisses and granites along the eastern side of the areas came the quartz, feldspar, and various rock fragments which were reworked into the Border Conglomerate, Manassas sandstone and Bull Run shale. The Border Conglomerate in all of the areas contains large rounded fragments of feldspar, quartz, schist, gneiss and granite, all of which are so similar to the adjacent rock that there is no difficulty in accounting for their source. The character of these three formations changes from north to south and is controlled by the character of the rocks from which they are derived.

On the western highlands there were limestones in the Potomac region, giving rise to the limestone phase of the Border Conglomerate. Further south there set in various schists and gneisses, mainly of igneous origin, though some were sedimentary. The great basaltic schists of the Bull Run and especially the Blue Ridge Mountains contributed to the formation of the trap phase of the Border Conglomerate which is so well exposed south of Culpeper and forms Cedar Mountain. The sandstones were formed of finer materials which were carried towards the center of the basin and rested conformably upon the Border Conglomerate. The muds and silts were accumulated by intertonguing with the sandstones, much of it being carried to the center of the basins and there forming the red shales.

It stands to reason that these highlands were higher along the western sides of the various basins, as they were closer to as well as a part of the Appalachian Mountains formed after Permian time. They were not so high on the western sides of the Farmville and Richmond basins as they were along the westernmost area as the folds of the Appalachian Mountains did not involve the rocks this far east. The Border Conglomerate, with two exceptions, is best developed along the western sides of the basin as a result of greater highlands on the west. This conglomerate formed as the basal Triassic member over the bottoms and sides of all the basins out of whatever material may have been available, but it is thicker everywhere on the west except near

Raccoon Ford in the Potomac area and near Mt. Airy in the Danville area, the two exceptions above mentioned.

These highlands were probably clothed with a representative vegetation composed of every plant phylum except the angiosperma, and upon the abundant plants various reptiles lived. The continental environment was not conducive to the preservation of the flora and fauna, as both were subject to decay before they could be covered and protected by soil. Evidently there were low highlands around the coal forming basins, which furnished the quartz, feldspars and other minerals for the filling of these swampy depressions in which the mesophytic plants grew. The plant and animal remains are earmarks of the swamps, which existed in late Triassic time, and these plants formed the coal measures.

The highlands were lowered considerably during Triassic time, as is shown by so much Triassic sedimentation and no traces of any material of Jurassic age. Very probably much of the peneplanation now shown in the areas was completed soon after the Triassic was formed, but this has been increased during the Cretaceous and Tertiary. The height of these upland regions above the Triassic basins was probably a little in excess of that of the Bull Run and Blue Ridge mountains today. While these uplands have been lowered by erosion, the Triassic basins have been lowered also though not at so rapid a rate, thus making the height of the mountains above the general level of the country somewhat uniform through the periods which have elapsed since Triassic time.

The forces responsible for the weathering and the accumulation of the Triassic sediments are of strictly continental nature. Many of the older writers consider the red muds, sands and gravels to have been accumulated in long lagoonal seas somewhat the size of the several Triassic basins of today. Some of the basins may have been of this nature, but in Virginia the environment was nothing else than continental. The three areas lying on the west, namely, the Potomac, Scottsville and Danville, differ in environment from the Farmville and Richmond areas. In the three western areas the highlands on either side, covered with a typical Mesozoic vegetation, were gradually lowered by certain agents of dynamical geology. These agents or forces were rain, ground water, diurnal and seasonal variations of temperature, streams, swamps, winds, and the effects of plant and animal organisms.

Raindrop impressions are common in many of the shales and muddy sandstones of all the western areas. These impressions were made upon mud flats of the streams and upon small alluvial fans of the slope washes. Along with these raindrops occur numerous sun cracks and so-called "fossil trails." The action of ground water must have been normal during Triassic time and is evidenced by the enormous and widely prevalent amounts of ferric oxide throughout the Triassic. Also various minerals, such as barite, pyrite, and the minerals of copper were formed chiefly through the influence of ground water near the end of Triassic time and certainly not later than Jurassic time, because these are not common in the Cretaceous a few miles to the east. Ground water must have fed the numerous streams and must have supported the vegetation.

The changes of temperature both daily and seasonal may not have been as sharp as they are in the Richmond and other basins today. The type of plant life suggests a little higher temperature average for the region and it was probably somewhere between temperate and subtropical. The seasons were less pronounced during Triassic time and it is unlikely that freezing and thawing were at all common. No evidences of ice are to be found throughout the Virginia Triassic.

The action of streams is shown by various muddy sandstones and shales which were formed by overflows in floodplains and temporary hillside washes. Oriented pebbles, somewhat assorted, occur in the conglomerate, which suggests the existence of stream action. These streams were not very large, their courses were more or less parallel with the areas and they were fed by smaller streams which entered approximately at right angles, as do most streams in regions of topographic infancy and youth. These regions were very young, being of the same age as the main chain of the Appalachian Mountains. A few streams may have flowed across the Triassic basins, especially near the close of Triassic time. Ripple marks of water origin are common along with raindrop prints, sun cracks, and "fossil trails."

Swamp conditions existed in the Farmville and Richmond basins, judging from the coal plants, the coal itself, and the character of the sediments. The plants are of strictly a mesophytic swamp type, as is agreed upon by all who have examined them. Great marshes existed 10-40 miles in length and the falling vegetation in these marshes formed into coal and carbonaceous shales. The conglomerates differ in their texture from those of the western areas. They are composed of water-worn pebbles of much more uniform sizes and are not a commingled mass of pebbles of all sizes. They show the presence of streams and sorting power in water, a mark entirely foreign to the great masses of the Border Conglomerate to the west. The Danville area suggests an environment between the swamp and purely the continental in that it shows many fragments of Araucarioxylon so common to the swamp areas. Also the conglomerates of this area, while they resemble the Border Conglomerate to the north, have some of the features of those in the coal-bearing areas.

The action of wind is not so well pronounced as the other agents. It is expressed in the water ripple marks. The action of plants and animals is fairly well seen, especially that of the plants. Bacteria of the iron secreting variety probably were present in great numbers, as is indicated by the red color of the sandstones and shales. Over 45 fossil plants are known, and when these are studied in the light of recent knowledge they may prove to be a larger flora. The great bulk of the plant fossils are restricted to the Richmond and Farmville basins, but this does not disprove the existence of plants in the three western basins. Palissya diffusa Emmons occurs in the Potomac and Araucarioxylon in the Danville area. The scarcity of plants in the western areas may be accounted for by poor means of preservation rather than by desert conditions. If one considers what unfavorable conditions exist today in valleys of high latitudes of the temperate belts the problem can be understood. Long valleys in the Appalachian region today are being filled up by muds, sands, and gravels whose color is red due to the action of soil bacteria and this is an analogous case to what transpired in Triassic time. All of the above named forces were functioning indiscriminately under conditions purely residual in the western areas during Keuper time, and to the east the swamps supported a coal-bearing flora. What other forces were present is not clear, but the sediments, plants and various other marks above referred to indicate nothing in the way of aridity, glaciation, inland seas or lagoons.

The methods of accumulation in the two sets of areas were quite similar. The material came from the highlands and from the sides and bottoms of the basins in either case but in different amounts. These two methods will be discussed somewhat at length and field evidence cited for them.

In the western areas where no swamps existed and only streams and temporary basins of water are indicated, narrow depressions or valleys, some long and some short, existed at the beginning of Triassic time after the folding of the Appalachian Mountain system. Upon the slopes grew the Mesozoic plants and there roamed the reptiles and other land animals of that time. The streams were typical of a country in topographic youth and even infancy. All the various agents of that time were instrumental in filling these basins. Many of the basins of small depth may have been wholly eroded since Triassic time but the main ones remain today, although much modified by faulting and peneplanation.

The earliest material accumulated was derived from the bottom and sides of the basins and in a small measure from the highlands. This material was broken rock from any source available; on the northwestern side of the Potomac basin fragments of limestone were accumulated or reworked, further to the south trap fragments, instead of the limestone, on the eastern side of the same basin quartz and schist fragments were accumulated, and so in each of the areas whatever was available was incorporated into this heterogeneous mass—the Border Conglomerate. This conglomeratic mass consisted of fragments of many sizes and these pebbles or boulders had been rounded or subrounded through the action of rain, organisms, etc. These fragments were not sorted at all, except for such sorting as might take place in small streams. From the highlands the finer materials, consisting of quartz, feldspars, amphiboles, pyroxenes, magnetite, calcite and small amounts of many other minerals were washed down by rains and moved by surface creep and organisms to fill the interstices of this pebble mass, and, acting as a cement, formed it into a conglomerate. Bedding planes had little chance to form and plant and animal remains decayed before they could be covered and fossilized.

After this Border Conglomerate formed the finer materials continued their accumulation from the highlands; the coarser materials formed near the sides of the basin, the finer particles were carried nearer the center, and some were carried to the center. These materials covering the conglomerate were closely associated, as is shown by the sandstones being intercalated with the shales today. But while there are deposits which may be termed either sandstones or shales, there are distinct sandstone and shale phases on either side of this transition series. The great bulk of the arenaceous material stopped immediately over the conglomerate and near the margins of the basins, forming the Manassas sandstone. The great bulk of the finer or argillaceous material moved on to the center, because of its size and the laws of transportation, and became the Bull Run shale. The last material to accumulate was towards the center of these basins and forms the principal mass of the Bull Run shales, the youngest of all the Triassic sediments.

Along the swamp areas or the Farmville and Richmond basins lower highlands existed but the material accumulated in a somewhat similar way. These basins were probably lagoons in early Triassic time and accumulated the conglomerate from the bottom and sides of their basins. While these fragments were forming they were rounded and somewhat sorted by water, a mark not common to the areas of residual origin. Later the sands and muds brought in by the streams, surface creep, etc., filled the interstices and acted as a cement. Much of this cement material formed along with the pebbles. After the conglomerate formed the same sequence of sediments took place as in the purely residual areas, the sands remained nearer the margins and the muds and silts moved towards the center. Finally, the plants took hold upon the shales and sands in this semi-aquatic and swampy environment and grew in such abundance as to form the peat which resulted in coal. In these swamps fish, reptiles, molluscs, and other forms of life lived. Lastly the swamps filled up from the silting in of fine material and by the constructive action of vegetation, leaving the shales the youngest of the series, the sandstones intermediate, and the conglomerates the oldest. The writer is of the opinion that the shales and late sandstones, with the flora which determined them, are equivalent to the Keuper or Upper Triassic in age—these overlie the Border Conglomerate—a mass of material accumulated during Lower and Middle Triassic time. This is merely suggested and it must be admitted that there are no plant or animal forms to corroborate such a statement.

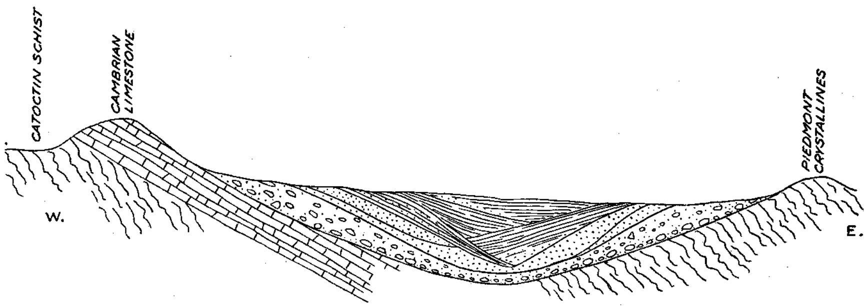

Figure 10. Sketch illustrating the accumulation of conglomerates, sandstones and shales in the Potomac area.

The accumulation of a basal conglomerate followed by sandstone and shale is common to all the Virginia areas whether this took place in valleys or in marshes. The difference in these two sets of environment is the character of the conglomerate and the presence of well preserved fossils. The plant life in the residually formed areas disintegrated and stood poor chance of preservation. The waters of the coal basins, rendered antiseptic by certain mosses, preserved the leaves and trees and converted them into peat, and along with them preserved many fossil remains of fish and other animals.

The arrangement of the sediments is in itself strongly suggestive of the method of origin. The basal conglomerate whether exposed on the east or on the west is of the same age, being the oldest Triassic member. This conglomerate was considered by the older geologists to be of one age on one side of a basin and of another age on the other side. For example, due to faulting and monoclinal structure in Virginia, all the formations dip west or northwest and little or no connection is seen between the conglomerates on either side of the basin. So the older geologists, accounting for origin of the sediments by long lagoons and not by residual methods and seeing two conglomerates, regarded the western one as the top Triassic member. Stose [68] regards the Triassic fan conglomerate as having formed near the close of Triassic time. Sandstones are found in all the areas from the periphery towards the center, and at the center shales are found unless conglomerates or the rocks of the basin have been exposed on the surface by faulting. The sandstones on the western side of the Potomac are often faulted out of the surface ex-

[68] Stose, G. W., Post-Cretaceous faulting in Appalachians: Geol. Soc. Amer. Bull., vol. 38, p. 498, 1927.

posures, but enough of the beds remain to show that they were formed there as well as on the other side. The shales often contain clay lenses, the finest material of the Triassic rocks, and in the western areas these clay lenses usually carry fossil plants. The original order of the conglomerates, sandstones and shales has been rendered difficult of interpretation on account of faulting and erosion, but the arrangement is strongly suggestive of the residual origin.

DIABASE INTRUSION

After the basins had been largely filled at the close of Triassic time, the sediments were intruded by various forms of diabase. The youngest of the sediments, the Bull Run shales, are involved in this intrusion. The diabase assumed forms of stocks, dikes and sheets, especially the first two forms. The dikes are the most prevalent and widespread of all the diabase forms. They are not limited to the Triassic sediments alone but are found cutting across the red beds into the older crystallines and igneous rocks which are adjacent. The igneous action involved these older rocks and was due to isostatic adjustments along the entire Piedmont belt from Prince Edward Island to Georgia. It was accompanied by profound faulting and in quite a few cases the diabase is found today where it came up along fault planes in the Triassic sediments.

The diabase, when it intruded the sediments and cooled as a great body, is found to be of a macrocrystalline texture, as in the Belmont and Sterling stocks. But further south, between Culpeper and the Rapidan River, the Mt. Pony and Buzzard Mountain stocks give evidence of cooling under less superstructure and are medium to fine-grained in texture. The dikes, depending upon their size, may be either macrocrystalline or aphanitic. They may parallel the strike or cut abruptly across it.

The alteration of the intruded rocks is rather pronounced in places and all three sedimentary formations are involved. Even the coal beds in the Farmville and Richmond areas are affected and converted into natural coke. The distance outward from the dike to which the alteration has taken place is subject to much variation. Any or all of the following may result from the intrusion: Change in color, in induration and in composition.

Dikes are found in every Triassic area in the State except the old Barboursville area which is now the southern extension of the Potomac area. They diminish in number and size towards the Virginia-Carolina State line. They are indicated by great boulders, actual outcrops, and by their peculiar brownish red and non-porous soil. Some of them can be traced for as much as 60 miles. The stocks are limited to the Potomac area.

