Geology of the Western Boundary
of the Charlotte Belt
at Brookneal, Virginia
by
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Thesis submitted to the Graduate Faculty of
Virginia Polytechnic Institute and State University
in partial fulfillment of the requirements of the degree of
MASTER OF SCIENCE
in
Geology

APPROVED:

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October, 1981
Blacksburg, Virginia
ACKNOWLEDGEMENTS

The author wishes to thank Dr. Lynn Glover III for assistance and advice in during this project. Special thanks to Dr. Stewart Farrar for his suggestions, aid in labwork and critical review of the thesis. Also appreciated are the critical thesis reviews and constructive comments of Dr. David Wones and Dr. David Gray. Dr. J. Alexander Speer, Dr. J. Fred Reed and many fellow graduate students who supplied incentive and advice. A special thanks also to for typing the thesis and offering support and advice over the past two years, to for drafting the figures and to for her help in making corrections and providing support through the difficult periods.

Funding for research, in both the field and lab, was provided by the Department of Energy Contract DE-AC05-78ET27001 to and and the Nuclear Regulatory Commission contract number NRC-04-75-237 also to and .
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INTRODUCTION

The nature and significance of the boundary between the western Wissahickon-Evington Group sedimentary sequence and the eastern Chopawamsic-James Run volcanic complex (Fig. 1) (continuation of the Charlotte Belt) has been one of the most controversial geological problems of the Maryland and Virginia Piedmont. Jonas (1932) recognized the continuity of the western sedimentary lithologies in extending the Wissahickon Schist, as defined in Maryland, through Virginia. The lithologic correlation was later discontinued because of the lack of detailed information between the mapped areas. Renewed proposals of lateral continuity between sequences in the western Piedmont of Virginia have appeared as more age determination work and mapping has been done on the units and intervening areas (Bland, 1978; Bland and Blackburn, 1980; Conley, 1978; Higgins et. al., 1977).

Published geologic maps of the folded, low metamorphic grade, central Virginia area of the western Piedmont cover a continuous area from Andersonville (Marr, 1980a; Marr, 1980b) through Fluvanna County (Fig. 1) (Smith, Milici and Greenberg, 1964; Ern, 1968; Brown, 1969). Some of the more detailed work in the area, including geochemical and sedimentological studies of the volcanics and Evington
Triassic sedimentary rocks

Metasediments: A, Arvonia; A(?), Arvonia(?)

Granite: C, Columbia; M, Melrose; I, Lineated; S, Shelton; LW, Leatherwood

Mafic Plutons: DM, Diana Mills; hg, hornblende metagabbro; RA, Rich Acres Fm.

Metasediments: EG(?), Evington Group(?); EG, Evington Group; FM, Fork Mountain schist

Metavolcanics: CF, Chopawamsic Formation; mvs, metavolcanic sequence; mvsr, metavolcanic-sedimentary rocks (Charlotte Belt).

Figure 1: Modern geologic map of the western Virginia Piedmont.
Group, led Bland (1978), Bland and Blackburn (1980) and Brown (1976) to conclude that the boundary between the eastern volcanic and the western sedimentary block separates two lithospheric plates.

Geologic mapping in the southern Virginia Piedmont (Fig. 1) (Conley and Toewe, 1968; Conley and Henika, 1973; Henika and Algor, 1973; Henika and Thayer, 1977) has defined the folded, high metamorphic grade Smith River Allochthon (Fig. 2). The allochthon is composed of the metasedimentary Fork Mountain schist intruded by the Leatherwood Granite and associated mafic plutons and bounded by the Ridgeway and Bowens Creek faults. The allochthon is separated from the volcanic Charlotte Belt by the Danville Triassic Basin (Fig. 1, Fig. 2) (Henika and Thayer, 1977; Conley and Henika, 1973; Conley, 1978). Originally all units of the allochthon were considered to be Precambrian in age (Conley and Henika, 1973) because of an erroneous age on the Leatherwood granite which intruded the allochthon prior to faulting. A later age determination of the Leatherwood granite indicates a Paleozoic age of 464 ± 20 Ma for intrusion (Odom and Russell, 1975).

The boundary between the western sedimentary and eastern volcanic terrane requires explanation for any reasonable tectonic model. The present report attempts to
define the boundary relations by describing the geology midway between the well studied central western and southwestern Virginia Piedmont areas (Fig. 1). The intervening area is 60 miles in length and been mapped only by reconnaissance methods (Jonas, 1928).

The study area comprises parts of the Brookneal, Long Island and Mike quadrangles located on the Falling and Roanoke Rivers, 30 miles southeast of Lynchburg, Virginia. The area was chosen because of the location between the two well studied areas, the relatively well exposed rock along the river valleys and the presence of possible Arvonia lithologies not previously demonstrated in southern Virginia.

