RELATIONSHIP OF IGNEOUS INTRUSIONS TO GEOLOGIC STRUCTURES IN HIGHLAND COUNTY, VIRGINIA

by

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TABLE OF CONTENTS

PAGE

ILLUSTRATIONS

INTRODUCTION

The area of this study is northeast of Monterey in northern Highland County, Virginia, in the Appalachian Valley and Ridge province (Figure 1). It lies well northwest of the Great Valley and approximately six miles southeast of the Appalachian Plateau. The Lower and Middle Paleozoic rocks which constitute the bedrock are folded into a series of northeast-trending synclines and anticlines. The sedimentary formations have been intruded by a large number of igneous bodies. Erosion has breached many of the anticlines producing a topography characterized by long linear ridges and intervening valleys.

The purpose of this investigation was twofold: (1) to map the bedrock, and (2) to use this map as a base for an investigation of the intrusive igneous units and their relation to the sedimentary formations.

The area of study includes approximately nine square miles immediately northeast of Monterey, Virginia. Approximately 60 days were spent on field work during the summer and autumn of 1969. Mapping was done on aerial photographs of scale 1:26,000 of the United States Geological Survey and on a preliminary version of the U.S.G.S. Monterey quadrangle 1:24,000 series. The area is bounded on the south and west by U.S. Routes 250 and 220 respectively, on the north by Wooden Run, and on the east by the west flank of Jack Mountain.

The sedimentary units which crop out in this area range from the Early Silurian Tuscarora Sandstone to the Middle Devonian Marcellus Shale. There are more than 60 intrusives in the area. Some are definitely discordant, while others appear to conform to the surrounding structures. The intrusives display a wide range of compositions; most are porphyritic and some contain abundant xenoliths representing a variety of sedimentary units.

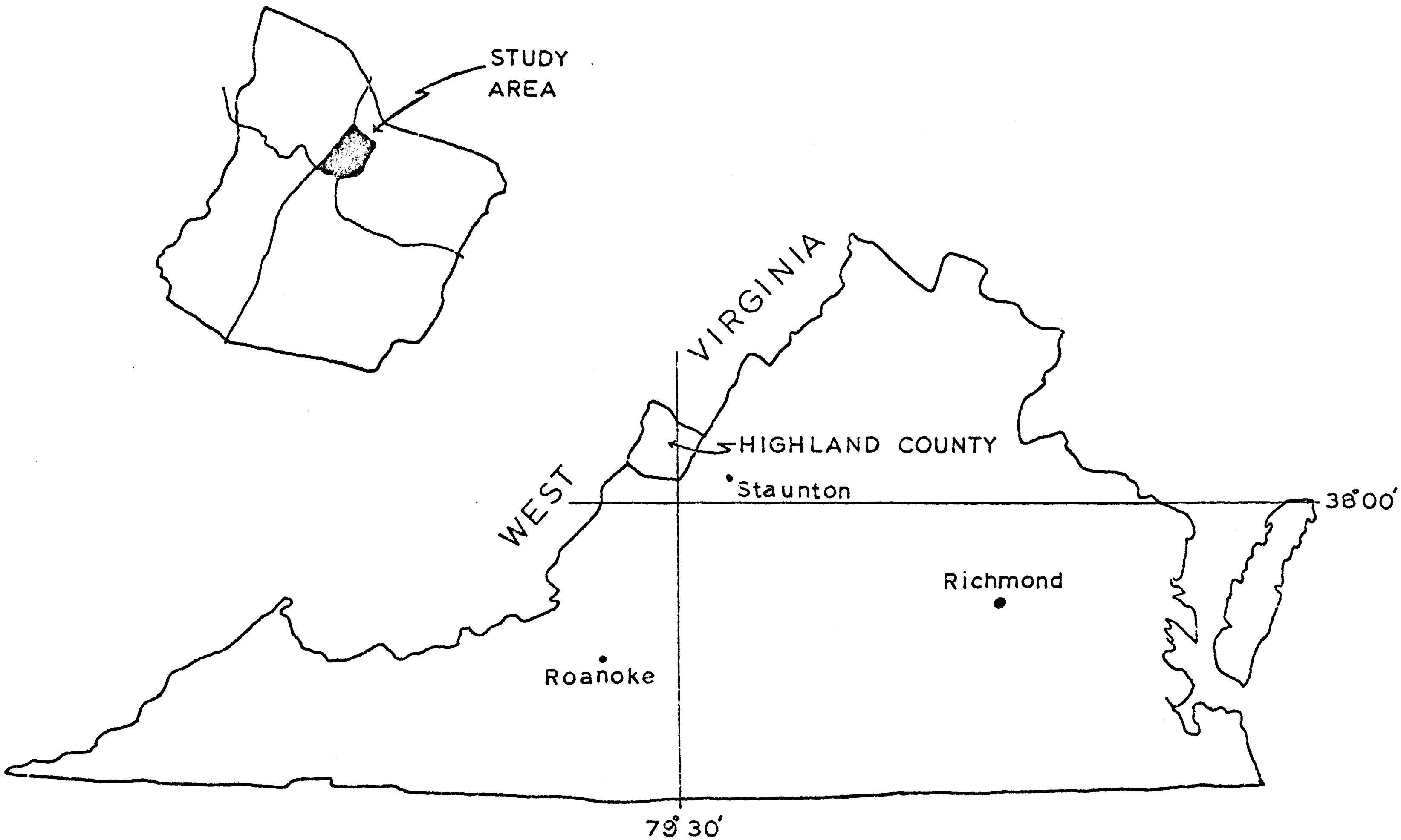

Figure 1 Location of the Study Area in Highland County, Virginia

PREVIOUS WORK

The first geological work in Highland County was done by William B. Rogers (1883-84) and Hotchkiss (1885). The initial investigation of the igneous bodies was done by Darton and Diller (1890) and by Darton and Keith (1898). These studies recognized two types of intrusive rocks: a basalt porphyry and a fine-grained porphyritic felsite, which was termed a "granite-felsophyre." Darton (1899) showed the location of some of the intrusive bodies in the Monterey area. Although subsequent work has made much of Darton's stratigraphy obsolete, this folio is the only comprehensive report covering the entire Monterey area.

Watson and Cline (1913) studied the intrusions of the Monterey area as part of their work on the intrusions of central western Virginia. They refer to Darton's basalt as a diabase and describe it as being similar to that found in other areas of Virginia west of the Blue Ridge. The "granite-felsophyre", however, was noted only in the Monterey area.