The finer textures are often spoken of as basalt and are so treated in this report. Many of the small dikes are basalt and very similar in every detail to the basalt or trap pebbles of the trap phase of the Border Conglomerate, which pebbles were derived from the basaltic schists of the Blue Ridge and regions between this system and the Triassic belt.

The age of the intrusion is evidently late Keuper time and possibly it continued into Jurassic time but certainly ceased before the beginning of Cretaceous time. None of the Cretaceous sediments east of the Triassic belt give the least indication of diabase intrusion. The extensive sheets of New England and New Jersey definitely place a time limit for some of the activity but not for all of the diabase forms.

FAULTING OF TRIASSIC SEDIMENTS

No factor has brought a more profound change upon the Triassic sediments than that of faulting. This is not felt so strongly until one has worked in the field, has recognized and traced some of the faults and tried to account for the thickness without taking into account the rôle played by faulting. In every region of eastern North America the Triassic strata are fractured and faulted and in every instance it is difficult to trace these faults. The principal difficulty is the lack of fossiliferous or persistent beds and the enormous amount of erosion which has taken place since the close of Triassic time.

In each of the five Virginia areas and their outliers there was a great down-faulting on the west near the close of Triassic time or shortly afterwards. This fault must have been of considerable displacement as it has given the strata on the western side of every basin a westward dip, despite the fact that foresetting must have inclined the beds eastward prior to the faulting. In Pennsylvania Stose[69] claims a displacement of at least 6,000 feet for the boundary fault. This fault was of the normal type shown by slickenside phenomena and the dip of the fault plane was rather steep. This fault, known as the Border Fault, now marks the western border of all the areas. Probably some of the Triassic beds were left on the west side of the fault after the lowering of the basin, but erosion has removed them.

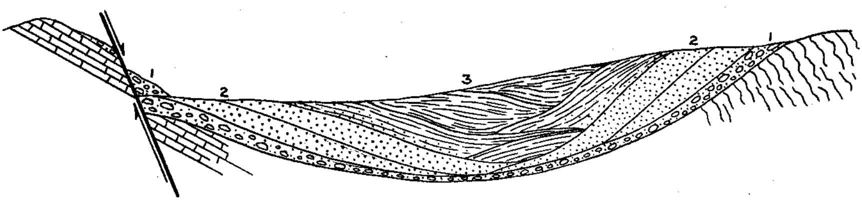

Figure 11. Sketch illustrating down faulting of the Triassic along the western edge. (1) Border Conglomerate, (2) Manassas sandstone, (3) Bull Run shale.

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[69] Stose, G. W., Post-Cretaceous faulting in the Appalachians: Geol. Soc. Amer. Bull., vol. 38, p. 495, 1927.

After this Border Fault had taken place and probably at the same time, faulting became rather prevalent over the basins, thus giving rise to the duplication of the strata. It is thought by some that this block faulting was very likely of a reverse type, but the writer could find no evidence to support such a view. The block faulting has the same general strike as that of the strata, occurs all the way across the areas and seems to be just as common on the one side of the basins as on the other. In a number of the larger faults slicken-sides indicated normal faulting but this can not be offered in every instance.

The strata in any cross section will be found in duplicate condition, and just how much to allow for this without fossil zones is impossible to state. This block faulting often conceals certain beds, as for instance sandstones along portions of the western margin of the Potomac area. Often the rocks of the basin itself are brought up to the surface. Such examples are seen west of Danville where the granite outcrops in the midst of the Triassic red beds, and at Boscobel in the Richmond area where the granite and granite-gneiss are exposed with red shales and sandstones on either side. Erosion could not have removed all the overlying material in either of these cases.

Some of the diabase stocks and many of the diabase dikes show faulting, as do the sediments they intrude, which places the age of the faulting to some extent. There is no way to place the age of the Border fault. At least some of this faulting took place after diabase intrusion, some is known to have occurred before the intrusion, and the dikes have come up along the fault planes.

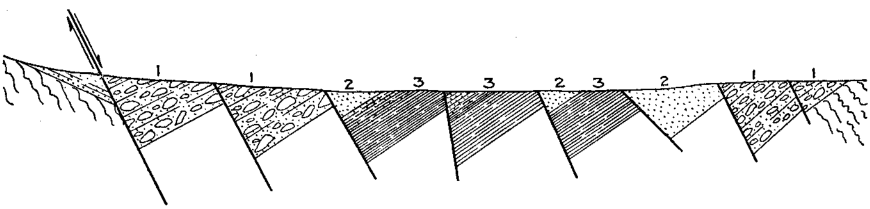

Figure 12. Sketch illustrating block faulting through the Triassic.
(1) Border Conglomerate, (2) Manassas sandstone, (3) Bull Run shale.

The matter of reckoning the faulting when estimating the thickness of the sedimentary rocks has been discussed. The old estimates assigned 20,000 feet or more to the Triassic beds. It is absurd to suppose any great thicknesses such as these could be deposited in such narrow basins. The basins are regarded as rift valleys by some but the dip of the strata is not in harmony with this. The method of accumulation has to be reckoned along with block faulting in the estimation of the thickness, as well as of the land relations of Triassic time.

PREVAILING RED COLOR

The Bull Run shales, the Manassas sandstone, and to a less extent the Border Conglomerate, show a red color. The coarse red sandstones are particularly impressive for their color, and when the individual grains are well rounded they resemble some of the oölitic iron ores. This red color attracted the attention of the early geologists and the majority assigned it as a mark of desert conditions, to the influence of the diabase bodies of rock upon the contained iron, to the alteration of iron to the ferric state through orogenic movements, to percolating waters dissolving the ferric oxide from the diabase and depositing it in the sandstones and shales, to the absence of organic matter, etc.

Red beds are known at many horizons of the geologic column, as the MacCrady, Catskill, Juniata, Mauch Chaunk, Permian, Triassic, Rhaetic, Chugwater, etc. Ferric iron alone is responsible for the red color of the Triassic rocks of Virginia. It occurs both as an envelope around the grains of quartz, feldspar and other minerals of the sandstones, and in their matrix, and also in the matrix of the shales. Its high opaqueness makes a negligible amount appear as a high percentage. The actual amount is very low as shown in the table of chemical analyses under the stratigraphy of the red sandstones.

I. C. Russell [70] advanced the idea of origin of the red color in formations. He claimed that there is a tendency under subaerial decay of rocks into soils under warm, moist conditions and in a luxuriant vegetation for the iron to become oxidized and form a coating around the sandstone grains and in the matrix. The prolonged discussion of the red bed problem between Russell and Crosby about 1890 is well known. Russell appended a good bibliography to his discussion in the United States Geological Survey bulletin on subaerial decay. Since his day many additions have been made and valuable suggestions have made his views clearer.

In 1898 Spring [71] made an important contribution to the coloring material of red beds and the cause of the same and his discussion is based on the light of data current at that time. He showed that red beds were not formed under desert conditions and that the red coat of iron oxide was tied up closely with organic life. This discussion is far more applicable to the great red bed problem than many of the earlier ones, and taken with those of Russell and Crosby and one of Harder to be mentioned later, forms a good nucleus around which to work. The paper of Hawes [72] which called attention in a brief manner to the presence of ferric iron in the Triassic (Newark) sandstones and shales and in sandstones and shales of other horizons should be mentioned.

A recent paper dealing with iron-secreting bacteria and their influ-

[70] Russell, I. C., Subaerial decay of rocks and the origin of the red color of certain formations: U. S. Geol. Survey Bull. 52, pp. 44-46, 1889.

[71] Spring, W., Sur les matieres colorantes à base de fer, des terrains de sediment et sur l'origin probable des roches rouges.
——— Recueil des trauveaux chimiques des Pas-Bas et de la Belgique: Tome 17, Ss. 201-221, 1898. Reviewed in Neues Jahrbuch für Min. Geol. und Pal., Bd.'l, Ss. 47-62, 1899.

[72] Hawes, G. W., Note on the microscopical characteristics of a thin section of Jura-Trias sandstone from the Connecticut Valley: Hitchcock's Geology of New Hampshire, vol. 3, pt. 10, pp. 239-240, 1878.

ence in forming iron ores of certain types has been published by Harder[73] and represents the results of a number of important laboratory experiments in which the power of certain bacteria to deposit iron has been observed, also the rate of deposition and the amounts of iron oxide formed. This is a new and a very important approach to the matter and is quite applicable to the problem of the color of red beds throughout the geologic column. Evidence supporting the existence of bacteria in the Paleozoic has been recognized for some time, and during the Triassic bacteria must have been involved in the formation of the residual soils which filled the valleys and depressions.

In the final analysis, the red beds of the Virginia Triassic formation represent certain environmental elements. All of these elements or factors have left marks which prove their presence and influence. The environment was that of a warm and moist climate with a luxuriant vegetation. The vegetation is seen in the typical Triassic fossils which are indicative of a warm and moist climate. In the coal-bearing areas the swamps supported a coal flora and in the valleys and on the highlands of the western areas there grew a Mesozoic vegetation consisting of ferns and conifers, as well as of other types.

The soils and material which were silted by gravity and other dynamic agents into the basins were affected by bacteria. These bacteria were of the oxidizing variety and in the presence in the soil of water which was not stagnant, the iron was oxidized into the ferric condition, formed as an envelope around the grains of sand and feldspar, and was disseminated through the matrix of the sandstones and shales. In many instances gray shales and small areas of gray and yellow sandstones occur. When these gray and yellow sediments are studied in thin sections and analyzed qualitatively they are found to contain iron oxide in the ferrous state. These sandstones and shales other than red, and especially the gray, were probably formed in stagnant bodies of water under conditions where plant decay prevailed and the iron was reduced and not oxidized. In the coal basins the bacteria were not those living in a habitat of decaying vegetation, but, on the other hand, in waters which were rendered antiseptic, hence the iron in these areas was oxidized and not reduced. Organic acids were liberated in the fermentative process of some of these mesophytic plants of the coal basin comparable to the euzymes set free by sphagnum in the peat-forming swamps of the present, and the woody tissue was preserved and iron-forming bacteria probably flourished in great abundance. Immediately underlying the coal seams and often directly above them red sandstone occurs. So the climate, when all the lines of evidence are summed up, was very probably not unlike that which prevails in north Georgia and the southern Appalachians at the present

[73] Harder, E. C., Iron-depositing bacteria and their geologic relations: U. S. Geol. Survey Prof. Paper, No. 113, 89 pp., 12 pls., 1919.

day, where valleys are being filled by material from the adjacent highlands which is accumulated in bedded deposits by the same dynamic agents common in Triassic time. Russell has shown very clearly that there is a belt of red soil at the present day in the temperate and subtropical regions of the earth wherever rainfall is sufficient and the soil deep and fertile enough to support a normal vegetation. It may be added that in these red soils there are iron depositing bacteria which convert any ferrous iron into the ferric state as it weathers along with the other soil elements from the various classes of rocks.

CORRELATIONS OF THE VIRGINIA TRIASSIC FORMATIONS

The three sedimentary formations which occur in the six main areas of the Virginia Triassic, whether they were deposited in the narrow valleys under purely residual conditions, or in swamps and marshes where grew a Mesozoic coal-forming flora, are remarkably similar over the state and have been assigned names to suit their various cases. Chronologically these formations are, from the oldest to the youngest, the Border Conglomerate, the Manassas sandstone, and the Bull Run shale, terms introduced in the study of the three western areas and the Farmville area and applied to the Richmond area. The writer has made a careful study of the lithologic and structural descriptions of the Triassic in the several eastern states of the United States and has found that the three leading types of sediments can be closely correlated with those of Virginia. The conglomerates in every state, regardless of the terms applied to them, are basal; the finest sediments, the shales, are the youngest, and the sandstones are intermediate in age. There is no sharp break from the sandstones to the shales when the natural gradation is preserved and often these sediments are so intertongued that it is difficult to establish boundaries. The scheme in the following pages, while it is diagrammatic, is meant merely to illustrate the lithologic, chronologic and the structural relationships of three sedimentary phases, namely, the conglomerates, sandstones, and shales. These diagrams represent the position of the sediments shortly after their accumulation before the basins were down-faulted and block faulted. All diabase intrusions are omitted in the schemes, as the sedimentary rocks are being considered.

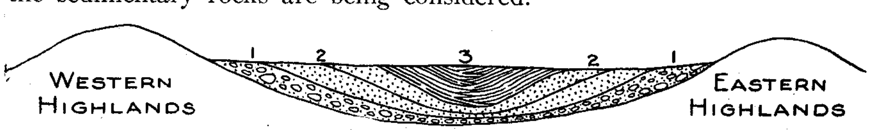

Figure 13. Sketch showing the arrangement of Triassic sediments in the Virginia basins. No. 1 represents the oldest of the sediments, the Border Conglomerate, accumulated on the bottom and sides of the basins and contemporaneous in age; No. 2, the Manassas sandstone accumulated toward the middle but separated by the accumulation of shales in the middle; No. 3, the Bull Run shale, youngest of the series accumulated near the center and grading into sandstone.

The Acadian area in Nova Scotia, New Brunswick, and Prince Edward Island bears a very close resemblance to the Triassic rocks of the Connecticut Valley. The rocks consist of trap and various phases of conglomerates, sandstones and shales, with prevailing red colors. No detailed descriptions of the Acadian area are available.

Emerson [74] speaks of the contemporaneity of the marginal conglomerates in the Massachusetts Triassic. He makes the formational divisions on a lithologic basis, and names five sedimentary formations and one igneous. His formations for Massachusetts are as follows:

Triassic Formations of Massachusetts
(Emerson)

............Unconformity............

5. Chicopee shale—Center of the basin.
4. Granby tuff—Not widely distributed.
3. Longmeadow sandstone—On each side of the Chicopee shale, and between it and the arkose and conglomerate.
2. Mt. Toby conglomerate—Eastern side of the basin.
1. Sugarloaf arkose—Western side of the basin.

............Unconformity............

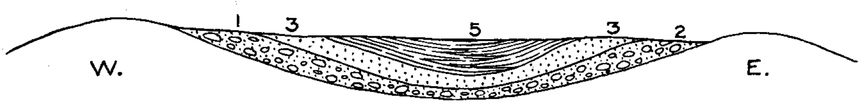

Figure 14. Sketch showing the Triassic sediments in Massachusetts. The numbers correspond to those of the Massachusetts Triassic column of Emerson.

The Triassic formations of Connecticut as given by Davis [75] with their respective thicknesses, inclusive of the trap rocks, are as follows:

Triassic Formations of Connecticut
(Davis)

	Feet
6. Conglomerates, sandstones, and shales	2,000- 3,000
Posterior trap overflow	50- 150
5. Sandstones and shales	300- 500
Main trap flow	300- 500
4. Shales with thin limestone	100- 300
Anterior trap overflow	50- 150
3. Shales	500- 500
2. Shales, sandstones and conglomerates	3,000- 3,000
Intrusive trap sheet	200- 400
1. Sandstones and conglomerates	500- 2,000
Total	7,000-10,500

[74] Emerson, B. K., Geology of Massachusetts and Rhode Island: U. S. Geol. Survey Bull. No. 597, Massachusetts Triassic, pp. 89-127, 1917.