Regional correlations with the stratigraphic units in the Brookneal area on the bases of lithologic description, structural position and field observation, indicate that equivalent units are continuous from the southern through the central Virginia Piedmont (Fig. 1). The western Charlotte Belt boundary is therefore continuous in the Virginia Piedmont (Fig. 1) and a similar geologic history is expected.

The boundary between the metasedimentary and metavolcanic units at Brookneal, is intruded by a single granite pluton. The Melrose granite is cut by mylonite zones that dip moderately to the southeast. Deformational
and metamorphic features change abruptly across these zones. The abruptness of change indicates that the mylonite zones are probably faults that brought the eastern lineated and western foliated Melrose granite together, eliminating the metamorphic and deformational transition area.

This fault, active at least three times after the intrusion of the granite, was probably also active during the Taconic Orogeny. It brought the eastern metavolcanic and western metasedimentary terranes together and eliminated the sedimentologically transitional area now absent from the Brookneal area.
Introduction

The structural disruption and variable effects of metamorphism preclude detailed stratigraphic analysis of the Brookneal sequence. The exceptions occur in the least deformed areas of volcanlastic deposition where, for example, scoured tops can be identified. The bulk of the stratigraphy will therefore be defined in terms of lithotectonic units.

Metamorphic Volcanic Sequence

A series of interbedded dominantly mafic to less common felsic and locally ultramafic schists and gneisses occupy the southeastern section of the map area (Plate 1). Mafic units weather to a red saprolite and the felsic units to white, gritty sands. The sequence locally contains beds of possible quartzite and commonly contains beds of volcanlastic sedimentary rocks with relict sedimentary structures. Overall thickness cannot be determined because the lower contact is intrusive and the upper contact is an erosional surface.

The mafic units are green to black, fine to medium
grained, amphibole schists and gneisses in layers ranging from 2 cm to 3 m. The contacts with felsic rocks are commonly gradational on top and sharp on the bottom. Locally, coarse microcline-plagioclase-quartz pegmatites are injected along the contacts. The amphibole schists are comprised of .5 to 1.8 mm hornblende, andesine, quartz, and secondary actinolite, albite, epidote and biotite or chlorite. Minor mineral phases include: pyrite, magnetite, ilmenite, titanite and zircon in .2 mm grains. A few layers of very coarse, amphibole schist of similar mineralogy are also included in the sequence.

The metamorphic grade decreases westward across the sequence in the map area as a result of overprinting events. In the highest grade, extreme southeastern map area, pockets of 1.5 cm andesine porphyroblasts occur with quartz in the amphibole-biotite schist. The decreasing grade is revealed mineralogically by a decrease in hornblende, biotite and andesine and an increase in actinolite, chlorite, epidote and albite.

Locally, coarse, black and massive ultramafic bodies occur within the bedded sequence. The lithology consists of 70 to 80 percent, 3 to 7 mm amphibole with accessory fine grains of chlorite, epidote, pyrite, magnetite and hematite. The rocks have been totally retrograded and highly deformed yielding a moderate grain size reduction.
The discontinuous bodies usually parallel the major structural trends.

The felsic beds are white, fine to medium grained and range in thickness from 1 cm to 1 m. In weakly deformed areas, original textures are preserved in quartz-plagioclase porphyries. Generally however, the deformation is more intense and the rocks are felsic gneises. The layers are commonly discontinuous. Foliation in the felsic units is not very pronounced because of the lack of platy minerals. The interbedded amphibole schists appear to be of lower competency, allowing the felsic units to remain less deformed.

The mineralogy of the felsic rock consists dominantly of 1 mm quartz and plagioclase phenocrysts and .2 mm groundmass of the same minerals. Groundmass accessory phases include fine grains of biotite, muscovite, apatite, garnet with chlorite rims, chlorite, epidote, allanite with epidote rims and local microcline occurring as porphyroblastic aggregates. Other rocks with similar character to the felsic units contain 25 percent amphibole or biotite as groundmass grains.

Metavolcaniclastic rocks, minerallogically transitional to the mafic and felsic rocks are medium grained equigranular, white and green, quartz-plagioclase-mica schists with a moderate mafic component. Beds of schist
range from 2 cm to 1 m and locally exhibit scoured tops. The rocks commonly contain 3 mm plagioclase, quartz, amphibole, biotite and chlorite. Minor minerals include: garnet, epidote, apatite and zircon in grains up to 1.5 mm. The higher concentration of platy minerals results in a more schistose fabric than the other lithologies of the sequence. In these rocks, the plagioclase to quartz ratio is slightly higher than in the more felsic units. Locally, the small garnets are visible in hand sample.