A number of other workers have studied parts of Highland County and have discussed the stratigraphy and structure. Swartz (1929) studied the Helderberg limestones in Virginia and West Virginia and described several measured sections near the area of the present study. The region is also included in Butts' (1940) report on the geology of the Appalachian Valley in Virginia. Dennison (1961) studied the stratigraphy of the Middle Devonian shales. Dennison and Textoris (1967) studied the stratigraphy and petrology of the Tioga Bentonite. In a study of the Devonian System in the Appalachian region, Oliver et al (1967) postulated a source for the Tioga ash in the Monterey area. This theory was later abandoned by Dennison and Johnson (1970).

Dennis (1934) examined the intrusive bodies in western Virginia including Highland County. Clough (1948), Parrott (1948), Tarleton (1948) and Ramsey (1950) mapped parts of Highland County adjoining the area of the present study and examined petrographically some of the intrusive rocks. Parrott (1948) recognized four types of intrusive rocks: (1) the "granite-felsophyre", (2) a blue-gray, yellow-weathering trachyte, (3) basalt, and (4) diabase. He also noted the presence of fragments of the adjacent sedimentary formations in some of the intrusive bodies.

Johnson and Milton (1955) reported on the igneous rocks of Augusta and Rockingham Counties and, in a later report (1963), noted a late Jurassic to early Cretaceous potassium-argon date of 152 $\pm$ 5 million years for the dikes in the Shenandoah Valley. Garner (1956) studied the igneous rocks to the north of Monterey in Pendleton

County, West Virginia.

Rader and Griffins (1960) described a series of dikes in the Hightown Valley west of Monterey and suggested that the granite-felsophyre should be called an andesite porphyry. They also noted sedimentary fragments in the dikes, but attributed them to fault brecciation after intrusion.

Based on biotite and whole rock potassium-argon dates, Fullagar and Bottino (1969) have assigned an age of 47 ± 1.2 million years (Middle Eocene) to the "andesite porphyry" from the area of the present study.

STRATIGRAPHY

Introductory Statement

The stratigraphic section in the study area includes about 2200 feet of Lower Silurian to Middle Devonian strata. In general, the rocks of the Tuscarora and Rose Hill Formations are sandstones with some interbedded shales and siltstones. These grade upward into shales, shaly limestones and limestones of the Cayuga and Helderberg groups. In turn, these units are overlain by the Needmore and Marcellus shales.

Silurian

The Silurian System in the Monterey area includes the Tuscarora Sandstone, Rose Hill Formation, Rochester Shale, McKenzie Limestone, Williamsport Sandstone, Wills Creek Formation, and Tonoloway Limestone and is approximately 1140 feet thick (Table I). There is some discussion in the literature (Butts 1940, p. 273) concerning the age of the Keyser Limestone. The correlation chart by Swartz and others (1942) places it in the Silurian System. This report will follow Butts (1940) and place it in the Devonian System.

Tuscarora Sandstone: The name Clinch Sandstone was given to this formation by Safford (1869, p. 292) for Clinch Mountain, Tennessee. According to Butts (1940, p. 230) the name Tuscarora is applied to the formation north of the thirty-eighth parallel and will be used in this paper.

The Tuscarora is a light gray to white, medium-to fine-grained, well-indurated quartz sandstone or quartzite. It is generally thick-bedded to massive and extremely resistant to erosion. According to Butts (1940) the Tuscarora conformably overlies the Ordovician Juniata Formation, and is conformably overlain by the hematitic sandstones and shale of the Rose Hill Formation. In the area of study only the upper contact was observed and no features were seen which would conflict with Butts' interpretation.

Rose Hill Formation: The lower portions of the Rose Hill Formation are maroon, medium-to thick-bedded, medium-grained, well-indurated, hematitic quartz sandstone with interbedded pink to olive shales and siltstones. Higher in the formation olive to pink shales predominate with some thin interbedded maroon sandstones.

According to Lesure (1957) both upper and lower contacts are conformable. The contacts are poorly exposed in the area and no features were observed which would imply unconformity. The Keefer Sandstone was not found and its absence may imply an unconformity between the Rose Hill Formation and the Rochester Shale. However, the Rochester Shale may be equivalent to the Keefer, in which case, the contact would be conformable.

Rochester Shale: Butts (1940, p. 247) states that the only observed occurrence of the Rochester Formation in Virginia was a 25 foot section on Virginia Route 284 about 1.5 miles southeast of Crabbottom (Blue Grass) in the Highland County, and that the formation probably continued southwest toward Monterey. As this distance is only seven miles along strike, it is probable that the sequence of olive drab to gray, fissile, calcareous shales which overlie the Rose Hill Formation is the Rochester. This unit is easily eroded and poorly exposed.

McKenzie Limestone: Butts (1940, p. 251) includes the McKenzie Limestone in the Cayuga Group. With this interpretation there are no rocks present equivalent to the Niagara Group and presumably the McKenzie lies unconformably on the Rochester Shale. Woodward (1941, p. 143) takes another position. He does not consider the McKenzie to belong to the Cayuga Group but considers it a shallow-water facies of the Lockport Limestone of Niagaran age. According to Woodward's interpretation, the McKenzie would conformably overlie the Rochester Shale. No evidence was found to confirm either interpretation as the contacts are everywhere obscured. Woodward (1941, p. 119-120) states that the contacts with the overlying Williamsport Sandstone and the underlying Rochester Shale are probably gradational and were arbitrarily placed.

The McKenzie is composed of three to five inch thick beds of limestone and shale. The limestone is abundantly fossiliferous. Homeospira (?) and Beyrichia were identified with the assistance of Dr. C. G. Tillman of Virginia Polytechnic Institute.

In the study area the formation's thickness is difficult to determine, but one section 170 feet thick was measured by Woodward (1941, p. 198) along Virginia Route 284 southeast of Crabbottom (Blue Grass). This thickness seems reasonable.

Williamsport Sandstone: The Williamsport Sandstone occurs as a zone of white, thin-to medium-bedded, fine-grained, quartz sandstones with interbedded shale. The formation forms a rounded, but pronounced ridge covered by blocks of well-indurated grayish-white quartz sandstone.

The Williamsport is well exposed in a roadcut on Virginia Route 629 about one-half mile south of its junction with Route 631. At this location, although tightly folded into a small anticline, the contacts show no signs of unconformity.

Wills Creek Formation: The Wills Creek Formation is composed of blue-gray calcareous shale, mudrock and thin-bedded to platy, fine-grained limestone. A prominent gray-white, medium-grained, argillaceous, quartz sandstone about three to five feet thick occurs in the upper half of the formation. The sandstone is generally pitted and limonite-stained. With the exception of this sandstone, the Wills Creek weathers easily to a greenish, shaly material.