[75] Davis, W. M., the structure of the Triassic formation of the Connecticut Valley: U. S. Geol. Survey, Seventh Ann. Rept. (1885-86), p. 467, 1888.

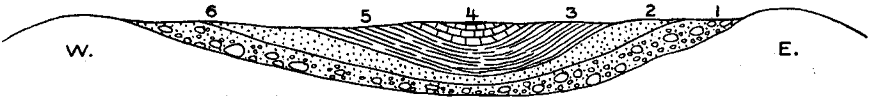

Figure 15. Sketch showing the arrangement of the Connecticut Triassic sediments as they were deposited in the basin. The numbers refer to the formations in the Connecticut section of the text.

The Massachusetts and Connecticut basins after accumulation had ceased, were downfaulted along the eastern margin with the fault plane dipping west, and later the block fault planes formed and dipped in the same direction. This main or Border fault for all the other areas south of the Connecticut area occurs along the western margin and the fault plane dips to the east. This feature is one of the interesting points in the contrast of the northern and southern Triassic areas. The Massachusetts and Connecticut beds dip from 20° to 30° eastward. The maximum width of the Connecticut area is not over 22 miles. When block faulting with the duplication of strata is considered with the method of accumulation, there is not such a great thickness of sediments. From all indications there must have been lagoons in the Connecticut area and not such extreme continental conditions as existed further south in Virginia and Maryland. The accumulation took place, however, in long and narrow basins and deposits along the margins and towards the center are of contemporaneous age, thus giving a plane of symmetry down the center of the basin, as far as formations and their respective ages are concerned.

In New Jersey Kümmel[76] distinguishes three sedimentary series or beds and the usual diabase forms. His formations or series and beds are as follows:

Triassic Formations of New Jersey
(Kümmel)

............Unconformity............

3. Brunswick beds—Central portion of the basin, also along the western portion. Consist of red shales and fine grain red sandstone.
2. Lockatong series—Western margin and central portion. Consists of shales, flagstones and argillites with little impure limestone.
1. Stockton series—Eastern margin and near center of the basin due to faulting. Consists of conglomerates, arkoses, sandstones and shales.

A. —Border conglomerate—Kümmel does not regard this as a separate and distinct horizon but claims for it a range throughout all the Triassic formation of New Jersey.

............Unconformity............

The so-called Border conglomerates of Kümmel are described as

[76] Kümmel, H. B., The Newark System of New Jersey: Geol. Survey of New Jersey Ann. Rept. of State Geologist for 1897, pp. 30, 36, 41, 52, 1897.

quartzite, calcareous and gneissic conglomerates, are found along the western margin of the New Jersey Triassic, are associated with the other Triassic rocks, and overlie the older crystallines from which they are derived. The Stockton series are limited to the eastern margin and consist of conglomerates, arkoses and sandstones. In all probability the New Jersey series and beds fit into the basin arrangement in a way similar to that of Virginia.

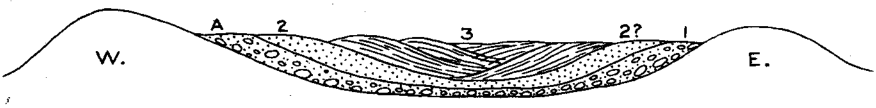

Figure 16. Sketch showing the position of the original arrangement of sediments in the New Jersey Triassic basin. The numbers refer to those in the accompanying New Jersey section.

The Triassic members of Pennsylvania have been discussed by a number of writers, and Wherry [77] gives the various formations as consisting of three series which, with their respective thicknesses, are as follows:

Triassic Formations of Pennsylvania
(Wherry)

............Unconformity............

3. Brunswick red shale and conglomerate range in thickness up to 16,000 feet.
2. Lockatong (Gwynedd) dark shale lens and carbonaceous sandstone and range in thickness of 1,000-3,500 feet.
1. Stockton (Norristown) arkosic sandstone and conglomerate and range up to 5,500 feet.

............Unconformity............

The Stockton is very probably the same conglomerate which occurs on both sides of the Pennsylvania basins, the Brunswick series in the central portion of the basin, and the Lockatong between the Stockton and the Brunswick. From all appearances the same general relations which are true of Virginia hold for Pennsylvania.

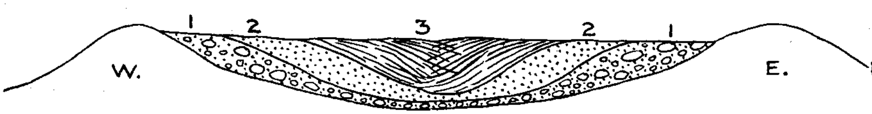

Figure 17. Sketch showing the probable arrangement of Triassic sediments in the basins of Pennsylvania. The numbers refer to the accompanying section.

The Triassic of Maryland has been carefully studied as to its stratigraphy and structure by George E. Dorsey [78] who describes two forma-

[77] Wherry, Edgar T., North border relations of the Triassic in Pennsylvania: Acad. Nat. Sci., Phila. Proc., vol. 65, pp. 114-125, 1913.

[78] Dorsey, George E., The stratigraphy and structure of the Triassic System of Maryland, Dissertation for Ph.D., Johns Hopkins University, 300 pp., 1919; Abstracted: Geol. Soc. Amer. Bull., vol. 30, pp. 155-157, 1919.

tions in the Triassic belts. He bases such a division on the lithology, as do the writers in all the other areas. His formations are as follows:

Triassic Formations of Maryland
(Dorsey)

............Unconformity............

2. Taneytown formation—Consists of quartz and limestone conglomerates, inclusive of the "Potomac Marble," and highly arkosic sandstones—located on the eastern portions of the Maryland areas.
1. Emmitsburg formation—Consists of soft red to purple shales and located on the western portion of the basin.

............Unconformity............

The present arrangement of the Triassic sediments in Maryland after normal and reverse faulting, and intrusion and erosion, according to Dorsey, shows the identity of the relations of the Maryland to the Virginia Triassic. The present day conditions, due to downfaulting on the west and duplication of the strata by block faulting, cause much misinterpretation of the strata. What Dorsey has done in Maryland is clearly borne out in Virginia, and in the latter state three clearly defined formations are apparent instead of two as in Maryland. The following diagrams will illustrate the basins as they were near the close of Triassic time in Maryland and as they are at the present day and given in the foregoing section.

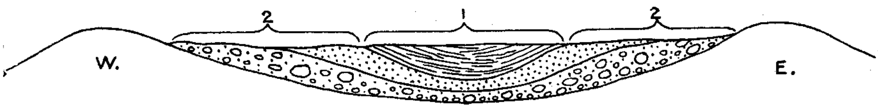

Figure 18. Sketch illustrating the accumulating of sediments in the Triassic basins of Maryland. The numbers refer to the Maryland section of Dorsey.

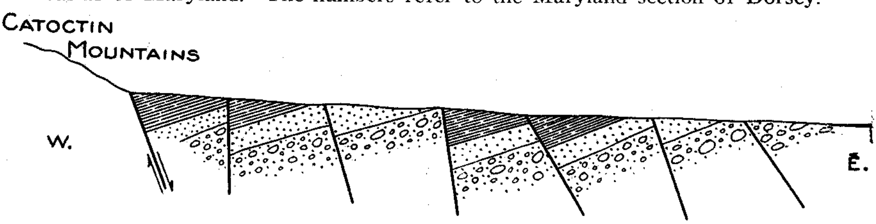

Figure 19. Sketch illustrating the present arrangement of sediments in Maryland.

The members of the Richmond basin as given by Shaler and Woodworth[79] do not fit into the scheme used for the other areas in Virginia. When the matter of faulting, the method of deposition, and the width of the basin are considered, the formational units of Shaler and Woodworth are in harmony with those of the other areas. The formations proposed in 1899 by Shaler and Woodworth are as follows:

[79] Shaler, N. S. and Woodworth, J. B., Geology of the Richmond Basin, Virginia: U. S. Geol. Survey Nineteenth Ann. Rept., pt. 2, p. 423, 1899.

Triassic Formations of Richmond Basin

(Shaler and Woodworth)

Chesterfield group:

5. Otterdale sandstone—Coarse sandstones, often feldspathic, with silicified trunks of Araucarioxylon; well developed north, south, and west of Otterdale. Thickness 500 + feet.

4. Vinita beds—Black fissile shale carrying Estheria ovata; passing upward and intercalated with gray sandstones; in James River bluff, west of Vinita Station, on Tomahawk Creek. Thickness 2,000 feet.

Tuckahoe group:

3. Productive coal measures—Interstratified beds of bituminous coal (usually three seams), coke, black shales (a. fish-bearing; b. estheria shales; c. vegetal shales), sandstones (feldspathic and micaceous), fossil plants; teeth, bones, and tracks of reptiles. Thickness 500 (?) feet.

2. Lower barren beds—Sandstones and shales under coal beds, often with arkose. Thickness variable, from 0 to 300 feet.

1. Boscobel beds—Local deposits; boulders of gneiss and granite. Thickness variable, 0 to 50 feet.

The Tuckahoe group of Shaler and Woodworth, consisting of the basal Triassic conglomerate, the Boscobel beds followed conformably by the coal-bearing sandstone associated with shales, the lowermost portion, poor to barren of coal, the "Lower Barren Beds," and the uppermost portion, carries coal seams, the "Productive Coal Measures," which were studied in the days when the underground relations were available in the coal pits, at least better than at the present time. The "Vinita Beds," presumably what the writers studied around Vinita, are just about as much shale as sandstone and in general quite similar to the Bull Run shales of the other areas. Certainly, with regard to structure and age, these shales are the same as those overlying the coals of the Farmville area.

The "Otterdale Sandstone," of Shaler and Woodworth, located near the center of the Richmond area in the vicinity of Otterdale, is plainly underlain by a coarse conglomerate comparable in every detail to the "Boscobel Boulder Beds." This is brought to the surface by a fault and is very probably the equivalent of the basal bed of the basin. The sandstone is associated with shales. At the most the writer can detect only three typical formations in the Richmond area besides the coal seams themselves. To correlate the formational units of Shaler and Woodworth with those proposed for the other areas the following table is given:

Proposed correlation of new and old formational names

		(Shaler and Woodworth)
3. Bull Run Shales	≎	Vinita beds Productive coal measures
2. Manassas sandstone	≎	Lower barren beds
1. Border Conglomerate	≎	Otterdale sandstones Boscobel beds

Ebenezer Emmons was the earliest geologist to make a report on the Triassic of North Carolina and in his report for the year 1852, page 120, he gives the following divisions of the Triassic:

Triassic Formations of North Carolina

(Emmons, 1852)

1. Inferior conglomerates and sandstones below the green and black slates.
2. Black slates with their subordinate beds and seams.
3. Sandstones, soft and hard, with freestone, grindstone grits, and superior conglomerate.

In his report to the North Carolina Geological Survey in the year 1856, page 273, Emmons gave the divisions which he recognized in the Deep and Dan River areas. These divisions are as follows:

Triassic Formations of North Carolina

(Emmons)

		Foreign Equivalents
Trias	1. Red sandstones, marls, etc. 2. Black or blue slate, with plants and a coal seam. 3. Conglomerate.	Keuper sandstone and marls, coal shale, group of the Thuringerwald
	....	Muschelkalk absent
Permian	Drab colored sandstones. Calcareous and bituminous shales. Coal, fireclay, argil, oxide of iron. Red sandstone, sometimes gray and drab. Conglomerate.	Rothliegende

From his section, Emmons evidently thought some of the lower red beds in North Carolina were Permian in age. In all of his references he brings out the three-fold series of conglomerates, sandstones and shales and coals. He introduced a fourth term shown in his map accompanying the report for 1856 which he terms the "Salines."

Campbell and Kimball[80] recently published a detailed discussion of the stratigraphy, structure, and composition of the Triassic coals of North Carolina. The descriptions of the three formations are very interesting. These formations agree in most details with the formations of the coal-bearing and the purely continental areas in Virginia. Conglomeratic phases are found on both sides of the Deep River basin and in the top and basal formations described in this recent report. The formations are as follows:

3. Sanford formation—Red conglomerates, sandstones and shales. Probable thickness 4,000 to 5,000 feet.
2. Cumnock formation—Gray, drab, and red sandstones. This is the coal horizon. Probable thickness 1,200 feet.
1. Pekin formation—Sandstone with a gray basal conglomerate. Probable thickness 2,000 feet.

The section of Campbell and Kimball shows a conglomerate in both the Pekin and Sanford formations, a fact fully in keeping with the structural relations of the Virginia areas. These formations will fit into the schemes above mentioned, thus making the basal conglomerate contemporaneous with the conglomerate of the Sanford formation. Faulting has played fully as important a rôle in the present day structure of the Triassic in North Carolina as in the other areas to the north. The total thickness of the Deep River beds is from 7,000-8,000 feet. One is not warranted in ascribing such a thickness to the Virginia Triassic beds when the block faulting is considered with its abundant duplication of beds. The threefold relation everywhere is very plain, all of which is approximately Keuper in age.

A strict correlation of the various Triassic formations or members in eastern North America is not possible with the field and laboratory data now known. The prospects of finding abundant or even adequate data for such a correlation are not at all encouraging at the present time. After an extended study of the field relations such as faulting, the collection of other fossils, and especially with core drilling and a study of the sediments, a better correlation than is now possible may be attained. The following tables of correlation are not offered in any other sense than that of suggestion, as the writer realizes they are open to many avenues of error. The first table represents the old view of regarding the top beds as youngest and the bottom ones as oldest, while the last table represents the beds as they were probably deposited. The last table is not intended to be critical of the correlations of others, but it works admirably in Virginia, and from what the writer has seen of the Triassic of Pennsylvania, Maryland and the Dan River Basin in North Carolina it applies in these areas. The arrangement of the beds in all the Virginia areas and their relations to the older rocks from whence they came clearly justify such a relation.

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[80] Campbell, Marius R. and Kimball, Kent W., The Deep River coal field of North Carolina: North Carolina Geol. and Econ. Survey Bull. 33, 95 pp., 1923.