A rare lithology included in this sequence is a fine grained, white to gray, foliated siliceous rock that appears to be a quartzite. The rock occurs in thin-bedded, 1 to 2 m intervals within the volcanic sequence. Fine (.2 mm) quartz comprises 95 percent of the rock with bed tops containing minor amounts of magnetite and hematite. It is fairly resistant and highly competent, locally enclosing boudins of amphibole schist.

**Rock Fabric**

Locally intense deformation is reflected in a well developed foliation and lineation defined by amphibole and micaceous minerals. In the most deformed areas, segregation of felsic minerals in mafic rocks occurred. Fabric is also defined by ribbon textures in quartz and more rarely in albite.
One or more tectonic S-surfaces are always observable in thin section and commonly two or three can be identified. Compositional layering is parallel or subparallel to the major foliation as folding is isoclinal.

In rocks from the weakly deformed, gently dipping beds of the western metavolcanic sequence amphibole is decussate and mica, though aligned, forms laths rather than spindles. Felsic beds locally include preserved igneous textures with euhedral plagioclase grains. The sedimentary units locally have scoured tops and retain lateral continuity.

Protoliths and Paleoenvironments

Protoliths of the mafic rocks are revealed by several features. The moderate titanium content, mafic composition, lateral continuity and contact relations of the rocks indicate that they are metamorphosed basalt flows with possible reworked tops. The interbedded felsic units retain some relict texture and composition of dacitic crystal tuffs, dacites under the Streckheisen (1979) classification, possible andesites and shallow intrusives. Locally cutting the mafic units are coarse mafic feeder dikes and sills and small pod-shaped ultramafic bodies which may have been volcanic chambers. Interbedded with and overlying the igneous units are possible quartzites or meta-tuffs and volcaniclastic rocks with preserved scoured
Evington Group

The Evington Group was defined in the Lynchburg Quadrangle by Brown (1958). It was then traced from the type locality eastward to the Brookneal area by Kaldy (1977). The portion of the Evington Group exposed in the Brookneal area is the Candler Formation. The aluminous schists and gneisses, small granite bodies and coarse sand to pebbly biotite schists weather to a gray or red-brown saprolite. The formation is restricted to the northwestern portion of the map area (Plate 1). The thickness of this formation cannot be determined because of an intrusive lower contact, intense folding and an upper erosional surface.

The structurally lowest, aluminous unit is a fine to medium grained, white and gray, banded, staurolite-sillimanite schist mapped as cf (Plate 1) and occurring in belts across the northwest map area. The banding is caused by the presence of interleaved quartz between the schistose layers. Original bedding cannot be identified in outcrop or in thin section. The composition appears to be fairly uniform. Major minerals include: oligoclase, quartz, biotite, muscovite, staurolite, fibrolitic sillimanite, garnet, and minor amounts of ilmenite, magnetite,
tourmaline, zircon, apatite and secondary hematite and chlorite. The schists are locally intruded by a concordant, fine grained, granite and associated pegmatite. The granite includes up to 45 percent quartz, and subsidiary amounts of microcline, plagioclase, muscovite, biotite, tourmaline and possible fibrolite. The pegmatite consists of very coarse perthitic microcline, quartz, plagioclase, and muscovite.

Farther to the southeast, the aluminous unit is a white and green banded, fine to medium grained, chlorite-muscovite to quartz-banded schist that is locally interbedded with thin layers of fine, amphibole schist. The major minerals include: chlorite, muscovite, quartz, albite, opaque minerals and epidote. Trace amounts of dominantly .1 mm biotite, allanite, apatite, hematite and zircon are also present. Retrograde features are common in this area including strained biotite spindles with cores of randomly oriented undeformed chlorite, sericitized plagioclase, zircon with halos in chlorite after biotite and chlorite-opaque or muscovite-opaque aggregates.

Structurally overlying and sparsely interbedded with the aluminous unit is a brown to gray, massive, coarse sand to pebble biotite schist. The scarcity of outcrop prevents the documentation of bed thickness and younging direction if such features exist. Locally, the rock is mica poor,
nearly a quartzite. The normally schistose fabric is almost gneissic in the highly deformed zones, with ribbonlike quartz porphyroblasts. The relict pebbles are quartz, oligoclase, rutilated quartz and microcline that range from 2 to 6 mm. The large grains are enclosed in a fine matrix of from .2 to .4 mm quartz, biotite, muscovite, titanite, calcite, garnet, tourmaline, apatite and opaque minerals.

Retrograde features in the Candler formation increase to the southeast. Plagioclase is albitized and sericitized, biotite is altered to strain free chlorite, opaque minerals and epidote, garnets are absent and all relict phases exhibit strain textures.

Rock Fabric

Preserved features in the Candler Formation indicate intense deformation that increases to the southeast. The aluminous schists exhibit a foliation that was formed pre- to early syn-peak metamorphism and as a result, strain textures have recovered. In areas with less intense strain features, subsequent recovery is not complete. Overprinted strain features are common in the southeastern Candler rocks, with ribbon development in both mica and quartz.