The contact with the underlying Williamsport Sandstone is conformable (Woodward, 1941, p. 181). The contact with the overlying Tonoloway Limestone is indistinct. In general, the Wills Creek tends to be more argillaceous, weathering to a shaly residue, whereas the Tonoloway weathers to dense platy fragments of fine-grained, blue-black limestone. Following Woodward (1941, p. 182) the contact was placed arbitrarily at the lowest occurrence of Tonoloway-type limestone.

Butts (1940, p. 257) measured 170 feet of Wills Creek in a section along Virginia Route 284 about two miles southeast of Crabbottom (Blue Grass) in Highland County. Woodward (1941, p. 197) measured 213 feet along the same section.

For the purpose of this study the Wills Creek and overlying Tonoloway Limestone were mapped together. The thickness of the combined units was approximately 410 feet as determined from the map, Plate 1.

<u>Tonoloway Limestone</u>: The Tonoloway Limestone is a blue-black, thin-bedded to laminated, fine-grained limestone with minor interbedded calcareous shales. Upon

weathering, the limestone forms dense, irregular blue-gray plates showing prominent laminations, mudcracks and intraformational breccias. These features are particularly well displayed on the east slope of the line of hills immediately east of Monterey.

As previously noted, the contact with the underlying Wills Creek Formation is indistinct and arbitrarily placed (Woodward, 1941, p. 182). The upper contact with the Keyser Limestone is distinct. The gray, coarse-grained, nodular limestone of the Keyser contrasts sharply with the blue-black, fine-grained Tonoloway. Woodward (1943, p. 46) states that although an unconformity is implied by the lithologic change, there are few data to suggest a major disconformity at this contact.

Butts (1940, p. 263) computed the thickness of the Tonoloway along Virginia Route 284 southeast of Crabbottom (Blue Grass) to be 400 feet thick. Woodward (1941, p. 241) briefly described a section half a mile east of Monterey in which the Tonoloway is about 550 feet thick.

Devonian

The Devonian System in Highland County includes the Keyser Limestone, Coeymans Limestone, Licking Creek Limestone, Oriskany Sandstone, Needmore Shale, Tioga Bentonite and Marcellus Shale. Table II gives pertinent information about the Devonian units in this area.

<u>Keyser Limestone</u>: The Keyser Limestone is the lowest member of the Helderberg Limestone (Swartz, 1929, p. 27), and may be time transgressive from Silurian to Devonian (Butts, 1940). Swartz et al (1942) would place it entirely in the Silurian System.

In Highland County the Keyser conformably overlies the Tonoloway Limestone and is conformably overlain by the Coeymans Limestone (Woodward, 1943). The lower portion of the Keyser is gray, medium-to thick-bedded, coarse-grained limestone, which weathers to a characteristic light gray to buff nodular surface. The buff-gray, fissile, calcareous Big Mountain Shale Member occurs in the lower part of the Keyser in Highland County. It is exposed in a roadcut along Virginia Route 629 about half a mile north of its junction with Route 631. The upper portion of the Keyser is mostly gray, thin-bedded, medium-to fine-grained limestone.

Woodward (1943, p. 47) measured 231 feet of Keyser Limestone east of Monterey. Swartz (1929) measured 228 feet of Keyser in the same section. The thickness of the Keyser is estimated from the geologic map (Plate 1) to be 230 feet.

<u>Coeymans Limestone</u>: The Coeymans is a dense, gray to pinkish-gray, very coarse-grained, crinoidal limestone. According to Swartz (1929, p. 39) the characteristic

fossil is Gypidula coeymanensis. Although the limestone is composed in large part of crinoid fragments, none could be identified positively.

In the area east of Monterey, the Coeymans is about 50 feet thick, as calculated from outcrop width and known dip. Swartz (1929, p. 63) obtained a value of 50 feet in the same section half a mile east of Monterey.

Licking Creek Limestone: Swartz (1929, p. 63) recognized three formations in the interval included in the Licking Creek. The lowest was the New Scotland Limestone, composed of 25 feet of gray, fine-grained limestone and massive gray-white chert. The second formation was the Shriver (?) Chert, which included 85 feet of bedded black chert. The uppermost unit was the massive, gray, sandy Becraft Limestone, 110 feet thick. Woodward (1943, p. 229) recognized the same three lithologies but used the names New Scotland Limestone, Port Ewen Chert and Port Jervis Limestone, respectively. Butts (1940) divided the same interval into the New Scotland Limestone Member and Becraft Member of the Helderberg Limestone.

For the purpose of this study, the Licking Creek Limestone is considered one formation which contains the New Scotland Limestone Member at its base. This member is shown on the map (Plate 1) where it could be easily recognized. Upper portions of the formation were not differentiated. The thickness of the Licking Creek was estimated from the map to be 230 feet.

Oriskany Sandstone: This unit consists of about 100 feet of highly fossiliferous, yellow-white, friable, medium-to coarse-grained quartz sandstone. Large molds and casts of Acrospirifer and Meristella occur in yellow-white irregularly shaped chert nodules. Edriocrinus sacculitera was found in one outcrop (number 81) on U.S. Route 220 about 200 yards south of the junction with Route 629. Butts (1940) lists an Edriocrinus from an unknown location between Monterey and Strait Creek. It is possible that these locations are the same. Table II lists those fossils which were identified with the assistance of Dr. C. G. Tillman.

According to Lesure (1957, p. 52-53), the lower contact with the Licking Creek Limestone is gradational. The contact with the overlying Needmore Shale is sharp and, according to Butts (1940, p. 294), represents a hiatus.

Needmore Shale: The Needmore Shale is easily eroded and consequently poorly exposed. According to Butts (1940, p. 294), it unconformably overlies the Oriskany Sandstone. It is overlain by the Tioga Bentonite with probable conformity since no reference to an unconformable contact was found in the literature.

The exact thickness in the study area is unknown due to weathering and colluvial cover; it is estimated to be 100-150 feet thick.

Tioga Bentonite: Typically the Tioga occurs as a brownish-gray zone rich in clay and abundant silt-and sand-sized mica flakes. This unit is weathered and poorly exposed in most places in the area but along U. S. Route 250 east of Monterey it was estimated to be about 15 feet thick. According to Textoris and Dennison (1970), it is composed chiefly of altered ash with crystals of biotite, K-feldspar and albite. It appears to be conformable with the underlying Needmore Shale and overlying Marcellus Shale.

Marcellus Shale: The black fissile shale overlying the Tioga Bentonite and Needmore Shale has been classified several different ways. Butts (1940, p. 307) calls it the Marcellus Shale Member of the Romney Shale. Later (1940, p. 308) he uses the name Millboro to refer to a mappable unit consisting of the Marcellus and Naples Shale Members of the Romney Shale. In the present work the name Marcellus Shale will be used following the usage of Dennison (1961, p. 40).

The top of the Marcellus is not seen in the area and the complete thickness of the unit is not known. From the geologic map it is estimated that there is a minimum of 200 feet of Marcellus present.