Triassic correlation table for Eastern North America (After the old scheme)

	Europe	Virginia (Roberts)	Massachusetts (Emerson)	Connecticut (Davis)	New Jersey (Kummel)	Pennsylvania (Wherry)	Maryland (Dorsey)	N. Carolina (Campbell & Kimball)	Virginia (Shaler & Woodworth)
Keuper	Rhaetian	Bull Run Shale	Chicopee Shale Granby Tuff	Shales Sandstones and Conglomerates	Brunswick Beds	Brunswick Shale and Conglomerate	Taneytown Formation	Sanford Formation	Otterdale and Vinita Beds
	Norian	Manassas Sandstone	Longmeadow Sandstone	Shales and Sandstones	Lockatong Series	Lockatong Shale and Sandstone		Cumnock Formation	Lower Barren and Productive Coal Measures
	Karnian	Border Conglomerate	Mt. Toby Conglomerate and Arkose Conglomerate	Sandstones and Conglomerates	Stockton Series	Stockton Sandstone and Conglomerate	Emmitsburg Formation	Pekin Formation	Boscobel Beds

Triassic correlation table for Eastern North America (To show probable chronological relations)

Portion of Basin	Virginia	Massachusetts	Connecticut	New Jersey	Pennsylvania	Maryland	N. Carolina	Virginia (Shaler & Woodworth)
Western Portion	Border Conglomerate	Sugar Loaf Arkose	Conglomerates Sandstones Shales	Lockatong Series Argillites, Shales with Associated Border Cgl.	Stockton ?	Taneytown Formation	Pekin Formation	——
	Manassas Sandstone	Longmeadow Sandstone	Sandstones Shales		Lockatong ?			Otterdale Sandstone
Central Portion	Bull Run Shales	Chicopee Shale	Shales with little Limestone	Brunswick Beds	Brunswick Formation	Emmitsburg Formation	Cumnock Formation ?	Vinita Beds
Eastern Portion	Manassas Sandstone	Longmeadow Sandstone	Shales Sandstones Conglomerates	Stockton Series Sandstone and Conglomerates	Lockatong Formation (Gwynedd)	Taneytown Formation	Sanford Formation	Productive and Barren Coal Measures
	Border Conglomerate	Mt. Toby Conglomerate	Sandstones Conglomerates		Stockton Formation (Norristown)			Boscobel Beds

BIBLIOGRAPHY

The following bibliography is arranged in alphabetical order by authors. It contains, for the most part, articles which have a direct bearing upon the Virginia Triassic, but at the same time it embraces a number of references which have to do with general Triassic conditions in other parts of the world. The Triassic literature of eastern North America exceeds 1,200 references and the general Triassic entries of the writer exceed 6,250 at present. Following the arrangement above mentioned, the references are classified under such headings as General Geology, Paleontology, Structural, Stratigraphic, Economic Geology, etc. Also a chronological arrangement is given, thus making the matter of reaching the various references as easy as possible for the reader. After most of the references is given a brief abstract of the article.

1. AGASSIZ, LOUIS, Remark on the geological position of the Newark System as indicated by fossil plants: Amer. Assoc. Adv. Sci., Proc., vol. 5, p. 46, 1851.

A very brief note in the discussion of a paper on Triassic plants, by W. C. Redfield.

2. ————, Geological position of the Newark System as indicated by fossil fishes: Amer. Assoc. Adv. Sci. Proc., vol. 4, p. 276, 1858.

A brief discussion of a paper on Triassic plants, by W. R. Johnson.

3. ASHBURNER, C. A., Coal: U. S. Geol. Survey, Min. Res., pp. 10-73, 1885; pp. 224-377, 1886; pp. 169-394, 1887; Triassic of Richmond Basin, p. 69, 1885; pp. 352-361, 1886; p. 361, 1887.

Gives brief accounts of the Richmond coals and production of coal.

4. BENTON, ED R., Notes on samples of iron ore collected in Virginia: 10th Census of U. S., 4to vol. 15, pp. 261-288, 1886.

Map of the James River basin of the Triassic, p. 261.

5. BERRY, EDWARD W., American Triassic Neocalamites: Bot. Gazette, vol. 53, No. 2, pp. 174-180, 1912.

Reviews the Neocalamites with special reference to plants of the Richmond Basin.

6. ————, The age of the plant-bearing shales of the Richmond coal fields: Amer. Jour. Sci., Ser. 4, vol. 34, pp. 224-225, 1912.

A brief note of Berry, stating that a communication from Zeiller had called attention to the plants of the Richmond Basin being Keuper in age and not Rhaetic, and this same view was endorsed by Nathort in a communication to Berry.

7. ————, A restoration of Neocalamites: Amer. Jour. Sci., vol. 45, pp. 445-448, 1918.

The plant, Neocalamites, is restored from fragmentary parts. It is pointed out that there is not such a break in plant life from the Paleozoic to Mesozoic as was thought by the early students. Two Rhaetic and three Keuper species of Neocalamites are mentioned, and it is pointed out that N. Knowltoni (Berry) of the Richmond Basin is closer in its resemblances to the Paleozoic Calamites than any of the five.

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A summary of the invertebrata containing all known forms of that time which occur in the American Triassic.

9. BUNBURY, C. J. F., Description of fossil plants from the coal field near Richmond, Virginia: Quart. Jour. Geol. Soc. London, vol. 3, pp. 281-288, 1847.

A description, with figures, of the Triassic plants collected by Sir Charles Lyell during his visit to the Richmond Basin. These plants are well described.

10. CAMPBELL, H. D. & BROWN, W. G., Composition of certain Mesozoic igneous rocks: Geol. Soc. Amer., Bull., vol. 2, pp. 339-348, 1891.

Samples for the analyses were taken from the Triassic diabase of the Potomac area in the vicinity of Culpeper; the locality referred to as the "Twins" is Buzzard Mountain. The field relations are not very extensive.

11. CAMPBELL, M. R., The coal fields of the United States: U. S. Geol. Survey, Prof. Paper 100-A, 1922.

Triassic coal analyses for the Richmond Basin are given on page 32.

12. CLARK, F. W., Analyses of trap rock, coke and coal from the Newark System: U. S. Geol. Survey, Bull. 42, 1887.

. Virginia natural coke from Richmond Basin, page 146, North Carolina natural coke, page 146, and North Carolina trap, page 138. These analyses compare closely to others made of the coal and coke in later years.

13. CLEMSON, T. G., Analysis of some of the coal from the Richmond mines: Pa. Geol. Soc., Trans., vol. 1, pp. 295-297, 1835.

14. ————, Notice of a geological examination in the country between Fredericksburg and Winchester in Virginia including the gold region: Pa. Geol. Soc. Trans., vol. 1, pp. 298-313, 1835.

Brief mention of the Triassic which lies between Fredericksburg and Winchester and deals with generalities.

15. CLIFFORD, WILLIAM, Richmond coal fields, Virginia: Manchester Geol. Soc., Trans., vol. 19, pp. 326-354, 355-358, 1888. Abs. Geol. Mag., vol. 6, pp. 138-140, Dec. 3, 1889.

Discusses mining methods, gives a few analyses of the coke, and briefly describes the character of the formations.

16. ————, Additional notes on the Richmond coal fields, Virginia, in reply to criticisms: Manchester Geol. Soc., Trans., vol. 20, pp. 247-256, 1889.

A reply to Newell's criticism in the Geol. Mag., op. cit., maintaining that the strata thin out near the margin and that they were deposited in irregular basins, and refers to the contemporaneity of coals on the margins of the basins.

17. CORNELIUS, ELIAS, On the geology, mineralogy and scenery of parts of Virginia, Tennessee, etc.: Amer. Jour. Sci., vol. 1, pp. 215-226, 317-331, 1818.

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18. CORYELL, MARTIN, East Virginia coal field: Amer. Inst. Min. Eng., Trans., vol. 3, pp. 228-231, 1875.

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20. CREDNER, H., Geognostische Skizzen aus Virginia, Nordamerika: Zeitsch. der Deutsch. Geol. Gesell., Bd. 18, ss. 77-85, 1886.

Reviews the opinions as to the age of the Richmond coal and the impossibility of correlating it with any of the European formations.

21. CROSBY, W. O., The color of soils: Boston Soc. Nat. Hist., Proc., vol. 23, pp. 219-222, 1885.

The color of soils is treated only in a general way but the article deals with the red color chiefly. The soils of the high and low latitudes are compared, and it is shown that with few exceptions the prevailing color of the soils of high altitudes is brown, yellow and buff, while the red color is more characteristic of the southern soils from Pennsylvania southward. The normal vertical order of colors in sedimentary detritus appears to be as follows (p. 222): (1) Bluish, grayish and neutral tints due to ferrous oxide; (2) the yellow and brown tints of ferric hydrates; and (3) in warm countries the red resulting from the dehydration of the ferric hydrates. This marks a great change in the accounting for the red soils and, applied to the Triassic, forms an important contribution.

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This is the second important paper on the red color of soils and is very applicable to the Triassic. He states that he attaches less importance to the matter of temperature but still believes it important. His closing remarks (82) are: "The general conclusion, then, to which the foregoing considerations lead is that the color-contrast is due chiefly to the difference in climate, but that the operation of this principle is modified in a general way by the essentially spontaneous tendency of the color to change from yellow to red." In connection with Crosby's views are to be noted those of I. C. Russell, and these two authors in America brought the matter of red beds to the consideration of geologists.

23. DADDOW, S. H. AND BANNAN, B., Coal, iron and oil, Pottsville, Pa., 808 pp. Map, 1866.

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24. DANA, J. D., The origin of the Jura-Trias in eastern North America: Amer. Jour. Sci., ser. 3, vol. 25, pp. 383-386, 1883.

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26. DARTON, N. H. AND DILLER, J. S., On the occurrence of basaltic dikes in the Upper Paleozoic series in the Central Appalachian region: Amer. Jour. Sci., ser. 3, vol. 39, pp. 269-271, 1890.

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29. FONTAINE, W. M., Mesozoic strata of Virginia (Notes): Amer. Jour. Sci., ser. 3, vol. 17, pp. 25-38, 151-157, 229-239, 1879; Abst., Amer. Nat., vol. 13, pp. 284-292, 1880; Neues Jahr., pp. 137-138, 1881.

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30. ————, Contributions to the knowledge of the older Mesozoic flora of Virginia: U. S. Geol. Survey, Monograph VI, pp. 144, plates 54, 1883; reviewed, Verhandl. der k. k. geol. Reich., 10, 1888 (Stür); Amer. Geolo-

gist, vol. 5, pp. 160-174, 1890 (Marcou); account in Rogers' Geology of the Virginias, vol. 6, pp. 38-40.

This marks the first attempt to collect and describe the Triassic flora of the Richmond Basin. The author mentions some forty species and gives a list of the undetermined ones. He compares the Virginia floras to those of North Carolina collected and described by Ebenezer Emmons. In conclusion, Fontaine correlates the plants of the Richmond Basin with the Rhaetic of Europe, where they remained until within the last decade when they were identified by Ziller, Nathorst and Berry as belonging to an age corresponding to the Keuper.

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36. GAY, W. B., Discussion of a paper on "the Richmond coal basin, Virginia" by J. B. Woodworth: Amer. Inst. Min. Eng., Trans., vol. 31, pp. 1011-1012, 1901.

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37. GILBERT, C. K., The name "Newark" in North American stratigraphy: Jour. Geol., vol. 2, pp. 55-61, 1894.

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38. GRAMMAR, JOHN, An account of the coal mines in the vicinity of Richmond, Virginia: Amer. Jour. Sci., vol. 1, pp. 125-130, 1818.

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39. GREER, JAMES, Oölite coal field of Virginia.

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40. HAWES, G. W., On the mineralogical composition of the normal Mesozoic diabase upon the Atlantic border: U. S. Nat. Mus., Proc., vol. 4, pp. 129-134, 1881; Abs. Neues Jahr, p. 44, 1882; reviewed by Dana, J. D., Amer. Jour. Sci., ser. 3, vol. 22, pp. 230-233, 1882.

This article refers entirely to the composition of Triassic diabase of Connecticut and New Jersey which is so similar to the diabase of Virginia that the account is found very helpful.

41. HEER, OSWALD, A letter concerning the geological position of the rocks of the Richmond coal field, Virginia, as indicated by fossils. In the "Geology of North America" by Marcou, Zurich, p. 16, 1856; in part: Amer. Jour. Sci., ser. 2, vol. 24, pp. 428-429, 1857.

Heer criticises the plant determination of Bunbury and Emmons and suggests his own views, namely, that there is no Oölite in Virginia or North Carolina.

42. HEINRICH, OSWALD J., The Midlothian colliery, Virginia: Amer. Inst. Min. Eng., Trans., vol. 1, pp. 346-359; 360, 364, 1873.

Heinrich was a mining engineer in the Midlothian coal mines for some time and wrote several important articles on this field. The above article emphasizes mining methods and gives certain structural features.

43. ————, What is the best system for working thick coal seams? Amer. Inst. Min. Eng., Trans., vol. 2, pp. 105-116, 1874.

Discusses methods of mining with relation to the dip of the coal beds, thickness and other structural features, overburden, etc. Compares the methods of France and Germany. Gives various estimates of cost and usual mining problems of that day.

44. ————, The diamond drill for deep boring, compared to other systems of boring: Amer. Inst. Min. Eng., Trans., vol. 2, pp. 241-263, 1874.

Gives estimates of this type of investigation for the Richmond Basin. Paper is technical and contains little geology.

45. ————, Deep boring with the diamond drill: Amer. Inst. Min. Eng., Trans., vol. 3, pp. 183-186, 1875.

Report on two drill holes of approximately 922 and 715 feet respectively and shows that this is the most desirable method of coal investigation, in rocks which are consolidated, but in the softer rocks other drilling machinery is more satisfactory.

46. ————, Remarks on trap dikes and on natural coke in the Richmond coal field, Virginia: Eng. and Min. Jour., vol. 19, p. 35, 1875.

Discusses underground relations of the diabase dikes with the coal seams, the thickness of the coke, etc.

47. ————, An account of an explosion of fire damp at the Midlothian colliery, Chesterfield County, Virginia: Amer. Inst. Min. Eng., Trans., vol. 5, pp. 148-161, 1876.

Gives an account of the mining structure, the probable causes of the explosion, and the fatalities.

48. ————, The Midlothian colliery, Virginia: Amer. Inst. Min. Eng., Trans., vol. 4, pp. 308-316, 1876.

Reviews in a brief manner some of the past history of the Midlothian Mining Company's achievements, the number of shafts, the recovering of the abandoned mines, the various costs and improvements. He adds that the Richmond and Danville Railway (branch of the Southern Railway) affords the best transportation to Richmond and to West Point on the York River, where boats from Baltimore, Norfolk, Washington and other cities can load.

49. ————, The Mesozoic formation of Virginia: Amer. Inst. Min. Eng., Trans., vol. 6, pp. 227-274, 1878.

Names and reviews various areas of the "Mesozoic Formation" (Triassic) in Virginia, gives description of the rocks, physical character of the coals, the stratigraphy of the formation, sections, fossils, economic products, coal analyses of beds north and south of the James River, the production, the classes of coal, and the rate of development. This is an excellent summary of the Triassic in Virginia. The author must have used quite a number of references, though none are mentioned. He names many of the fossil floras and faunas, probably from the reports of Emmons, Lyell, Bunbury, and others. He recognizes three principal lithological units, namely, conglomerates, sandstones, and shales, and, in addition to these, he names other rock facies, as psephites, psammites, and slates. He also mentions thin limestone layers, something not mentioned by other writers.