Protoliths and Paleoenvironments

Smith, Milici, and Greenberg (1964) concluded that the
high sodium and alumina content of Candler lithologies mapped by them, results from a volcanic source terrane for the protoliths. This interpretation is consistent with the abundant plagioclase and relatively low quartz content of the aluminous schist. The high mica content and uniform composition of the schist indicates that the protolith was probably a fairly quiet water mud derived from the weathering of a single source terrane.

The overlying pebbly biotite schist was a graywacke derived from a western source terrane. The rutile and microcline suggest erosion from a Lynchburg or possible Blue Ridge basement source. The lithology coarsens westward across the map area, grading either laterally or vertically, and suggesting a westward source direction.

Hornblende Metagabbro

Intrusive into the Candler schist is a coarse, massive, hornblende metagabbro with a finer amphibolite around it. The body crops out in Falling River stream cuts and weathers to a red saprolitic soil. The hornblende metagabbro forms a 10 to 25 meter thick dike in the northwest portion of the Brookneal map area (Plate 1). On the geologic map of Virginia (Jonas, 1928), the body widens northward and extends for about 15 km, apparently
concordant to the major structural trend.

The coarse grained, massive, green to black amphibolite contains 60 to 70 percent hornblende grains of 0.8 to 1.5 cm that are slightly fractured but otherwise undeformed and randomly oriented. Between the hornblende grains are 2 to 3 mm grains or 3 cm zones of interstitial andesine of An$_{35}$. Retrogression has commonly altered hornblende to epidote, biotite and opaque minerals that are aligned in thin cleavage bands. Plagioclase is sericitized and magnetite is altered to hematite. Minor minerals include: titanite, zircon, apatite and muscovite.

The fine amphibolite exhibits more deformation and retrogression than the coarse grained amphibolite. Grains of 1.5 to 2 mm actinolite comprise 85 percent of the rock. Minor minerals include: epidote, plagioclase, biotite, and lesser amounts of apatite, muscovite, quartz and titanite.

Rock Fabric

The southeast edge of the generally massive pluton is macroscopically foliated, possibly cut by a small shear zone splay. In thin section, spaced cleavage bands cut the massive areas and increase in regularity towards the well foliated finer grained sections.

The metagabbro body intruded a folded Candler terrane just prior to the intrusion of the Melrose Granite as
indicated by mafic xenoliths in the granite. The fine
grainend amphibolite may have been a chilled margin, an
associated sill or the result of deformation.

Melrose Granite

The Melrose Granite (Jonas, 1932) is a late- to post-
tectonic, semi-concordant pluton with respect to the
metamorphism of the Candler Formation. The coarse grained
rock crops out to the west of the Arvonia(?) syncline and
to the east of the Candler lithologies in the western
central map area (Plate 1) in exposures that weather to a
white, gritty saprolite.

In the western areas of the Melrose, the rock is a
greenish, slightly metamorphosed, undeformed,
hypidiomorphic granular, biotite quartz monzonite to quartz
diorite under the classification of Streckheisen (1973)
(Fig. 3). The main components are 1 cm oligoclase grains
and lesser amounts of 1.5 cm highly perthitic microcline.
Quartz comprises 8 to 15 percent of the rock as 1 cm
recrystallized aggregates. The mafic phases constitute 15
percent of the rock and include green, retrograded, 8 mm,
sagenitic biotite and 5 mm, euhedral, pleochroic, primary
titanite. Minor constituents include zircon, apatite,
magnetite and secondary epidote, hematite, calcite,
muscovite and titanite replacing ilmenite.
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<tr>
<td>Calcite</td>
<td>--</td>
<td>x</td>
<td>x</td>
<td>0.3</td>
<td>--</td>
<td>x</td>
</tr>
<tr>
<td>Allanite</td>
<td>--</td>
<td>--</td>
<td>--</td>
<td>x</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td>Zircon</td>
<td>0.3</td>
<td>0.2</td>
<td>x</td>
<td>x</td>
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<td>x</td>
</tr>
</tbody>
</table>

Figure 3: Modal analyses and locations for Melrose and lineated granite samples in Brookneal, Virginia. Modes by point count of thin sections and slabs where appropriate.
Eastward across the area, the quartz and microcline content of the body increases to that of a monzogranite (Fig. 3) under the Streckheisen (1973) classification. The pink banded granite includes a strong planar and weak linear fabric and the grain size is reduced from the western, type locality. The biotite and titanite occur as broken or recrystallized grains and decrease in content as muscovite and epidote increase. The perthitic microcline augen have non-perthitic rims that are recrystallized or broken into small non-perthitic grains associated with plagioclase. Plagioclase grains are saussuritized, albitized, sericitized and altered to calcite, decreasing in content to amounts less than microcline.