<u>Alluvium and Colluvium</u>: Colluvial material consisting mostly of blocks up to boulder size occur in significant amounts at several locations in the area. The colluvial cover is extensive in the southeast corner of the area and on small stream divides along the eastern edge of the area. The colluvial cobbles and boulders are predominately hematitic quartz sandstone and white quartzite, probably derived from the Rose Hill Formation and Tuscarora Sandstone, which crop out on the slope to the east.

Reworking of the colluvial material has resulted in deposits of alluvium along most stream channels.

STRUCTURAL GEOLOGY

Introductory Statement

Plates 1 and 3 show the major structures in the area. Structure Sections A-A' and B-B' (Plate 2) were drawn across the northern and southern parts of the area. The major folds in the area include the Monterey syncline and Jack Mountain anticline.

Monterey Syncline

The western edge of the area covers the Monterey syncline which plunges gently to the south from a point about 1.5 miles north of Monterey. The structure is asymmetric, the steeper southeastern limb dipping approximately 75 to 80 degrees northwest. Dips of the northwest limb range from 10 to 30 degrees southeast (Parrott, 1948, p. 83). The axis of the syncline is east of Monterey.

A small anticlinal fold occurs within the area west of the synclinal axis. The anticline strikes north 70 degrees east and exposes about six feet of Oriskany Sandstone on each of the vertically dipping limbs. The Needmore shale adjacent to the sandstone is horizontal and may be overturned.

Jack Mountain Anticline

The Jack Mountain anticline (Structure Section A-A', Plate 2) is in the south-central part of the area. It is generally symmetrical with dips on both limbs averaging

30 to 40 degrees. The structure plunges northeastward 10 to 20 degrees. A prominent nose is formed by the resistant Tuscarora Sandstone and the lower part of the Rose Hill Formation.

The trend of the axis of the fold changes north of the nose as Middle Silurian and Lower Devonian carbonates form a tight anticline, which separates the Monterey syncline from another syncline to the east.

Other Folds

A north-plunging, slightly asymmetric syncline occurs in the north central portion of the study area. The northwest limb of this syncline dips a maximum of 60 to 70 degrees, whereas the southeast limb dips 70-90 degrees. The synclinal axis changes from a north trend in the south to N.30°E. in the more northerly part of the structure. A small anticlinal fold brings the Oriskany Sandstone to the surface along the axis of the structure as shown on Plate 1.

To the east of the north-central syncline is an area of gently undulating folds, which are collectively synclinal. This synclinal form plunges gently southward and forms a valley separating two parts of Jack Mountain.

Faults

Two small faults are seen in roadcuts along Virginia Route 629 on the nose of the Jack Mountain anticline.

These faults have dropped portions of the Keyser Limestone to a level of the upper Tonoloway Limestone. Displacement along the faults is estimated at a maximum of 30-50 feet. The fault surfaces are poorly exposed but appear to dip sub-parallel to the bedding planes. Thus, these are reverse or small thrust faults, probably developed during the folding of the Paleozoic strata.

IGNEOUS ROCKS

Sixty separate intrusions consisting of seven types of igneous rocks were found within the study area (Plate 1): "andesite porphyry", andesite, basalt, olivine basalt porphyry, trachyte I, trachyte II and diatreme breccias.

The igneous rocks were studied in hand specimens and in thin sections. Where possible, phenocrysts were separated from the specimens and X-ray powder defraction tracings made. Several samples were collected and studied from every outcrop of the igneous bodies in an attempt to determine variations within particular intrusions.

Table III shows a comparison of the characteristic features of the rocks. Plate 3 shows the mapped intrusions numbered to reference. The names applied to the various rock types are consistant with the nomenclature of Streckeisen (1967) and Moorhouse (1959). Phenocryst percentages were determined by the point counting method.

"Andesite Porphyry"

The most common type of igneous rock is what will be called an "andesite porphyry". This name is problematic in that although the rock contains no free quartz the plagioclase is very sodic.

The "andesite porphyry" intrusions (Plate 1) are poorly exposed because of weathering. The 26 intrusions range in size from several square feet to larger bodies

50 to 80 feet wide and 300 feet long. Intrusion number 130 (Plate 3) is a typical example of the rock. Contacts are rarely exposed and the dip of the intrusions is not generally known. Some bodies are clearly discordant; other intrusions, particularly those in the Monterey syncline appear conformable.

The "andesite porphyry" is a light gray rock with an aphanitic matrix in which are set conspicuous phenocrysts of feldspar, hornblende, and less commonly, biotite. Hornblende is found in all of the samples of "andesite porphyry" while biotite is absent from some of the intrusions. Most specimens are highly weathered with much of the phenocryst material removed. The matrix is composed of subhedral crystals of feldspar, of which some show incipient albite-type twinning and finely divided magnetite.

The plagioclase phenocrysts commonly have been removed by weathering, but those present show albite and, in some cases, Carlsbad twinning. The composition of the plagioclase was determined to be in the oligoclase range by the Michel-Levy method using the extinction angles of albite twinned crystals and was verified using the extinction angles of the combined Carlsbad-albite twins. X-ray powder defraction tracings were in agreement with the optical identification. Rader and Griffins (1960) reported plagioclase compositions within the same range from a similar group of intrusions in Hightown Valley west of the study area.

Most phenocrysts of feldspar and hornblende are subhedral to anhedral in shape and average 2-4 millimeters in length. The biotite and hornblende crystals are commonly broken and show coronas of finely divided opaques, presumably magnetite, implying oxidation of the earlier formed crystals at the time of emplacement (Figure 2). The plagioclase crystals are commonly zoned and show some rounding and corrosion of the margins.

No baked contacts were observed. One intrusion (number 16, Plate 3) showed fewer and smaller phenocrysts near the contact. Otherwise textural changes related to the form of the intrusions were not observed.