50. HITCHCOCK, C. H., The geological map of the United States: Amer. Ins. Min. Eng., Trans., vol. 15, pp. 465-488, 1886.

This map includes the Triassic of Virginia with that of all the eastern states, indicated by a violet color. Various maps in their chronologic order are discussed in order to show the evolution of the geologic map and these are the maps of Maclure (1809 and 1817), James Hall (1843), Lyell (1845), E. Hitchcock (1853 and 3rd ed. 1856), Marcou (1853), Marcou (1858), H. D. Rogers (1856), Hall and Lesley (1857), and the geological map of Canada of 1869 but dated 1866.

51. HOBBS, W. H., Former extent of the Newark System: Geol. Soc. Amer., Bull., vol. 13, pp. 139-148, 1902.

The various views held by American geologists are reviewed, the "Local Basin" and the "Broad Terrane" hypotheses considered and explained, the coarseness of the sediments, the distributions of the conglomerates, etc. He concludes his paper with five reasons favoring the "Broad Terrane Hypothesis": (1) If the present United States areas were connected by lines drawn through their outer margins, the area of Triassic sediments would about equal that unoccupied by such sediments; (2) the near similarity of Triassic areas which lie close to each other and marked differences of those far apart; (3) extensive post-Triassic erosion has removed so much material and thus the once connected basins are now separate; (4) the similarity of structures of all the basins, and the preservation of a possible western fold and a possibility of a fold which may have extended eastward and may now be removed by erosion; and (5) the rivers of Connecticut show by their orientation relations to fault directions.

52. HOOKER, J. D., Note on the vegetable structure of the coal from the Richmond coal field, Virginia: Quart. Jour. Geol. Soc. London, vol. 3, pp. 268-269, 1847.

Hooker made a microscopical examination of the wood for Sir Charles Lyell and rendered his report to him. This is his report in brief form.

53. HOTCHKISS, JED., On the Virginians; their agricultural, mineral, and commercial resources: Soc. Arts (London) Jour., vol. 21, pp. 238-251, 1873.

Brief mention is made of the Virginia Triassic on pages 239-240 in relation to the coal of the Richmond basin.

54. ————, Virginia; a geographical and political summary, Richmond, 320 pp., 1876.

A map showing the Triassic areas of Virginia.

55. ————, The resources of the Virginias on and near the proposed route of the Richmond and Southwestern Railway: In the "Virginias", vol. 1, pp. 90-93, 96, 106-109, 1880.

The coal resources of the Richmond basin are stressed and W. B. Roger's geological map of Virginia is republished.

56. ————, The production of coal in the United States by coal fields for the Census Year ending June 1, 1880: In the "Virginias", vol. 3, p. 13, 1882.

The amount of Triassic coal produced in the Richmond basin during the year is given.

57. ————, The natural coke of Virginia: In the "Virginias", vol. 4, p. 164, 1883.

A reply to Raymond, and the origin of the coke is mentioned with reference to W. B. Rogers and Sir Charles Lyell.

58. ————, The Richmond, Virginia, coal field: In the "Virginias", vol. 4, p. 171, 1883.

Gives the contents of an anonymous article from "The Mining Herald" of Shenandoah, Pa., which mentions the progress of coal mining in the Richmond basin during the early part of the eighties. There are a number of references by Hotchkiss, which have been omitted in this bibliography, because they are general and their contents have already been used by him in the articles quoted.

59. HUNT, T. STERRY, Remarks on natural coke in the Richmond coal field, Virginia: Eng. and Min. Jour., vol. 19, p. 35, 1875.

These remarks were made after the paper of O. J. Heinrich on whether or not the coke of the Richmond basin should be so classified on account of its high volatile matter. According to Wurtz's analysis the volatile matter was considered too high.

60. JACKSON, C. T., On the identity in age of the coal-bearing rocks of Virginia and North Carolina: Boston Soc. Nat. Hist., Proc., vol. 5, p. 186, 1855.

Suggests that the coal measure may be an equivalent of the European Lias.

61. ————, Note on the copper mines, so called, at Elk Creek, Fauquier County, Virginia: Amer. Asso. Adv. Sci., Proc., vol. 6, p. 183, 1856-59.

An account of copper minerals in a trap dike, which has intruded the red sandstone. This could not be located during the recent field work in that vicinity.

62. JOHNSON, W. C., Description of the Richmond coal field: Report of the Commission on National Foundry, Doc. 168, p. 41, 1839.

The Richmond coal after some investigation by Johnson was recommended for use in the iron foundries, as it had been used previous to that time for such purpose.

63. JOHNSON, W. R., Analysis of natural coke from the Richmond coal field, Virginia: Phila. Acad. Nat. Sci., Proc., vol. 1, pp. 223-224, 1841-42-43.

Gives the physical and chemical properties of the coal.

64. ————, American coals: Report to the Navy Department of the United States, Washington, 607 pp., 1844.

Richmond coal discussed and analyses given, pp. 308-451.

65. KEITH, ARTHUR, Geology of the Cactoctin belt: U. S. Geol. Survey, Fourteenth Ann. Rept., pt. 2, pp. 283-395, 1894.

Discussion of the Triassic, pp. 345-358. Keith discusses the sedimentary series, dividing it into conglomerate, sandstone and shale; also the diabase. The composition of each of the types of rocks and their origin are discussed. The physical and mineral composition of the diabase is treated, also its forms, distribution, and various contact phenomena. Faulting is discussed at length and the strike and dips are given. The contribution is the best up to its time for the Virginia Triassic. It deals with a small portion of the Potomac area only. It is accompanied by a geologic map and numerous plates. The rocks adjacent to the Triassic area, such as the Catoctin schist, are well discussed.

66. ————, Harper's Ferry Folio: U. S. Geol. Survey Folio, No. 10, 3 pp., 1894, topographic, areal and economic maps, structural sections and column.

This folio represents the only careful mapping in the Virginia Triassic, and it is very helpful, especially around Leesburg. The scale of the maps is approximately 2 miles to the inch. The eastern portion at the Potomac River is somewhat near the middle of the Triassic basin, and most of the Triassic in Loudoun County is included in this folio.

67. KNOWLTON, F. H., The fossil wood and lignite of the Potomac formation: U. S. Geol. Survey, Bull. 56, p. 50, pl. 7, figs. 2-5, 1889.

A specimen of Araucarioxylon virginianum, which was sent in from near Taylorsville by W. J. McGee, is described. This same species was later described by Knowlton from the Richmond Triassic near Otterdale, Chesterfield County.

68. ————, Report on some fossil wood from the Richmond basin, Virginia: U. S. Geol. Survey, Nineteenth Ann. Rept., pt. 2, pp. 516-519, 1899.

Systematic descriptions of two species of silicified wood, Araucarioxylon virginianum and A. woodwortheni, from the Triassic, near Otterdale, Chesterfield County. These were studied macroscopically and in thin section, and figured.

69. LANEY, F. B., The geology and ore deposits of the Virgilina district of Virginia and North Carolina: Virginia Geol. Survey, Bull. 14, 176 pp., 20 pls., 16 figs. and map, 1917.

Triassic dikes are discussed on pages 38-39, and sandstone on pages 38-39 and 59. A conglomerate is reported as associated with the sandstone near Scottsburg. The youngest of the igneous rocks is the diabase, which occurs as dikes, and such occur well distributed in this region.

70. LEA, ISAAC, Remarks on the age of the Newark system: Phila. Acad. Nat. Sci., Proc., vol. 10, pp. 90-92, 1858.

A brief compilation of the various views as to the age of the rocks called the Newark series. Refers to the entire belt in the eastern United States.

71. LULL, R. S., Fossil footprints of the Jura-Trias of North America: Boston Soc. Nat. Hist., Memoirs, No. 11, vol. 5, pp. 461-557, 1904.

A discussion and figures of the reptiles, particularly of the Connecticut Valley. This applies to the reptile tracks found at various places in Virginia.

72. ————, Rulers of the Mesozoic: Yale Review, pp. 352-363, January 1914.

A brief review of the Triassic reptiles.

73. LYELL, SIR CHARLES, On the structure and probable age of the coal field of the James River basin, near Richmond, Virginia: Quart. Jour. Soc. London, vol. 3, pp. 261-280, 1847.

Discusses the stratigraphy as seen in the coal pits and over the area, and the plants are described by Bunbury. Lyell describes the fossil fish and figures them in the plates accompanying his article. The thickness of the coal and its relation to the intruding trap are considered. His decision as to the age is that the coal is probably lower Oölite and Liassic.

74. ————, A second visit to the United States: London, 2 vols., 1st ed. 1849, 3rd ed. 1855.

The third edition, pages 279-288 of Vol. I, gives an account of Lyell's visit to the Richmond coal field. This is his second visit to the vicinity of Richmond.

75. ————, Remarks on the age of the Richmond coal field, Virginia: In Marcou's Geology of North America, p. 16, 1858.

A statement to the effect that the age is changed by Bunbury for the Richmond coals because the beds with which they have been compared have been changed.

76. ————, Elements of geology, London and New York: Published as a Manual of Geology. 6th edition published 1866.

Gives a brief account of the Richmond coals.

77. MARCOU, JULES, Note sur la houile du comté de Chesterfield prés Richmond (Etat de Virginie): Geol. Soc. de France, Bull., sr. 2, tome 6, pp. 572-575, 1848-49.

Gives a summary of the various views on the age of the Richmond coal and proposes a new age based on the floras and faunas.

78. ————, The Triassic flora of Richmond, Virginia: Amer. Geol., vol. 5, pp. 160-174, 1890.

The several opinions as to the age of the coals are reviewed, the principal ones being those of Newberry, H. D. and W. B. Rogers, Lyell, Emmons, and Fontaine. Marcou points out that D. Stür of the Austrian Survey and Fontaine determined the age; Stür agrees with Marcou, Zeiller, Heer and Emmons that the coals are Keuper in age, while Fontaine regards them as Rhaetic.

79. MERRILL, GEORGE P., Weathering of micaceous gneiss in Albemarle County, Virginia: Geol. Soc. Amer., Bull., vol. 8, pp. 157-168, 1897.

The cause of the red color in the soil is discussed. The formation of zeolites in the soil and their power to conserve the potash constitute an important part of the paper. This particular region bordered on the west side of the Scottsville area when the sediments of this basin were being accumulated and much of the red sands and clays is derived from the weathered micaceous gneiss and the schists.

80. NEWBERRY, J. S., Remarks on the copper ores in the Triassic sandstones of the United States: New York Lyc. Nat. Hist., Proc., vol. 2, ser. 2, pp. 16-17, 1874.

Compares the occurrence and causes of the copper minerals in the Triassic sandstones of the eastern United States to those in the Triassic of Texas and New Mexico and considers them somewhat the same.

81. ————, Remarks on the geological position of the Triassic and Jurassic rocks of America: New York Acad. Sci., Trans., vol. 5, pp. 17-20, 1885-86.

Brief statement to the effect that the plant and animal fossils determine the age of these rocks.

82. ————, Remarks on the former extent of the Newark system: New York Acad. Sci., Trans., vol. 7, p. 39, 1887.

Claims the Triassic basins of the Connecticut Valley and New Jersey were separate during the time of formation, as indicated by the occurrence of Cretaceous sediments between the two areas, resting on the older rocks.

83. NEWELL, F. H., Richmond coal field, Virginia: Geol. Mag., vol. 6, pp. 138-140, Dec. 3, 1889.

Reviews Clifford's article (Entry No. 15); he claims that the coal does not thin out towards the margin of the basin, as was Lyell's view; that it was not laid down in a restricted basin. Claims that faulting and movements have been intense upon the coal beds.

84. NICOLLS, W. J., The story of American coals: Lippincott, Phila. and London, 2nd ed., 396 pp., 1904.

Treats of the origin, development, transportation and consumption of the coals. Gives the early history of mining in the Richmond basin and places the first output around 1750.

85. NUTTALL, THOMAS, Observations on the Geological structure of the Valley of the Mississippi: Phila. Acad., Nat. Sci., Jour., vol. 2, pt. 1, pp. 14-52, 1821.

Part 1 deals with the probable limits and character of the Secondary Formations, and the Virginia Triassic is mentioned, pages 35-37. This treatment is rather historical, as were many of that day.

86. PATTON, J. H., Natural resources of the United States: New York and London, 523 pp., 1888.

The Triassic is discussed, pages 22-25. The coal of the Farmville and Richmond basins is described.

87. PEALE, A. C., Lists and analyses of mineral springs of the United States: U. S. Geol. Survey, Bull. 32, 1886.

Gives the mineral springs which occur in the Triassic areas but no shipments or analyses.

88. PIERCE, JAMES, Practical remarks on the shell marl region of the Eastern Shore of Virginia and Maryland and upon the bituminous coal formations

in Virginia and the contiguous region: Amer. Jour. Sci., vol. 11, pp. 54-59, 1826; Trias, pp. 57-59.

Discusses coal mining in the Richmond basin. Only general remarks are given. Names some of the old mines.

89. PRIME, FREDERICK, The coals of the United States: Rept. of the Mining Industries of the United States, by Pumpelly, Tenth Census of the U. S., vol. 15, pp. 605-687, 1886.

Gives the production of the Richmond basin.

90. RAYMOND, R. W., The natural coke of Chesterfield County, Virginia: Amer. Inst. Min. Eng., Trans., vol. 11, pp. 446-450, 1883; in the "Virginias", vol. 4, pp. 145-146.

Describes a 15-foot bed of coke near Midlothian, gives a section and the causes of the coke formation. Points to the old views in which the coke is supposed to be due to trap intrusion, but claims that no trap is found in the mine samples. The only specimens he saw were sent to him, and he did not see the coke *in situ*. His short notice is followed by the report of a chemical examination of the carbonite by T. M. Drown. He gives the results of examination of a dull and a lustrous specimen. The analyses are very good. The specific gravity for the dull and lustrous specimens are respectively 1.375 and 1.350.

91. REDFIELD, W. C., The fossil fishes of Virginia: Amer. Jour. Sci., vol. 34, p. 201, 1838.

A note which mentions a shale from the Richmond basin with specimens of fossil fish.

92. ————, Short notice of American fossil fishes: Amer. Jour. Sci., vol. 41, pp. 24-28, 1841; abs. pp. 164-165; abs., Amer. Assoc. Geol. and Nat., Proc., pp. 17-18, 1840-42.

Lists and describes certain fishes from the Connecticut Valley and New Jersey, some of which are common to Virginia. Also remarks on the wide extent of the so-called Newark deposits.

93. ————, On the relations of the fossil fishes of the sandstone of Connecticut and other Atlantic States to the Liassic and Jurassic periods: Amer. Jour. Sci., vol. 22, ser. 2, pp. 357-363, 1856; Amer. Assoc. Adv. Sci., Proc., vol. 10, pp. 180-188, 1857; Abst., Amer. Sci. Discovery, p. 338, 1857; Edinburgh New Phil. Jour., n. s., vol. 5, pp. 369-370, 1857.