Xenoliths of Candler schist and hornblende metagabbro increase near the western margin of the Melrose granite. Contacts with the units are sharp and irregular. The granite was cut by mafic and aplitic dikes.

Rock Fabric

Strain textures increase with the changing mineralogy. Near the western edge of the body, coarse grained granite remains nearly undeformed. Deformation fabric increases to the east, becoming mylonitic and locally ultramylonitic. Just west of the Arvonia(?) syncline on the southwestern corner of the map area (Plate 1), a continuous 125 m thick
ductile deformation zone cuts the Melrose granite. Granulation and microstructural strain features are preserved in the Melrose.

**Lineated Granite**

The lineated granite is a late syn- to post-tectonic pluton that occurs in areas east of the Arvonia(?) syncline in the east central map area (Plate 1). A Pb/Pb isotopic ratio from zircon fractions near point AGO-277 (Fig. 3) yielded a middle Ordovician 470 Ma minimum age (Sinha and Glover, personal communication, 1981). The ridge forming lithology weathers to a pink or white gritty saprolite containing small quartz rods.

The granite is medium grained, lineated to foliated, white to pink, mica poor and lacking in mafic minerals. The leucocratic composition generally includes 37 percent quartz and 35 percent microcline (Fig. 3). The microcline grains are locally as much as 4 mm but more commonly 1 mm and very rarely perthitic. Plagioclase occurs in quantities of 25 percent or less and is commonly untwinned. Muscovite is common but epidote is minor and locally contains cores of allanite. Mafic minerals compose only 3 to 4 percent of the rock as biotite and trace amounts of titanite, chlorite, opaque minerals and garnet.

The lineated granite appears to intrude the overlying
layered volcanic sequence as pods and possible dikes. Few xenoliths are present in the body. It was later cut by aplitic, mafic and pegmatitic dikes.

Rock Fabric

On the southeast side of the Arvonia(?) lithologies, granite exhibits a strong linear fabric. Planar fabric also exists but it is less common and generally includes a strong linear component. The lineations are cylindrical rods of microcline and quartz grains or aggregates enclosed in mica. The lineations are formed by two intersecting cleavages identifiable in thin section. The second cleavage event apparently caused the partial recovery of earlier strain features. Ribbons of quartz contain extinction bands and lamellae oriented at oblique angles to them.

Relation between the Melrose and Lineated Granites

Early investigators of the Brookneal area concluded that the striking difference between the western Melrose and eastern lineated granites is because they are two separate plutons that have been faulted together (Jonas, 1932). The eastern pluton is more leucocratic than the western. In fact, they may be two bodies but this study suggests that the two granites may be the same body that
has undergone varied intensities of deformation and metamorphism.

The composition of the granite may reflect the composition of the country rock. Mobility of ions during metamorphism and mylonitization may have locally changed the composition of the granite. Extreme fluidization during mylonitization is documented to have significantly altered the composition of granites in Scotland depending upon the composition of country rock (Beach, 1976). In mafic country rocks, mylonitized granite includes more iron and magnesium rich minerals than its undeformed counterpart. At the contact with the hornblende metagabbro body, the reaction between the rock types during metamorphism caused the granite to locally assume a dioritic composition.

The early strong and late moderate deformational events in the eastern lineated granite as opposed to the early minor and late strong episode to the west, caused general recovery of granulation and intense strain features in the eastern areas (see Microstructure and Structure sections). An early medium grade metamorphism in the eastern section produced the allanite and garnet in the lineated granite. A later, lower grade metamorphism overprinted both areas and produced rims and retrogression of the existing phases in the east, and the primary metamorphic assemblages of epidote-albite-biotite in the
Trends in modal analyses (Fig. 3) and the mineral features produced near the mylonite zone in the Melrose granite indicate that deformation and metamorphism are probably responsible for the appearance and composition of the lineated granite. Near the mylonite zones, the mafic content is reduced and the microcline-quartz content is increased relative to the composition of the undeformed Melrose. The newly formed microcline porphyroblasts are small and non-perthitic. The lineated granite appears to be the end product of these deformational and metamorphic processes (Fig. 3).

If the eastward increasing leucocratic trends (Fig. 3) of the granite are the result of deformation and metamorphism, and the extremes of the body were faulted together, then both the east and west granites are the same pluton. The metamorphic and deformational transitional area between the eastern and western types now exposed, was faulted out by movement on the mylonite zones.