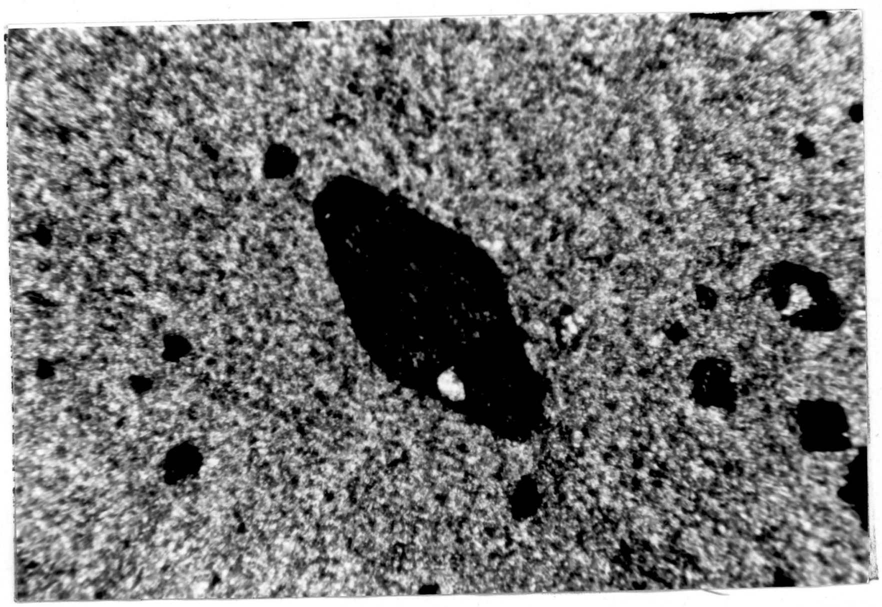

Figure 2. Hornblende phenocryst in "andesite porphyry"

Andesite

Andesite forms nine intrusive masses (Plate 1). The andesite is a dense aphanitic, dark, steel-gray rock which in places contains phenocrysts of hornblende. In outcrop, the rock is massive with crude columnar jointing oriented normal to the intrusion walls occurring in the large bodies. Most bodies are elongate dikes or plugs, clearly discordant. They range from 10 to 20 feet in width and are as much as 200 feet long. Outcrop number 39 (Plate 3) is characteristic of the andesite.

The plagioclase crystals of the matrix are about 0.1 to 0.2 millimeter long, larger than those in the "andesite porphyry". Some plagioclase crystals and a few crystals of a clinopyroxene, probably augite, occur as microphenocrysts up to 0.5 millimeter in length.

Feldspar phenocrysts are subhedral and zoned with some alteration in the cores of the crystals. Most hornblende crystals are anhedral and have extensive opaque coronas.

Basalt

Basalt occurs in seven small, generally circular plugs. The rock is commonly jointed and, in some cases, contains calcite amygdules. The rock is generally fresh with few weathering effects. A typical example is outcrop number 158 (Plate 3).

The basalt has a subophitic texture. Phenocrysts of augite and olivine were found in some specimens and constitute less than five percent of the rock. Most augite phenocrysts are zoned with alteration in the cores. Olivine phenocrysts, most of which are anhedral in shape, show some alteration.

Olivine Basalt Porphyry

The olivine basalt porphyry is almost identical to the basalt in mineralogy but it is distinguished by 40-50 percent phenocrysts of olivine and euhedral augite (Figure 3). On a weathered surface the augite phenocrysts stand out and give the rock a very coarse appearance. Amygdules of calcite and a zeolite, probably thomsonite or natrolite, are common. The olivine basalt porphyry occurs as apparently conformable intrusions, small plugs and as a major constituent of the diatreme breccias and accounts for six of the igneous bodies. Intrusion number 250 (Plate 3) is typical of this rock type.

In thin section augite is seen to be zoned with fragments of an opaque mineral, probably magnetite, within a marginal rim. The augite is euhedral to subhedral in shape and reaches a maximum length of 12 millimeters.

Olivine phenocrysts differ in amounts of alteration. The olivine in samples 177 and 250n (Plate 3) was determined to be between Fo_{73} and Fo_{84}, by the use of the

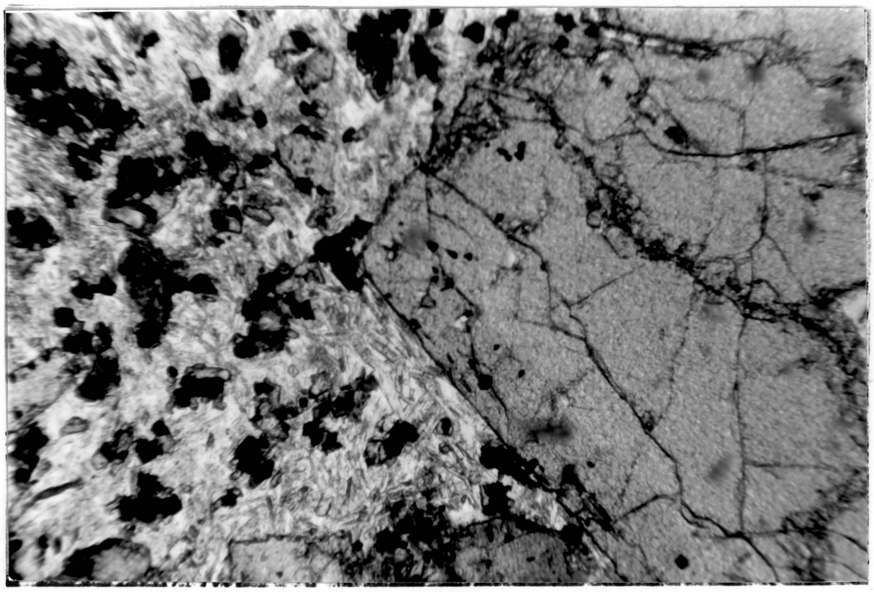

Figure 3. Augite phenocryst in plagioclase, magnetite, clinopyroxene matrix, Olivine Basalt Porphyry

Fisher and Medaris (1969) X-ray method with a calcium fluoride internal standard.

Diatreme Breccias

Diatreme breccias occur in several locations within the study area. In outcrop they occur as dark brown to black highly porous masses composed of an estimated 50 to 90 percent xenoliths of sandstone, limestone, shale, andesite and olivine basalt porphyry, as well as fractured individual augite crystals (Figure 4) and irregularly shaped vitrophyre masses. The breccias commonly have a calcareous matrix, as demonstrated by reaction to acid, and contain visible calcite filling small fractures. The lithic fragments range in size from less than 1/4 inch to about four feet in diameter and are somewhat rounded and corroded. They appear unaltered and many of the sedimentary xenoliths are fossiliferous.

Dr. C. G. Tillman (personal communication, April, 1970) has tentatively identified Buchiola, a Lower to Middle Devonian pelecypod, from a black shale fragment and a dalmanitocean (?) trilobite from an argillaceous limestone xenolith. The black shale is believed to be the Marcellus. If this assumption is correct, there has been at least 500 feet of vertical mixing within the intrusion.

Definite contacts between the breccias and the wall-

Figure 4. Clinopyroxene crystal in diatreme breccia

rock were not seen, but country rock within 25 feet of the contact was observed to be unaltered.

The largest breccia body (number 85, Plate 3) is exposed approximately 550 feet along a N.35°W. strike and is typical of the diatreme breccias. It is apparently discordant, but there is no dislocation of the sedimentary units around the intrusion. At least one smaller breccia mass (number 142, Plate 3) appears to strike concordantly with the host rock.