In this discussion Redfield assigned the term "Newark" to the series known as the New Red Sandstone and also known by many other names under which it has gone in American terminology. Redfield's proposal of this term will be found in a footnote, p. 357 of Amer. Jour. Sci., 1856, and p. 181 of Amer. Assoc. Adv. Sci., Proc., 1857. In Triassic geology it is important to know these papers and they apply to any and every section of the eastern United States Triassic. Redfield was one of the great pioneers in the Triassic from the Connecticut Valley to North Carolina. He proposed this term from Newark, New Jersey, where the red sandstones are so well exposed. The term was used for some time and then fell into disuse. During the last decade of the last century, C. K. Gilbert and I. C. Russell (Entry No. 37) proposed to revive the term. This term has never been universally popular in America and has never been popular in the South. It does not commit the age of the beds as do terms like Keuper, etc.

94. ————, On the relations of the post-Permian fishes of Connecticut and other Atlantic States to the Triassic and Jurassic periods: Edinburgh New Phil. Jour., n. s., vol. 5, pp. 369-370, 1857.

Mentioned as an abstract in Entry No. 93, and was given with J. H. Redfield.

95. RIES, H. AND SOMERS, R. E., The clays of the Piedmont Province, Virginia: Virginia Geol. Survey, Bull. 13, 1917.

Triassic clays are discussed in brief on pages 7, 17, and 25. Locations are given on page 7. An excellent discussion of the clays of the different localities and areas is given on pages 17-26, and a table showing water required for mixing, plasticity, air shrinkage, tensile strength in pounds per square inch, and fire shrinkage for cones 1, 03, 05, and 010. Twelve specimens are reported. The report is very good for the Triassic clays.

96. ROBERTS, JOSEPH K., The Triassic of northern Virginia: Dissertation for Doctor's degree, Johns Hopkins University, Baltimore, Maryland, June, 1922. 189 pp., 4 maps, 68 figs. Abs., Pan-American Geol., vol. 39, pp. 185-200; 289-296, 1923; vol. 41, pp. 22-30, 1924.

The three areas of Virginia between the Potomac and James rivers were studied during the summers of 1920 and 1922 as a basis for the dissertation. The main points of the investigation were the mapping of the areal geology, and a study of the stratigraphy, sedimentation, structure, and the forms of the diabase. A fairly complete bibliography of the Triassic of eastern North America is given. The contents of this article are included in the Triassic report for Virginia.

97. ROGERS, H. D., On the geological age of the coal formation of the vicinity of Richmond, Virginia: Phila. Acad. Nat. Sci., Proc., vol. 1, p. 142, 1843.

Brief mention of the age as being Triassic.

98. ————, Remarks in reference to the Triassic system: Phila. Acad. Nat. Sci., Proc., vol. 1, p. 250, 1843.

Mentions the occurrence of Posidonmya minuta from the Farmville area, Prince Edward County, and states that this indicates the age to be that of the New Red Sandstone.

99. ————, Address delivered at the meeting of the Association of American Geologists and Naturalists, held in Washington, May, 1844: Amer. Jour. Sci., vol. 47, pp. 137-160; 247-278, 1844.

Reviews the work done in the United States and makes mention of the progress on the Triassic.

100. ————, Geological map of the United States and British North America: Johnson's "The physical atlas of natural phenomena", pp. 29-32, pl. 8, 1856.

Gives a brief summary of the Triassic system, as to its extent, fossils, age, structure, origin, coal, minerals and the trap rocks.

101. ROGERS, W. B., Report on the geological reconnoissance of the State of Virginia: Philadelphia, 143 pp., pl. 1, 1836. Reprinted in the Rogers' annual reports and other papers relating to Virginia geology, New York, pp. 21-122, pl. 1, 1884.

This report treats of the coal of the Richmond basin in a more detailed way than it is treated in any of the papers on the coal previous to that time. Also the red sandstone from several localities was mentioned.

102. ————, Report on the progress of the geological survey for the year 1836: Richmond, 14 pp., 1837. Reprinted in the Geology of the Virginias, pp. 123-145, 1880.

The main item is the coal of the Richmond basin, and the Potomac area is discussed.

103. ————, Report on the progress of the geological survey for the year 1839: Richmond, 161 pp., 2 pls., 1840. Reprinted in the Geology of the Virginias, New York, pp. 285-410, 1889.

Chiefly restricted to the areas of the Triassic lying immediately east of the Blue Ridge, what are now the Potomac, Scottsville, and Danville areas. Besides the areal extent of the Triassic, the composition of the sedimentary and igneous rocks is treated, and also the general and associated metamorphism. This is one of the best of Rogers' reports and the first one to deal with that portion of the Triassic lying in Pittsylvania County and which borders on the Carolina line and extends into North Carolina as the Dan River area.

104. ————, Report of the progress of the geological survey for the year 1840: Richmond, 132 pp., 1840. Reprinted in the Geology of the Virginias, New York, pp. 411-435, 1884.

Concerning the areal extent of the Triassic in northern Virginia between what is now Point-of-Rocks and Rapidan Station, the northern portion of the Richmond basin, and the natural coke near Richmond.

105. ————, On the prevailing dip in the various areas of the New Red Sandstones of the Atlantic slope: Amer. Jour. Sci., Proc., pp. 64-65, 1840-42.

Gives a general discussion of the general dip of the sandstones and shales and supports the theory of his brother, H. D. Rogers, who claimed that the Triassic beds in all probability deposited in an inclined position. He cites the effect of the diabase and basalt upon the sedimentary rocks.

106. ————, On the porous anthracite or the natural coke of eastern Virginia: Amer. Jour. Sci., vol. 43, pp. 175-176, 1842; Amer. Assoc. Geol. and Nat., Proc., p. 68, 1840-42.

Discusses the structure and how it occurs. This marks one of the earliest papers on this particular subject.

107. ————, On the geologic age of the Richmond coal field, Virginia: Phila. Acad. Nat. Sci., Proc., vol. 1, p. 142, 1842.

Claims for the Richmond coal an age as late as the Liassic of Europe.

108. ————, On the age of the coal rocks of eastern Virginia: Amer. Assoc. Geol. and Nat., Trans., pp. 298-316, pls. 13-14, 1840-42; Abst., Amer. Jour. Sci., vol. 43, p. 175; Amer. Assoc. Geol. and Nat., Proc., p. 68, 1840-43. Reprinted in the Geology of the Virginias, New York, pp. 645-656, 1881.

Very little additional data, but gives figures of some of the fossil plants.

109. ————, Observations on the subterranean temperatures in the coal mines of eastern Virginia: Amer. Assoc. Geol. and Nat., Trans., pp. 532-538, 1840-42; Abs., Amer. Assoc., Geol. and Nat., Proc., p. 69, 1840-42; Amer. Jour. Sci., vol. 43, p. 178, 1843.

Gives a number of observations on the mine temperatures in the Richmond basin, but with no figures of depth. A brief account of the stratigraphy and structure of the rocks.

110. ————, Difficulty in determining the age of the coal beds of North Carolina and Virginia: Amer. Assoc. Adv. Sci., Proc., vol. 4, p. 300, 1851.

Listed but not printed.

111. ————, Age of the Deep River coal field, North Carolina: Amer. Acad. Arts, Proc., vol. 3, pp. 69-70, 1852-57.

Correlates the Triassic rocks of Pennsylvania, Virginia, and North Carolina on the basis of the fossil life, the structure, and sediments.

112. ————, Remarks on the fossils from the Middle Secondary strata of North Carolina, Virginia, Pennsylvania and Massachusetts: Boston Soc. Nat. Hist., Proc., vol. 5, pp. 18-19, 1854; Amer. Jour. Sci., ser. 2, vol. 19, pp. 123-125, 1855; Abs., Ann. Sci. Discov., pp. 330-333, 1855.

Compares the fossils from the various areas and uses about the same descriptions as are contained in some of his former papers.

113. ————, Observations on the occurrence of natural coke in the Richmond coal field, Virginia: Boston Soc. Nat. Hist., Proc., vol. 5, pp. 53-56, 1854; Abs., Ann. Sci. Discov., pp. 320-322, 1855. Reprinted in the Geology of the Virginias, vol. 4, pp. 158-159, 1883.

Discusses the intrusion of the coal beds by the trap dikes, the relations, and the baked fire clay.

114. ————, On natural coke in the Richmond coal field: Amer. Acad. Arts, Proc., vol. 3, pp. 106-107, 1852-57.

Mentions that the rocks overlying the trap were deposited after the trap had flowed out as an extrusive form.

115. ————, On lignite from Lancaster County, Pennsylvania, and from the Richmond coal field, Virginia: Boston Soc. Nat. Hist., Proc., vol. 5, pp. 189-190, 1855.

The specimens from these two localities are quite similar and the conclusion is reached that they are of the same age.

116. ————, Remarks on the age of the coal-bearing rocks near Richmond,

Virginia, and of the Triassic of North Carolina: Boston Soc. Nat. Hist., Proc., vol. 5, p. 186, 1855.

Compares the plants of the coals of these two areas and concludes from these plants and the character of the coals that they are of the same age and that they resemble the Liassic of Europe more closely than they do any other age.

117. ————, On a new locality for Posidonmya in the Mesozoic rocks of Virginia: Boston Soc. Nat. Hist., Proc., vol. 5, pp. 201-202, 1855.

The locality is near the junction of Banister and Dan rivers in what is now termed the outlier of the Danville area which lies east of Houston. This form has been reported from the Farmville area and Rogers tied the two localities on this basis.

118. ————, Local metamorphism produced by trap dikes in Prince William County, Virginia: Boston Soc. Nat. Hist., Proc., vol. 5, pp. 202-204, 1855.

Describes the occurrence of trap dikes in Prince William County and their various effects upon the sandstones in the formation of structures and minerals. Gives no exact locations. Assigns several hundred feet to the width of some of the dikes. Thinks that the sandstones were covered by a trap sheet, which has been eroded in post-Triassic time.

119. ————, Remarks on the deposition of inclined strata of the Triassic system: Boston Soc. Nat. Hist., Proc., vol. 7, p. 174, 1859-61.

States that the Triassic strata illustrate how inclined strata can be deposited.

120. ————, List of geological formations found in Virginia and West Virginia, Macfarlane's American geological railway guide, pp. 179-185, 1879.

Outlines the Triassic rocks in the column and indicates their age with brief description.

121. ————, The iron ores of Virginia and West Virginia, "The Virginias", vol. 1, pp. 128-130; 138-140; 152-153; 160-161, 1880.

Mentions the iron minerals which occur in Triassic strata.

122. ————, Table of geological formations found in Virginia and West Virginia, "The Virginias", vol. 1, pp. 14-15; 1880; reprinted in vol. 3, p. 61, 1883.

Merely gives the position and age of the Triassic rocks in the column, and is about the same as that given in Macfarlane's guide.

123. ————, Geology of the Virginias (a reprint of the annual reports and other papers), New York, D. Appleton and Company, 1884. Copyright by Emma Rogers, xv and 832 pp., 15 pls., 1 map. Reviewed by H. D. and J. L. Campbell, Amer. Jour. Sci., ser. 3, vol. 30, pp. 357-374, 1884; vol. 31, pp. 193-202.

Numerous references to the Triassic, most important of which are as follows: pp. 63, 69, 85, 86, 98, 261, 324, 325, 468, 471-480, 533, 645-658, 717, 718, 720, 725, 735, 766, 767, 768.

124. RUSSELL, I. C., On the former extent of the Triassic formation of the Atlantic States: Amer. Naturalist, vol. 14, pp. 703-712, 1880.

Russell held the view that the several Triassic areas now detached were once one long expanse of red formations. This article is a compilation of ideas along this line and he advances certain lines of argument to support his view. These arguments are well brought out in his U. S. Geol. Survey Bull., No. 85, which is listed as No. 128, and the arguments are given under this entry.

125. ————, Subaerial decay of rocks and origin of the red color of certain formations: U. S. Geol. Survey, Bull. 52, 65 pp., 1889. Reviewed by J. D. Dana in Amer. Jour. Sci., ser. 3, vol. 39, pp. 317-319, 1890.

The Triassic (Newark) is treated on pages 44-45. This article is very important in the study of the causes of the prevailingly red colors in the Triassic rocks and it applies to the red rocks of various formations throughout the geologic column. The red color of the rocks in southern portions of the United States is discussed as contrasted with the other colors of north-

ern latitudes. The northern colors have taken place in a glaciated country, in contrast to the southern conditions where atmospheric decay has been going on in an uninterrupted manner for long periods of time. The coloring matter is the red ferric oxides in the red rocks and the hydrated ferric and ferrous oxides in the other rocks. This article, with that of Crosby (Entries Nos. 21 and 22), forms important landmarks in the red bed literature of America.

126. ————, The Newark System: Amer. Geologist, vol. 3, pp. 178-182, 1889.

Russell states that there are numerous horizons ranging from the Silurian to the Jurassic to which the Triassic rocks in eastern North America have been assigned. He tabulates up to 1888 the 65 various references which have dealt with this matter of age relationship, beginning with that in 1817 of William Maclure who terms it Old Red Sandstone. In the matter of the selection of a formational or a serial term, he warns of the need "to avoid all terms which imply a greater knowledge of the relations of the rocks of their constancy in lithological or other characters, than is warranted by the facts at hand". He further states, "By adopting a name which does not imply correlation it is not intended to throw doubt on any of the classifications that have been made, but the scarcity of fossils, particularly of invertebrates, in the Newark system as well as the great diversity of opinions regarding its position in geological history, demands the adoption of a name which does not imply more than is definitely known concerning it". Russell closes this paper with the statement that the term "Newark" meets all the requirements and that none of the other terms proposed are appropriate.

127. ————, Has "Newark" priority as a group name? Amer. Geol., vol. 7, pp. 238-241, 1891.

Russell and Gilbert in the early nineties proposed the revival of the term "Newark" for the Triassic system in eastern North America. C. H. Hitchcock objected to the adoption or survival of this term, and in the above article Russell discusses Hitchcock's objections. These objections outlined are as follows: (1) A geographic term used for a formation should show an exposure in its entirety, and this is not the case at Newark, New Jersey; (2) Connecticut River Sandstone was used before Redfield's proposal of Newark, though the former was never formerly adopted; (3) Dana used the term Newark in his lectures but never in his writings; (4 and 5) the Triassic is as well represented in Connecticut as in New Jersey, and since it was first studied in the former region, it should be named from that region. Each of these objections are met by Russell, who ends his statements by saying that to introduce a new name for a system of rocks already properly designated would only add confusion, thus advocating the use of the term "Newark".

128. ————, The Newark System: U. S. Geol. Survey, Bull. 85, 344 pp., 13 pls., 4 figs., 1892.