**Aplitic dikes**

Aplitic dikes intrude the Melrose-lineated granite at various points across the map area (Plate 1). The dikes were intruded pre- to-syn deformationally, because they are folded and commonly foliated.
The pink to white, medium to fine grained aplite occurs sparsely in 2 m thick dikes in the western, foliated granite and more commonly as 1 cm to 1 m dikes in the eastern lineated granite. The least deformed aplite consists of 1.5 mm interlocking grains of microcline, quartz, plagioclase and lesser amounts of muscovite, biotite, epidote, apatite and titanite. Generally however, the aplite is deformed to a white, felsic gneiss or cherty mylonite.

Mafic Dikes

A series of mafic dikes intrude the Melrose and lineated granites across the map area (Plate 1). The dikes are medium to coarse grained amphibolite in the east and amphibole-biotite schist to the west. These green to black, lithologies weather to a red saprolite. The 1 to 10 m thick intrusions were intruded before the last deformation as they are foliated.

The amphibolite consists 80 percent of 2 mm actinolite, and lesser amounts of andesine to albite, quartz, and finer grains of epidote, chlorite, muscovite, titanite, hematite and apatite. The amphibole-biotite schist appears to be mineralogically gradational with granite. At its center, the schist contains 28 percent fine actinolite, biotite, epidote, quartz, andesine to
albite and accessory minerals.

Rock Fabric

All dikes exhibit a planar fabric defined by amphibole and platy minerals. The amphibolite exhibits a spaced cleavage with zones of randomly oriented grains whereas the amphibole-biotite schist is ubiquitously foliated.

Arvonia(?) Formation

The Arvonia(?) graphitic meta-pelites, meta-sandstones and meta-carbonates delineate a belt across the center of the map area and occur as small outliers overlying the Evington Group and the metavolcanic sequence (Plate 1). The unit appears to be the southern extension of the Arvonia sequence of central Virginia. Though fairly certain, correlation is not absolute because of the lack of mapping in the intervening areas (see Regional Correlations). Unlike the other lithologies in Brookneal, the Arvonia(?) schists are resistant to weathering. These rocks divert all intersecting streams and rivers creating a continuous lineament into central Virginia. As a result of intense folding and an erosional upper surface, thickness of the sequence cannot be determined in the Brookneal area.

The graphitic meta-pelites comprise about one half to two thirds of the sequence. The second most common
lithology is a metamorphosed limey mudstone that constitutes about one quarter of the Arvonia (?) sequence. The remainder of the sequence consists of a minor metasandstone and an extremely rare marble.

Along the western edge of the belt, quartzite to meta-graywacke and chlorite-muscovite schists alternate in 3 cm to 1 m thick layers. Contacts are sharp, but deformation has destroyed any sedimentary structures. The white to buff, fine grained metasandstones consist of at least 60 percent, 0.2 mm quartz and minor amounts of fine grained microcline, plagioclase, biotite and chlorite. The schists consist of muscovite, chlorite, quartz, albite and minor amounts of magnetite and hematite.

To the east, the chlorite-muscovite schists are gradually replaced by bedded sequences of fine grained, green and white banded, plastically deformed calc-silicates and local thin bedded marbles. The calc-silicates consist of fine grained chlorite, calcite, dolomite, quartz, pyrite and minor amounts of plagioclase, actinolite, muscovite and apatite. The banded white, gray and buff marble occurs in a 1 meter discontinuous bed consisting of 70 percent calcite and small amounts of quartz, muscovite, chlorite, biotite, plagioclase, zircon, pyrite, apatite and tourmaline.

Farther to the east in the syncline, the metamorphic
grade apparently increases. Thin (1 cm) to 1 m thick beds of fine to medium grained, green banded, amphibole-chlorite calc-silicate schists are interbedded with the massive meta-sandstone and thinly layered biotite schist. The calc-silicates differ from those to the west by the presence of from 10 to 50 percent actinolite, up to 10 percent biotite and minor amounts of epidote. They also include calcite, quartz, plagioclase and trace amounts of chlorite, dolomite, apatite, tourmaline and titanite. The biotite schist is also calcareous, probably a higher grade equivalent of the chlorite schist. It includes 40 percent 0.2 mm biotite and lesser amounts of actinolite, calcite and the other calc-silicate constituents.

A massive, very fine grained, graphitic "button" (definition from Roper, 1972) schist replaces the bedded sequence at the middle of the syncline and continues to the eastern edge. The silver-black, contorted schist locally contains pods of vein quartz. No compositional layering can be identified but quartz content increases locally. The mineralogy commonly includes 60 percent muscovite and lesser amounts of quartz, disseminated graphite, pyrite, titanite, hematite, biotite and chlorite.