In most of the breccia intrusions olivine basalt porphyry was the predominant igneous rock found. In two of the breccias (number 176 and 177, Plate 3), however, andesite fragments were common. Vitrophyre masses occur in another breccia (number 174, Plate 3), as well. A contact occurs between andesite and diatreme breccia (number 160, Plate 3) but no relative age could be established.

Trachyte I

Trachyte I is somewhat similar to the "andesite porphyry". It is a light gray aphanitic rock with 35 to 40 percent phenocrysts. In hand specimen a pronounced flow structure is defined by the alignment of phenocrysts. This rock is best seen in outcrop number 56 (Plate 3).

The most prominent feature of the rock is the presence of large, generally euhedral to subhedral, colorless alkali feldspar crystals (Figure 5a). They are 5 to 10 millimeters in length and in thin section appear slightly rounded. These phenocrysts are commonly zoned with a core of plagioclase surrounded by a rim of potassium feldspar (Figure 5b). Extensive opaque coronas occur around biotite phenocrysts.

The intrusions are commonly discordant. One body, (number 17, Plate 3), is well exposed and is concordant with the strike of the host rock, but dips vertically cutting the sedimentary host rock.

Trachyte II

Trachyte II occurs as intrusion number 178 (Plate 3). It is a hard, dense, blue to purple, vitreous rock with minute phenocrysts. Although this intrusion is poorly exposed and the contacts are hidden, it is relatively resistant to erosion and forms a small hill. In thin section the matrix appears as radiating bunches of microlites. Phenocrysts of plagioclase, hornblende, magnetite and biotite are extensively embayed and corroded.

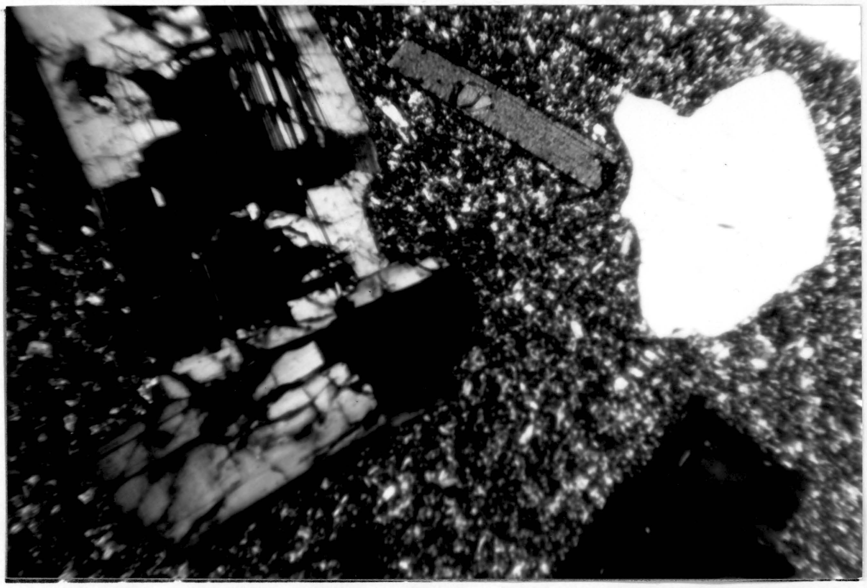

Figure 5a. Plagioclase, biotite and K-feldspar phenocrysts in trachyte I

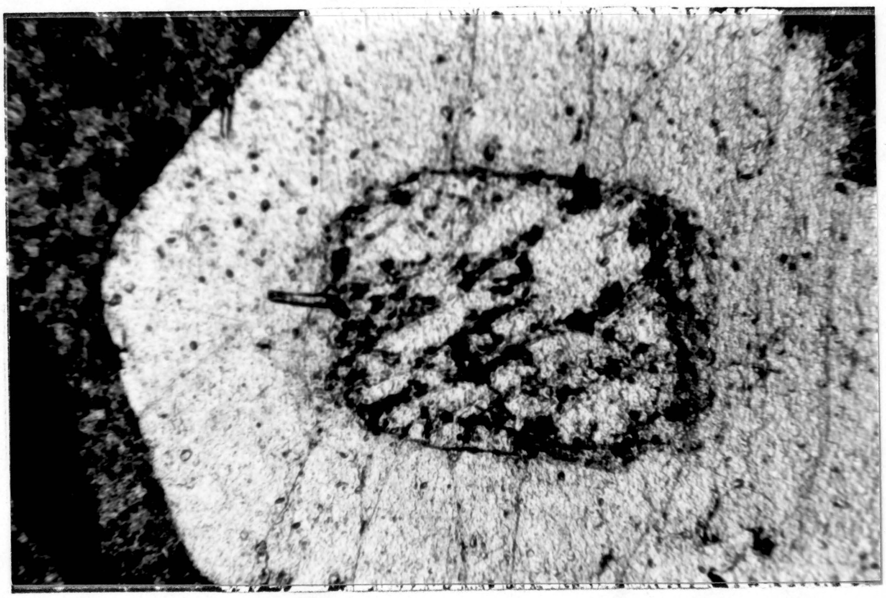

Figure 5b. Zoned phenocryst plagioclase core, Sanidine rim. trachyte I

AGE OF INTRUSIVES

Oliver et al (1967), while investigating the Tioga Bentonite, suggested that the intrusions of "andesite porphyry" along the Tioga horizon in the Monterey syncline might be flows. This theory was based on the presence of the "andesite porphyry" bodies at the Tioga horizon and on the fact that the bentonite regionally increased in thickness toward this part of Virginia, suggesting a possible source volcano in the Highland-Augusta County area. The principal lines of field evidence which might be used to support the theory are: 1)The "andesite porphyry" units occur conformably at the Tioga horizon, but do not cut the overlying Marcellus Shale, 2)The "andesite porphyry" occurs as a breccia with abundant xenolith at one location (number 275, Plate 3) and the absence of any observed Tioga, 3)The intrusions occur at the Tioga horizon on both flanks of a small syncline within the Monterey syncline. Other evidence, however, appears to refute this theory. Recent revisions in the thickness maps of the Tioga no longer show the maximum thickness of the Tioga to occur in Highland County (Dennison, personal communication, April, 1970). The mineralogy of the "andesite porphyry" does not appear to be similar to that of the Tioga ash. Textoris and Dennison (1970), indicate that biotite is the chief femic mineral in the Bentonite.

Only a minor amount of biotite was noted in the "andesite porphyry". Also, no "andesite porphyry" is found at the same horizon in the syncline in the north central part of the area. Thus, the "andesite porphyry" occurs as discrete bodies and not as a continuous mass, which might be expected for flows. Finally, radiometric dates obtained by Fullagar and Bottino (1969) from the "andesite porphyry" units in the Monterey syncline and Jack Mountain anticline (numbers 16, 248, 101, 102, Plate 3) averaged 47 $\pm$ 1.2 million years, or Middle Eocene.