The most comprehensive treatment up to its time of the eastern North American Triassic. The bulletin begins with the naming and describing of the areas of the Triassic, which are as follows: Acadian, Connecticut Valley, Southbury, New York-Virginia, Barboursville (of the older writers), Scottsville, Danville, Dan River, Taylorsville, Richmond, Farmville, Deep River, and Wadesboro.

The fossil floras and faunas are next discussed and various features which indicate the geological horizon of the red beds are indicated.

The conglomerate, sandstone, shale, slate, limestone, and coal are described, their distribution shown and probable thickness of the Triassic system estimated.

The environment of Triassic time and evidences of glaciation and those for a mild climate are set forth in chapter five.

The fossil faunas are briefly named and reviewed, namely, mammals, ba trachians, reptiles, fishes, insects, crustaceans, molluscs, and fossil footprint Some space is devoted to consideration of the plants.

Chapter VII deals with the diabases, their mineral and chemical compos tion, the forms, as of dikes and sheets, and a discussion as to their distrib tion and age.

The structural features are considered as a whole and individually for ea area, with especial emphasis on the structure of the coal basin. The origin of the fault structure and the absence of oil and gas close the eighth chapter.

Chapter IX discusses one of Russell's favorite Triassic subjects, namely the former extent of the Triassic. In this he outlines the two views, the local-basin and the broad-terrane hypotheses. Evidences of the broad-terrane hypothesis are: "(1) The stratigraphic incompleteness of all of the Newark areas now remaining; (2) the presence of marginal faults which have determined the limits of some of the areas in certain directions; (3) the evidence of great erosion since the Newark rocks were deposited". The arguments favoring the local-basin hypothesis are: (1) No isolated outliers have been found; (2) the scarcity or absence in surrounding regions of the Triassic igneous rocks. The arguments favoring this local-basin idea were brought out by W. M. Davis.

The discussion is closed with the general matter of correlation with the several lines of approach and finally with a comparison with the European column.

Appended to this discussion is a highly perfect bibliography, compilation of which represents a vast amount of time, consisting of 198 pages, arranged alphabetically by authors and by subjects.

129. SCHIMPER, W. P., Traite de paléontologie végétale: Paris, tome I, 738 pp., 1869; tome II, 968 pp., 1870-72; tome III, 896 pp., 1874; folio atlas, 110 pls., 1874.

A few of the fossil floras of the Richmond basin are described and figured, tome I, pp. 276, 610.

130. SCHMITZ, E. T., The structure of the Richmond coal basin: Amer. Inst. Min. Eng., Trans., vol. 24, pp. 397-408, 1896.

Discusses the stratigraphy of the Clover Hill district and gives several sections with their structure. Outlines hypothesis for the origin of the basin and its present form. He thinks the basin due to folds and depressions in the region from the elevation of the Appalachian Mountains and the breaking up of the region by igneous action. Claims that his investigations are not in harmony with Heinrich's views on the extent of the Triassic areas and that the areas were never connected along the Atlantic coast.

131. SCIENCE, Dinosaur tracks (Loudoun County, Virginia): Science, vol. 68, No. 1508, p. xiv.

A brief statement that dinosaur tracks were found recently on sandstone slabs near the town of Aldie. The location is near the old home of President Monroe.

132. SEWARD, A. C., Floras of the past: Nature (London), vol. 64, pp. 633-634, 1901.

A brief review of Fontaine's Status of the Mesozoic Floras of the United States.

133. SHALER, N. S. AND WOODWORTH, J. B., Geology of the Richmond basin, Virginia: U. S. Geol. Survey, Nineteenth Ann. Rept., pt. 2, pp. 385-516, 32 pls., 26 figs., 1899.

This report is chiefly concerned with the areal extent, the stratigraphy and the structure of the Triassic rocks of the Richmond basin. The Triassic system is divided into two main series, which are as follows:

Chesterfield Group:
- Otterdale sandstone
- Vinita beds

Tuckahoe Group:
- Productive coal measures
- Lower barren beds
- Boscobel bowlder beds

The coal beds are discussed in detail and many pits of which there is little or no trace today are named. The underground relations were very well known as there were many pits open then. A number of faults are located and discussed. Igneous dikes and their effects upon the coal beds are one of the important points and the scarcity of dikes is significant compared to their wide occurrence in northern Virginia.

The different views on the matter of structure, from that of Volney in 1803, are reviewed. The structures of both margins north and south of the James River are well described. The economic geology is concerned with the coal chiefly but soils, building stones, and ores are included.

134. SHANNON, EARL V., The mineralogy and petrology of intrusive Triassic diabase at Goose Creek, Loudoun County, Virginia: U. S. Nat. Mus., Proc., vol. 66, art. 2, 86 pp., 32 figs., 9 pls., 1924.

The discussion is opened with jointing and fissuring in the region. The diabase is divided into normal diabase, diabase pegmatite, albitic pegmatites, and aplitic albite rocks. The primary, accessory, and secondary minerals are described in great detail, as is the structure of the various classes of rocks. The chemical composition of each of the major classes of diabase and the quantitative classification is given; also the composition for pyroxenes and a number of the other minerals. The matter of miarolitic cavities with their original and second generation minerals, the hydrothermal action along seams and fissures, hydrothermal joint fillings and their various minerals are treated. The mineral content of the four types of diabase is carefully studied, and the plates exhibit some very characteristic features about the Belmont stock.

135. ————, An occurrence of Xonotlite at Leesburg, Virginia: Amer. Min., vol. 10, No. 1, pp. 12-13, 1925.

The description of a mineral found near Leesburg in the limestone phase of the Border Conglomerate as a result of the intrusion of diabase. The mineral is described crystallographically and several analyses are given.

135-A. ————, Mineralogy and petrography of Triassic limestone conglomerate metamorphosed by intrusive diabase at Leesburg, Virginia: U. S. Nat. Mus., Proc., vol. 66, Art. 28, No. 2565, pp. 1-31, 3 pls., 1925.

The limestone phase of the Triassic conglomerate and the basalt is described briefly and this is followed by the hydrothermal alteration of the basalt and the minerals of such change replacing the limestone. Such minerals are: Diopside, vesuvianite, magnetite, colerainite, garnet, serpentine, xonotlite, thusmasite and wollastonite.

Low-temperature vein minerals are described, namely, diopside, anhydrite molds (?), datolite, apophyllite, barite and calcite. Crystallographic measurements for various minerals are given.

136. SILLIMAN, B., Note on the Richmond coal field, Virginia: Amer. Jour. Sci., vol. 43, p. 14, 1842.

Statement as to the value of the Richmond coal and a few remarks on the specimens received from the pits.

137. SILLIMAN, B., AND HUBBARD, O. P., Chemical examination of bituminous coal from the pits of the Midlothian Coal Mining Company, south side of the James River, 14 miles from Richmond, Chesterfield County, Virginia: Amer. Jour. Sci., vol. 42, pp. 369-374, 1842.

A very detailed account of the composition of a specimen of coal from the Richmond basin.

138. STEVENS, R. P., Remarks on the natural coke or "carbonite" of the Richmond coal field, Virginia: New York Lyc. Nat. Hist., Proc., vol. 1, ser. 2, p. 73, 1874.

Argues that the natural coke was not formed through the influence of trap dikes or sheets, as suggested by Rogers and other geologists of that time.

139. STONE, R. W., Coal on Dan River, North Carolina: U. S. Geol. Survey, Bu 471 (Contr. Econ. Geol., pt. 2, for 1910), pp. 137-169, 1912.

This area is an extension of the Danville area of Virginia, and the stru ture and stratigraphy as well as many of the other features are identic This report reviews the literature of the field, gives the analyses of the co the stratigraphy and the structure.

140. STUR, D., Die lunzer (Lettenkohlen) flora in der "older Mesozoic beds of coal field of eastern Virginia": Verhandl. der K. K. Geol. Reichs., Band

ss. 203-217, 1888. Reviewed by Marcou in Amer. Geol., vol. 5, pp. 160-174, 1888; Abs., Amer. Jour. Sci., vol. 37, ser. 3, p. 496, 1888.

A review of Fontaine's work, and from the plants described Stür determines the age as Lettenkohle.

141. TABER, STEPHEN, Geology of the gold belt in the James River basin, Virginia: Virginia Geol. Survey, Bull. 7, 271 pp., 10 pls., 23 figs., 1913.

Mentions a number of diabase dikes which are of Triassic age, pages: 46-47; 85-87; 116-117.

142. TAYLOR, R. C., Richmond coal basin and its coal trade: Pennsylvania State Jour., vol. 2, p. 567, 1833-34.

Gives a few statistics and remarks on the advantages of the basin to develop the cities near it.

143. ————, Memoir of a section passing through the bituminous coal field near Richmond, Virginia: Geol. Soc. Pa., Trans., vol. 1, pp. 314-325, 1835.

Discusses the quality and quantity of the coal and its general character. Also some description of the associated rocks.

144. ————, Review of the geologic phenomena and the deductions derived therefrom in 259 miles of sections in parts of Maryland and Virginia. Also a notice of certain fossil Acotyledonous plants in the secondary strata near Fredericksburg: Geol. Soc., Trans., vol. 1, pp. 314-325, 1835.

Mentions the Triassic conglomerate near what is now Point of Rocks, Maryland, and the red sandstone.

145. ————, Statistics of coal...............Philadelphia, 1st ed., 1848; 2nd ed. 1855.

Gives the coal production of the Richmond mines for the years 1822-1828.

146. TOMLINSON, C. W., The origin of red beds: Jour. Geol., vol. 24, pp. 153-179, 1916.

This paper deals with the vital problem of red beds and is as applicable to the Triassic as to any others. The distribution and nature of coloring matter receives some treatment in the beginning of the discussion. Then the author takes up whether the coloring matter is original or of later age and whether the ferruginous material is in the same form later that it was in the beginning when the sediments were being accumulated. Barrell's hypothesis is reviewed. Refers to the rôle of organic matter in the western red beds and the general matter of the variations in the hydration of ferric oxide. The first part of the paper is closed with the theme of whether the coloring matter was a chemical or a mechanical sediment.

Part II is concerned with the environment of the time when the red beds were accumulated. All the various present day conditions where red beds are known to be forming are discussed and then the other features, besides the matter of color, which are indicative of the environment of the red beds, are considered.

His summary as to the most important points brought out in the discussion is as follows: "(1) Rapid erosion on landmasses of considerable relief; (2) decomposition not complete in advance of transportation; (3) sediments diminishing in thickness and in coarseness of grain away from sources of material and clastic sediments giving place to non-clastic in the same direction; (4) fluviatile deposition most important; (5) all deposits in relatively shallow water, or sub-aerial; (6) oscillating marine and non-marine conditions at edge, non-marine in most of region of deposition; (7) moderate aridity long continued with less arid conditions in other parts."

Finally the diastrophic changes and their relation to red bed sedimentation are discussed.

47. WARD, LESTER F., Sketch of paleobotany: U. S. Geol. Survey, Fifth Ann. Rept., pp. 357-452, pls. 56-68, 1885.

On page 440 a brief mention is made of the Triassic plants.

48. ————, The plant-bearing deposits of the American Trias: Geol. Soc. Amer., Bull., vol. 3, pp. 23-31, 1891.

Gives the American and foreign distribution of the Triassic plants, devoting most of the space to the American forms and deposits. The plants of the Connecticut Valley, Pennsylvania, Virginia, and North Carolina are named. A very good compilation of the work up to that time.

149. ————, Status of the Mesozoic flora of the United States (1st Paper): U. S. Geol. Survey, Twentieth Ann. Rept., pt. II, pp. 211-748, 158 pls., (pls. XXI-XLVIII are Triassic entirely), 1900.

150. WASHINGTON, H. S., Chemical analyses of igneous rocks (published from 1884 to 1913 inclusive with a critical discussion of the character and use of analyses): U. S. Geol. Survey, Prof. Paper 99, 1201 pp., 3 figs., 1917.

Gives a number of the analyses of the Virginia diabase and Triassic rocks along the Atlantic Coast, which to a great degree are similar to those of Virginia. Many of the early analyses are classed as inferior. Their quantitative classifications are given in some cases.

151. WATSON, THOMAS L., Weathering of diabase near Chatham, Virginia: Amer. Geol., vol. 22, pp. 85-101, 1898.

Watson's home was near this locality and he was very familiar with the region around Chatham. He collected both fresh and altered diabases and gives the analyses of them. The varieties collected were fresh, altered and decomposed olivine diabase and fresh quartz diabase. Analyses for the augite and feldspar minerals are given. The mechanical analysis of the decayed rock was determined. One of the most important parts of the paper is the order of decay in the component minerals.

152. ————, Some further notes on the weathering of diabase in the vicinity of Chatham, Virginia: Amer. Geol., vol. 24, pp. 355-369, 1899.

Somewhat a continuation of the paper of Entry 151, in which more analyses are given, and comparison made with the minerals and other rocks of Triassic areas along the Atlantic Coast.

153. ————, Geological map of Virginia: Va. Geol. Surv., Charlottesville, Joel H. Watkins, draftsman, scale 1:500,000, 1914. Revised 1916.

The map is compiled from information from all sources available, both from the U. S. Geol. Survey and from the works of W. B. Rogers and others. Some of the Triassic areas are incorrectly given.

154. ————, Mineral resources of Virginia, Lynchburg, Virginia: 618 pp., 83 pls., 101 figs., 1907.

This publication was prepared for the Jamestown Exposition, held at Norfolk in 1907. Various references are made to the Triassic with regard to the natural resources of the rocks of this age. The following are the main references: Barite, pp. 308-309; coal, pp. 339-347; copper minerals, p. 518. The resources of the Triassic are dealt with only in a general way, such as is necessary for popular needs in a publication of this kind.

155. ————, Mineral production of Virginia for 1908: Virginia Geol. Survey, Bull. I-A, 1909.

Triassic coal is briefly mentioned, pp. 53-54; sandstone, pp. 87-88.

156. ————, Mineral production of Virginia for 1909 and 1910: Virginia Gec Survey, Bull. VI, 1910.

Triassic coal is mentioned on pp. 39 and 41.

157. ————, Mineral production of Virginia for 1911 and 1912: Virginia Geo Survey, Bull. VIII, 1913.

Brief mention is made, pp. 8 and 9, of the reopening of the Gayton mine about 1909 and a fairly large tonnage is reported.

158. WEED, W. H., AND WATSON, THOMAS L., The Virginia copper deposits: Ecor Geol., vol. 1, pp. 309-330, 1906.

The Triassic areas are mentioned, pp. 310 and 330.

159. WILLIAMS, ALBERT, JR., Coal: U. S. Geol. Survey, Mineral Resources, (18ε and 1884), 1885.

Brief statement of the Richmond field, pp. 97-98.

160. WOODWORTH, J. B., The Atlantic Coast Triassic coal fields: U. S. Geol. Survey, Twenty-second Ann. Rept., pt. 3, 1900-01.