Rock Fabric

Deformation in the Arvonia(?) Formation is intense and
well displayed. The first mylonitic foliation in the graphitic, button schist is of the same generation as the first foliation in the other Arvonia (?) lithologies. The foliation was transposed by later deformation in all but the meta-arenite units where lineations developed instead. The folia are defined by platy minerals and amphibole. In the graphitic unit, quartz veins are deformed into ribbons. The last surface is a spaced, semi-brittle crenulation cleavage that cuts across the major foliation as a possible conjugate set (Casey, 1980). This cleavage however, is not defined by mineral growth. The graphitic schist exhibits features of four deformational events.

Protoliths and Paleoenvironments

The protoliths for the Arvonia(?) sequence were carbonaceous muds deposited under possible euxinic conditions. The calc-silicates were limey and carbonaceous muds with interbedded sandstone and siltstone. The abundant muds indicate deposition below wave base or in a low energy, protected basin. Interbedded sandstone was either sand turbidite or storm generated because only these types of high energy deposits can exist in an otherwise low energy environment. The relatively clean marbles were limestones of probable shallow water origin.
Jurassic(?)—Triassic Dikes.

Pristine, mafic dikes with a north-south trend cut the Brookneal terrane (Plate 1). They crop out on hills and in streams, and weather to black spheroids. The rock is a pyroxene-plagioclase, diabase with varying amounts of magnetite. They possess no deformation or metamorphic features. The dikes are associated in structural sequence to the "Jurassic(?)—Triassic rifting event that formed the Danville Basin."
REGIONAL CORRELATIONS

Lateral equivalents of the Brookneal lithologies are herein correlated by comparison with published lithologic descriptions, structural and stratigraphic relations and field observations in reports on areas shown in Figure 1. Correlation, though fairly certain, cannot be considered absolute because mapping is not complete between the areas.

Metavolcanic Sequence

Similar sequences to the metamorphosed interbedded basalts, dacites, volcaniclastics and possible andesites of the metavolcanic sequence of Brookneal, are represented in the northern and central Virginia Piedmont by the Chopawamsic Formation (Fig. 1) (Southwick, Reed and Mixon, 1971) and in the southern Virginia Piedmont by the Metamorphosed Volcanic-Sedimentary Rocks (Charlotte Belt) of Henika and Thayer (1977) (Fig. 1).

The Chopawamsic Formation has been mapped along strike from northern central Virginia to the Appomattox River at Andersonville (Fig. 1) (Marr, 1980a; Marr, 1980b; Ern, 1968; Brown, 1969; Smith, Milici and Greenberg, 1964). The rocks are a sequence of greenschist to amphibolite grade felsic-intermediate-mafic volcanics intruded by small ultramafic bodies.
In the Danville, Virginia area, the Metamorphosed Volcanic-Sedimentary rocks of Henika and Thayer (1977) bear striking resemblance to those in Brookneal. The two sequences were considered to be equivalent by the mapping of Jonas (1928) and are shown as such on the geologic map of Virginia. In the Danville area, the sequence includes alternating mafic and felsic metavolcanic layers and minor interbedded psammitic and pelitic metasediments which may be of volcanogenic origin. The metamorphic grade decreases westward to the Danville Basin (Fig. 1) where locally, greenschist facies mineralogy prevails. In the low grade areas, volcanic protoliths are revealed by relict textures (Henika and Thayer, 1977).

These volcanic-sedimentary sequences are considered to be an extension of the Charlotte Belt (Conley and Henika, 1973; Conley, 1978). The amphibolite grade volcanic rocks of the Charlotte Belt continue southward through the Carolinas and into Georgia. The Chopawamsic-Charlotte volcanic belt was referred to as the Atlantic Seaboard Volcanic Province and proposed to be an island arc (Higgins, 1972).

Evington Group

The Evington Group (?) and paragonite schists of Buckingham and Fluvanna counties (Fig. 1) (Smith, Milici
and Greenberg, 1964; Brown, 1969) are of lower grade than those of the Evington Group to the south. The green, highly aluminous, sodic, uniform phyllites are overlain by and locally interbedded with graywackes and subgraywackes. These units have already been tentatively correlated with the Evington group (Smith, Milici and Greenberg, 1964; Higgins, et. al., 1971; Brown, 1970; Bland, 1978; Bland and Blackburn, 1980).

West of Danville, Virginia, the Fork Mountain schist (Fig. 1) is slightly coarser than the staurolite-sillimanite schists of the lower Evington Group in the Brookneal area but contact relations, deformation style, metamorphic grade, minerals and mineral abundances are identical. Associated with the Fork Mountain schist is a biotite-garnet schist (Henika and Thayer, 1977; Conley and Henika, 1973; Henika, 1980) which is similar to the pebbly biotite schist of Brookneal.

The Evington Group is believed to have been deposited from lower Cambrian through early Ordovician times (Brown, 1970) making it in part time equivalent to the 570 to 540 Ma Chopawamsic metavolcanic unit (Seiders, et. al., 1975; Higgins, et. al., 1977). In the Brookneal area, the relations between the two lithologies has been largely obscured by granite intrusion and a fault, though nowhere are any intermediary lithologies or interfingering
relationships exposed.