The field relations do not definitely confirm either theory although the writer favors a post-Devonian age for the "andesite porphyry". This belief is based on the evidence previously mentioned, plus the fact that Johnson and Milton (1963) report late Jurassic to early Cretaceous potassium-argon dates for the intrusions of the nearby Shenandoah Valley. Thus, post-Devonian igneous activity in west central Virginia would seem to be established.

The olivine basalt porphyry and diatreme breccias are post-Marcellus in age. Although the olivine basalt porphyry is amygdaloidal, the vesicles could have formed at a shallow depth and do not imply a flow. The olivine basalt porphyry was observed to cut the Marcellus Shale (numbers 14, 15, 250, Plate 3). The diatreme breccia (number 85, Plate 3) contains a fossil bearing Marcellus type shale xenolith.

The highest strata cut by trachyte I, trachyte II and the basalt are lower than the Marcellus, but because of the similarity to the other intrusive types are believed to be essentially equivalent in age.

CONCLUSIONS

The physical condition of the magma at the time of intrusion is problematic. The temperature was probably low since there is no apparent contact alteration of the wallrock. This would imply a relatively volatile (water) rich magma. However, the presence of volatiles should have resulted in deuteric or perhaps hydrothermal alterations which were not seen.

Coronas of a finely divided opaque mineral, probably magnetite, were observed around the broken hornblende crystals in the andesite and "andesite porphyry". The condition of these crystals implies their formation occurred much earlier and that they were oxidizing at the time of emplacement. Zoned plagioclase crystals found in these rocks and in the trachytes indicates fairly rapid emplacement and cooling since the feldspars were not able to completely readjust to the apparently rapidly changing conditions.

The magma which produced the "andesite porphyry" was just SiO_2-saturated since the rock is seen to be rich in plagioclase but contained no observed free quartz or alternatively, feldspathoids. It is possible that some free quartz may exist in the matrix; however, repeated searches failed to discover it. Attempts to differentiate the type of feldspars found in the matrix by staining with sodium cobaltinitrate and rhedozinate failed.

Diatreme breccias found in this study show similarities to those described in other areas (Rust, 1937; Snyder and Gerdemann, 1965; Miser and Ross, 1922). They are generally dark rocks containing abundant xenoliths of essentially unaltered country rock. There has been extensive vertical mixing within the intrusion with some xenoliths being raised while others were dropped stratigraphically.

There are, however, some significant differences. The diatreme breccias reported in Arkansas, Kansas and Missouri were attributed to ultramatic magmas and resulted in deformation of the surrounding rock over an area as much as ten miles in diameter. The breccias in Highland County are much smaller, the largest being approximately 550 feet wide, and there is no apparent deformation of host rock structures. No fragments of high-grade metamorphic rocks or other possible basement lithologies have been found in Highland County Breccias. In addition, the magma which produced the breccias in this area appears to have been an olivine basalt or, in some cases (number 174, 176, 177, Plate 3), an andesite.

Reitan, Szekely and Foster, (1970) postulated that gas-charged explosive intrusions can occur where fracturing of a magma chamber leads to a rapid release in pressure. This should result in release of volatiles which would rise at near sonic speed along the fractures. This mechanism would account for the relatively small amount of magma present and for the abundance of xenoliths, however, it would also appear to require a deep source. The absence of basement rocks as xenoliths argues against a deep source for the Highland County breccias. It might be that these breccias are relatively near surface features which resulted when the magma rose to a shallow level (relatively low lithostatic pressure) perhaps reacting with some of the carbonate-rich sedimentary rock allowing the release of abnormal amounts of CO_2. This gas release might cause enough explosive activity to form a diatremic structure.

Most of the intrusions occur in a zone trending N.70°E. No apparent zonation of igneous rock types was observed within this zone. There is a pronounced joint set striking north 70-80 degrees east and dipping vertically or steeply to the north or south. Several of the intrusions of "andesite porphyry" (number 215, 217, 130) appear to have been emplaced along this joint set. Several possible explanations exist for this relationship. First, the joint system could have been produced at the time the paleozoic sediments were folded and later served as a site of dike emplacement. It should be noted (Plate 1) that the belt of intrusions is located across the nose of the Jack Mountain anticline and the adjacent nose of the north-plunging syncline. It is possible that the joints are the result of stresses induced by the interaction of the two major folds.

A second explanation for the occurrence of the intrusions and joints is that the joints are related to the same period of activity which produced the igneous material and thus developed later than the major folds.

The writer favors the second explanation. The trend of the joint set is N. 70-80°E. It is found to continue across the nose of the Jack Mountain anticline and the adjacent syncline. If the joints were related to the development of the folds, the trend of the joints might be expected to change on different structures or on different areas of the same structure. This is not the case. It would appear that the joints are genetically related to the intrusions.

Several writers including Zartman et al (1967), Fullagar and Bottino (1969), and Dennison and Johnson (1970) attribute the igneous intrusions in Highland County to activity along a 38th Parallel Lineament. Regional considerations on this scale are beyond the scope of this study. The writer believes, however, that the intrusions in the present study occurred sometime after the period of major folding, probably during Tertiary time and were emplaced along joints which were genetically related to the intrusions.

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RELATIONSHIP OF IGNEOUS INTRUSIONS TO GEOLOGIC STRUCTURES IN HIGHLAND COUNTY, VIRGINIA

Leroy Paul Kettren, Jr.

Abstract

Mapping of a nine square mile area northeast of Monterey in Highland County, Virginia has revealed at least 60 igneous intrusions of seven rock types: "andesite porphyry", andesite, basalt, olivine basalt porphyry, trachyte I, trachyte II and diatreme breccia. The intrusions are emplaced in a sedimentary sequence ranging from the Middle Silurian Rochester Shale to the Middle Devonian Marcellus Shale. The trachytes are porphyritic with phenocrysts of plagioclase, potassium feldspar, biotite, and hornblende. The "andesite porphyry" contains phenocrysts of hornblende, biotite and plagioclase in a fine-grained groundmass. The intrusions are elongate plugs, often showing crude columnar jointing perpendicular to the contacts. The diatreme breccias contain xenoliths of most adjacent formations, olivine basalt porphyry, and individual augite crystals. Fossils found in some xenoliths indicate as much as 500 feet of mixing within the intrusions.

The intrusions occur in a zone trending N.70°-80°E., which appears to coincide with the strike of a prominant joint set. The zone of intrusions crosses the nose of the north-plunging Jack Mountain anticline. It is believed

that the intrusions are related to the joint set and are the result of a relatively recent period of activity.