This report deals with the Richmond, Virginia, and the North Carolina Triassic coals. The coals of the Richmond basin are discussed in connection with their geologic relations, age, structure, history, and the methods of mining, the composition, the natural coke, and the distribution. The Farmville field is also treated on pp. 42 and 43, showing its stratigraphy to be very similar to that of the Richmond basin.

161. ————, The history and conditions of mining in the Richmond coal basin, Virginia: Amer. Inst. Min. Eng., Trans., vol. 31, pp. 477-484, 1 map and 1 section, 1902.

Gives a very brief review of the early history of the mining and some details on the stratigraphy and structure. Summary of the literature on the basin.

162. WOOLDRIDGE, A. S., Geological and statistical notice of the coal mines in the vicinity of Richmond, Virginia: Amer. Jour. Sci., vol. 43, pp. 1-14, 1842.

General statements on the fossils, with production of the pits, their depth, and description of the pits.

163. WURTZ, H., Preliminary note upon the "carbonite" or so-called "natural coke" of Virginia: Amer. Inst. Min. Eng., Trans., vol. 3, pp. 456-457, 1875.

Gives an analysis of the coke and describes the physical properties. Mentions the trap controversy.

164. ZEILLER, R., Paléontologie végétale. (Ouvrages publiés en 1888): vol. 5, pp. 1235-1261, 1888.

Lists and figures some of the Triassic flora which occur in the Richmond and Deep River basins of Virginia and North Carolina. Gives other references to the Virginia Triassic.

165. ————, A letter on the flora of the Richmond coal field, Virginia, in "The Triassic flora of Richmond, Virginia" by Marcou: Amer. Geol., vol. 5, p. 172, 1890.

Gives a list of Triassic plants studied:

Equisetum rogersi, Schimp. or E. Arenaceum, Jaeg.
Macrotaeniopteris magnifolia, Rogers
Acrostichides linneaefolius, Bunbury
A. rhombifolius, Fontaine
A. microphylius, Fontaine var.
Asterocarpus virginiensis Fontaine
A. platyrrhochys, Fontaine var.

Zeiller mentions the works of Emmons of North Carolina and Fontaine of Virginia.

›6. ————, Paléontologie végétale. (Ouvrages publiés en 1891): vol. 8, pp. 865-908, 1891.

Gives other figures of the Richmond and Deep River Triassic plants.

AUTHORS ARRANGED CHRONOLOGICALLY WITH ENTRY NUMBERS OF THE ACCOMPANYING BIBLIOGRAPHY

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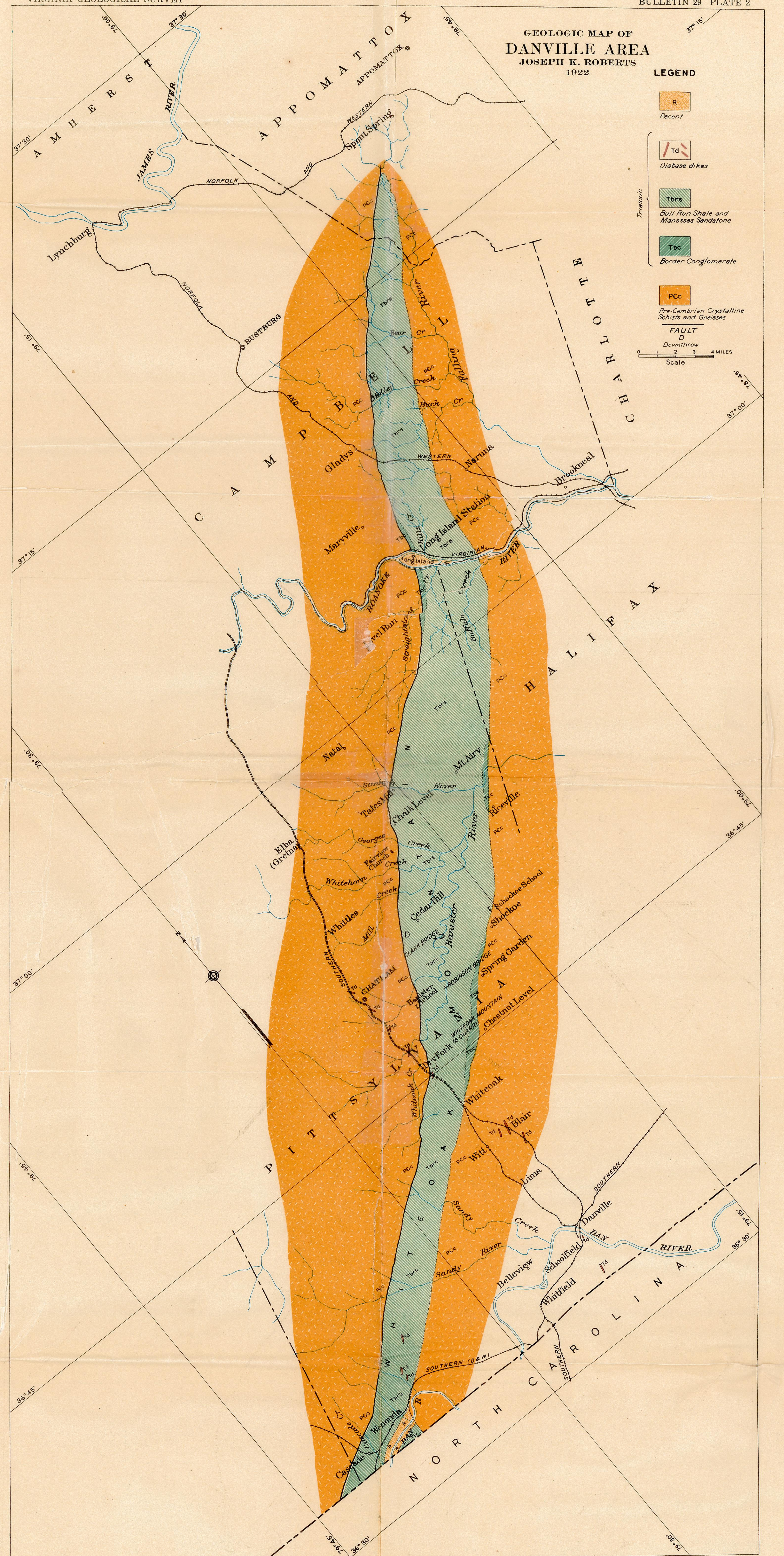
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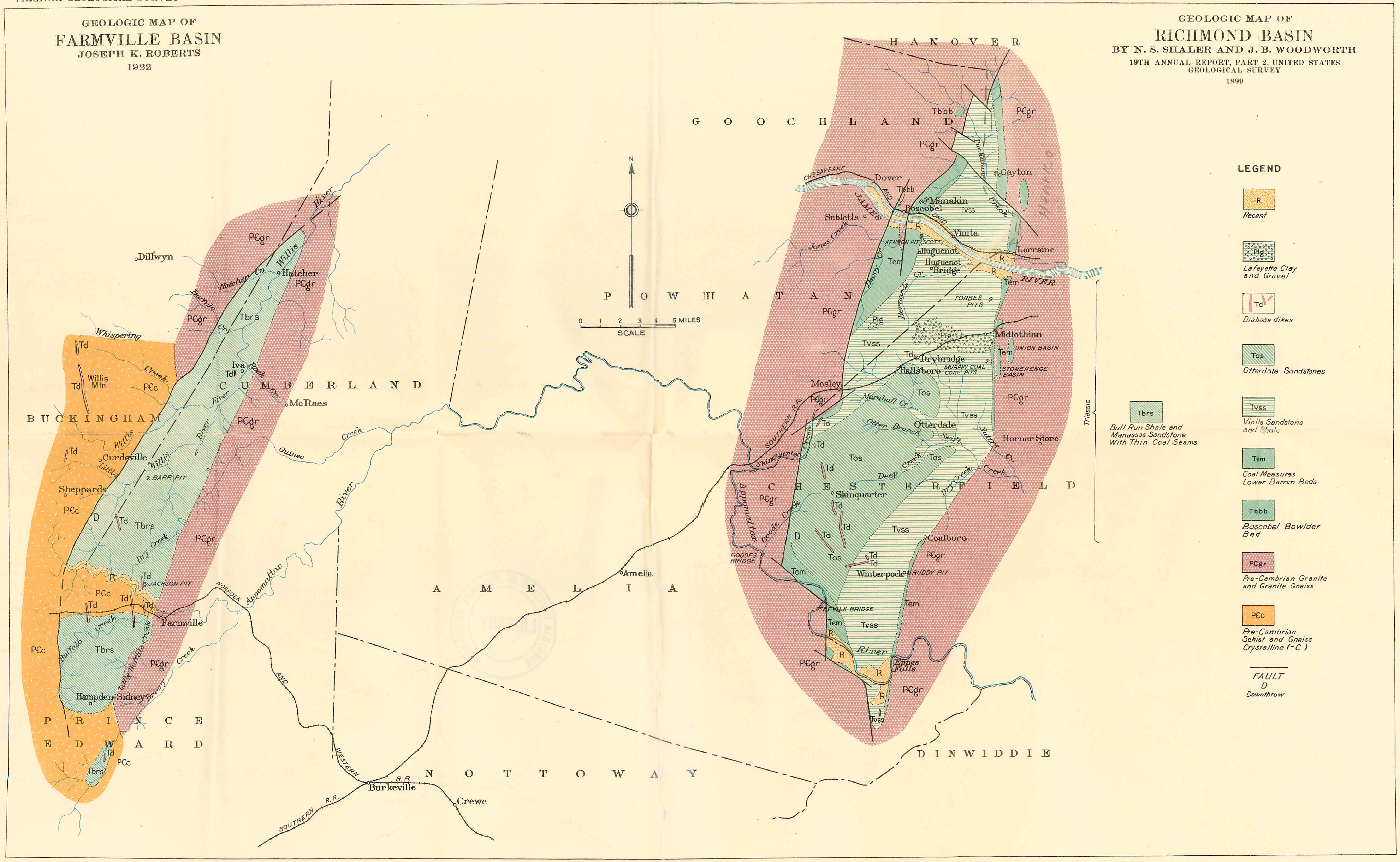
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DINWIDDIE
0 1 2 3 4 5 MILES
SCALE
N
Dillwyn
Hatcher
McRaes
Iva
Curdsville
Sheppards
Farmville
Hampden-Sidney
Willis Mtn
BARR PIT
JACKSON PIT
Amelia
Burkeville
Crewe
NORFOLK AND WESTERN
SOUTHERN R.R.
Dover
Sabot
Manakin
Boscobel
Sublets
Vinita
Huguenot
Huguenot Bridge
Lorraine
Gayton
KENNON PIT (SCOTT)
FORBES PITS
Midlothian
UNION BASIN
STONEHENGE BASIN
Drybridge
Hallsboro
MURPHY COAL CORP. PITS
Mosley
Otterdale
Horner Store
Skinquarter
Coalboro
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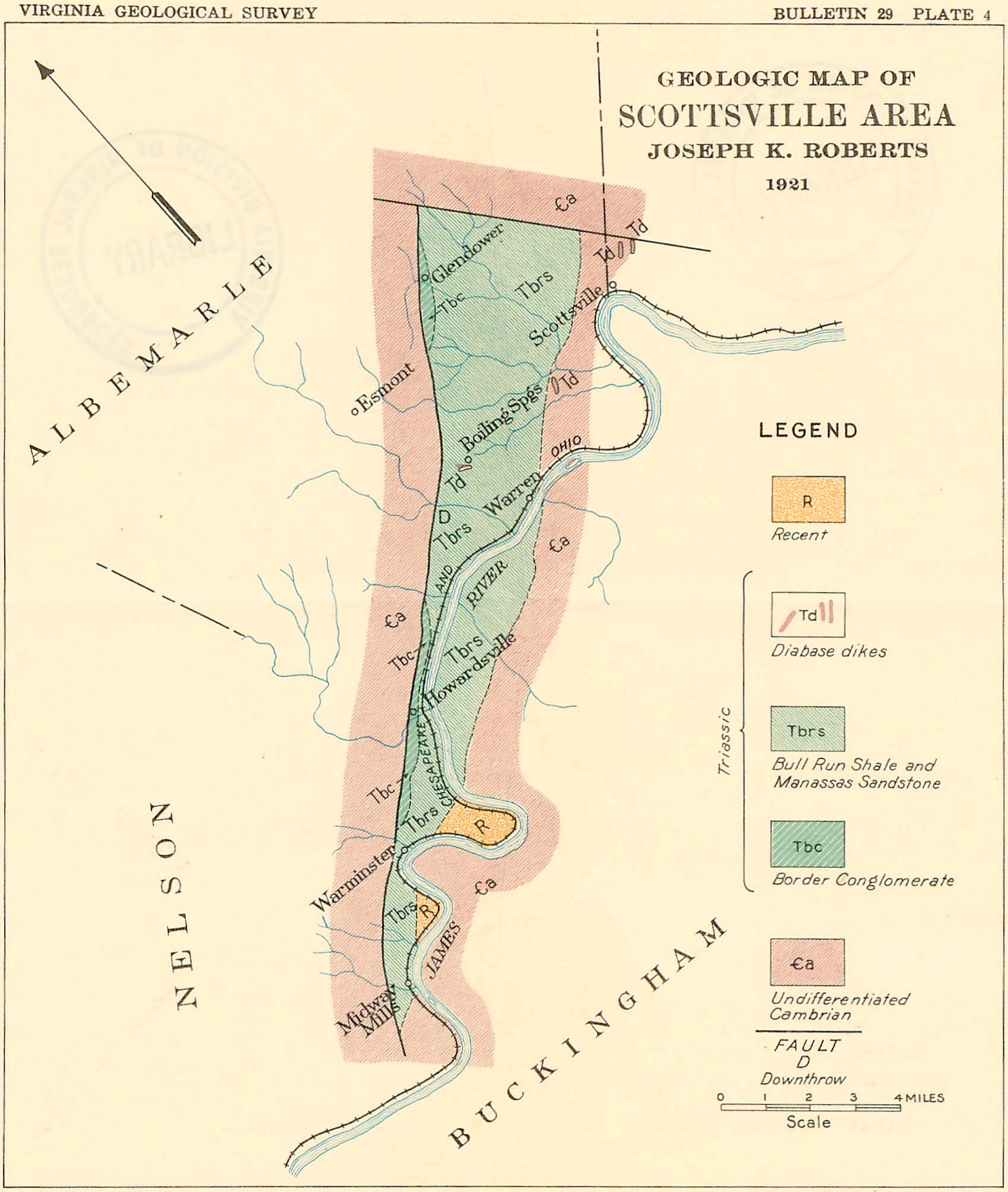
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JAMES
RIVER
CHESAPEAKE AND OHIO
€a
Tbrs
Tbc
Td
R
D
LEGEND
R
Recent
Td
Diabase dikes
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Triassic
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0 1 2 3 4 MILES
Scale