TABLE I Silurian Units in the Highland County Study Area

Formation	Group	Named By	Type Section	Thickness in Study Area	Thickness in Adjacent Areas	Lithology	Contacts	Fossils
Tonoloway Limestone	Cayuga	Ulrich (1911, Pl. 28)	Tonoloway Ridge, Md.	mapped with Wills Creek	450 ft. (Butts, 1940) 550 ft. (Woodward, 1941)	blue-black laminated limestone	both conformable (Woodward, 1941)	high-spired gastropods, small brachiopods
Wills Creek Formation	Cayuga	Uhler (1905, p. 20)	Wills Creek, Cumberland, Md.	410 ft. includes Tonoloway	170 ft. (Butts, 1940) 213 ft. (Woodward, 1941)	blue-gray limestone, calcareous shale, gray-white qtz. sandstone	both conformable	none observed
Williamsport Sandstone	Cayuga	Reger (1924, p. 395)	Williamsport W. Va.	30 ft.	31 ft. (Woodward, 1941)	gray-white quartz sandstone	both conformable (Butts, 1940)	none observed
McKenzie Limestone	Cayuga (Butts, 1940)	Ulrich (1911, Pl. 28)	McKenzie Station Cumberland, Md.	170 ft. (estimate)	170 ft. (Woodward, 1941)	gray limestone, olive-gray shale	lower: debated upper: conformable (Butts, 1940)	Homeospira(?) Beyrichia mesleri
Rochester Shale	Clinton	Conrad (1839, p. 62)	Rochester N.Y.	30 ft. (estimate)	0-30 ft. (Woodward, 1941)	olive-gray fissile shale	both uncertain	none observed
Rose Hill Formation	Clinton	Swartz (1923, p. 28)	Rose Hill Cumberland, Md.	350 ft. (estimate)	200-600 ft. Woodward 1941	maroon: quartz sandstone, shale	lower: conformable upper: uncertain	homolonotid trilobite
Tuscarora Sandstone		Darton (1896, p. 2)	Tuscarora Mountain Pa.	6 ft. exposed	72-165 ft. (Clough, 1948)	gray-white quartz sandstone	both conformable	none observed

TABLE II Devonian Units in the Highland County Study Area

Formation	Group	Named By	Type Section	Thickness in Study Area	Thickness in Adjacent Areas	Lithology	Contacts	Fossils
Marcellus Shale		Hall (1839, p.295)	Marcellus N.Y.	Top not exposed	not reported	black fissile shale	lower: conformable	none observed
Tioga Bentonite		Ebright, Fettke, Inghram (1949)	Tioga County, Pa.	10-20 ft. (estimate)	120 ft. (Dennison	gray brown clay & mica	both conformable (Dennison, 1961)	Leiorhynchus limitare, & inarticulate brachiopods
Needmore Shale		Willard (1939, p.199)	Needmore, Pa.	170-180 ft. estimate	not reported	gray calcareous shale	upper: conformable lower: unconformable (Butts)	trilobite fragment
Oriskany Sandstone		Hall (1839, p.308)	Oriskany Falls, N.Y.	100 ft.	100-150 ft. from outcrop	yellow-white medium grained quartz sandstone	upper: unconformable, lower: conformable	Acrospirifer murchisoni, Edriocrinus sacculitera, Meristella sp., Platystoma sp.
Licking Creek Limestone	Helderberg	Swartz (1939)	Licking Ck., Franklin County, Pa.	230 ft. from outcrop	220 ft. (Swartz, 1929) 198 ft. (Woodward, 1943)	gray sandy limestone, black chert, gray-white cherty ls.	both conformable (Swartz, 1929)	"Spirifer" concinnus, Atrypa sp. (New Scot. Memb.)
Coeymans Limestone	Helderberg	Clarke, & Schuchert (1899, p.874)	Coeymans N.Y.	50 ft. from outcrop	50 ft. (Swartz, 1929)	coarse grained gray limestone	both conformable	crinoid fragments
Keyser Limestone	Helderberg	Swartz (1913, p.85)	Keyser W. Va.	230 ft. from map	228 ft. (Swartz, 1929)	thin bedded gray ls., olive shale, gray nodular limestone	both conformable, (Woodward, 1943)	favosited coral

TABLE III Igneous Rocks in the Highland County Study Area

Name	Number of Intrusions	Texture	Percent Phenocryst	Matrix	Phenocrysts	Pc Composition Ol Composition	Highest Strata Cut	Structures
andesite porphyry*	26	felty to trachytic, holocryst, hypid. gran.	8-10	Pc. 92% Mt. .5-1%	Pc 7-8% Hb 1% Il 1-2%	An_{14} - An_{28}	Tioga Bentonite	
andesite	9	trachytic, holocryst., hypid. gran.	0-7	Pc 88-91% Mt 5-6% Cpx 1-3%	Pc 0-5% Hb 0-2%	An_{34} - An_{42}	Coeymans Limestone	crude columnar jointing
basalt	7	subophitic, holocryst. hypid. gran.	0-5	Pc, Mt, Ol, Cpx	Ol, Cpx	An_{54} - An_{60}	Needmore Shale	minor calcite amygdules
olivine basalt porphyry	6	holocryst, hypid. gran.	40-50	Pc 36-40% Mt 7-8% Bt 1-2% Cpx 8-10%	Ol 12-17% Cpx 28-33%	An_{54} - An_{60} Fo_{73} - Fo_{84}	Marcellus Shale	calcite & zeolite amygdules
trachyte I	2	holocryst., xeno. gran.,	25	Pc, Kspr } 73% Mt 1% Qtz ?	Kspr 7-8% Pc 13-14% Bt 3-4% Hb 0-1%	An_{17} - An_{24}	McKenzie Limestone	
trachyte II	1	felty, hypocryst., xeno. gran.	23	Dvt. gl. 78%	Hb 1-2% Mt 1% Bt 2-3% Pc 18%	An_{8} - An_{10}	Wills Creek Formation	
diatreme breccia	9	50%-90%	xenoliths: gray-white quartz sandstone (Tuscarora?), olivine basalt porphyry, hematitic quartz sandstone (Rose Hill?), andesite, vitrophyre, augite, shale (Marcellus?), limestone.					

Abbreviations:

An. – andesine
Bt. – biotite
Cpx. – clinopyroxene
Dvt. gl. – devitrified glass
Fo. – forsterite
gran. – granular
Hb. – hornblende
holocryst. – holocrystalline
hypid. – hypidiomorphic
hypocryst. – hypocrystalline
Il. – ilmenite
Kspr. – potassium feldspar
Mt. – magnetite
Ol. – olivine
Pc. – plagioclase
Qtz. – quartz
xeno. – xenomorphic