The contact relations between the eastern metavolcanic and western metasedimentary sequences is a point of contention. Brown (1969) and Marr (1980b) describe an interfingering relationship between the Evington Group and Chopawamsic Formation in the Dillwyn and Andersonville quadrangles. Southwick, Reed and Mixon (1971) report that the Chopawamsic Volcanics unconformably underly and interfinger with the Wissahickon schists to the north. A similar interfingering relation described for the Chopawamsic and the Quantico Formations (Arvonia equivalent) in northern Virginia has been resolved as tectonic (Pavlides, 1976).

In the Danville area, a Triassic basin overlies this juncture.

Hornblende Metagabbro

Mafic bodies similar to the hornblende metagabbro of Brookneal, are common in the western Virginia Piedmont (Fig. 1). They have consistent contact and structural relations, and range in composition from noritic to ultramafic. Such bodies are the Diana Mills pluton of central Virginia (Ern, 1968), and the Rich Acres Formation of southern Virginia (Conley and Henika, 1973). The Rich Acres Formation was proposed to be cointrusive with the
Leatherwood granite making it approximately 464 ± 20 Ma (Odom and Russell, 1975). This age is consistent with the 459 Ma, Pb/Pb Ordovician date obtained for the similar Garrison Mafic Complex of northern Virginia (Pavlides, 1976).

**Melrose-Lineated Granite**

A series of late syn- to post-tectonic plutons similar to the Melrose and lineated granites have been identified along the western Virginia Piedmont (Fig. 1). In northern central Virginia, the Columbia metagranite exhibits similar composition, deformation and contact relations. The granite is intrusive into the Chopawamsic volcanic sequence and unconformably overlain by the Arvonia lithologies (Brown, 1969). The Columbia pluton recently yielded a 445 ± 25 Ma, U/Pb concordia (Higgins, et. al., 1977), similar to the 470 Ma age of the lineated granite. The plagioclase granite of Marr (1980b) is mylonitic, titanite bearing body and lies along strike with the Columbia and Melrose plutons.

In the southern Virginia Piedmont (Fig. 1), the lineated Shelton Granite is intrusive into the metamorphosed volcanic-sedimentary rocks (Charlotte Belt) and exhibits a high microcline to plagioclase ratio (Henika and Thayer, 1977), similar to the Brookneal lineated
granite. Rb/Sr whole rock studies yielded a 425 Ma minimum age for the Shelton granite (Kish, et. al., 1979). The western, Leatherwood Granite is co-intrusive with the mafic Rich Acres Formation and cut by a mylonite zone (Conley and Toewe, 1972). The Leatherwood pluton contains mafic minerals and a high plagioclase to microcline ratio, similar to the western Melrose. The 464 ± 20 Ma age of the Leatherwood (Odom and Russell, 1975) overlaps the preliminary 470 Ma age of the Melrose-lineated granite (Sinha and Glover, personal communication, 1981), making them at least in part, time equivalent. The Shelton and Leatherwood Granites however, are not in such close proximity as the eastern lineated and western Melrose granites. The Leatherwood however, may have been transported westward during the emplacement of the allochthon.

Arvonia(?) Sequence

The Arvonia sequence of central Virginia (Fig. 1) is similar to that of the Brookneal Area. The Arvonia slates are foliated and lineated rocks with thin metasandstone lenses. Towards the eastern edge of the Arvonia basin, the metamorphic grade increases to the garnet-amphibolite facies. The slates are moderately graphitic, contain minor amounts of calcareous material and are underlain by a basal
quartzite and conglomerate. The sequence in Arvonia was defined by Brown (1969) and subsequently mapped southward along strike into the Andersonville quadrangle (Marr, 1980b). Through this distance, the Arvonia slate becomes a garnet bearing, graphitic button schist similar to that in the Brookneal Area. The belts can be traced into each other by following a continuous 200 gamma magnetic anomaly produced by the juxtaposition of the magnetite rich, metavolcanic sequence and the non-magnetic Arvonia sedimentary sequence. A major Piedmont lineament is also continuous from Arvonia into the Brookneal area.
Introduction

The rocks of the Brookneal area range from undeformed to ultramylonitic and display seven or eight possible fold generations and late brittle faulting (Table 1). Nowhere do the lithologies exhibit all events but locally four can be recognized in a single unit.

Associated with the folding events, rocks of the Brookneal area have undergone three regional metamorphic events and one localized retrogression (Table 1). Relative time constraints on these events by intrusion and isotopic dating are not rigid. Constraints on the areal extent of the events are difficult to define. The intense deformation has destroyed previous metamorphic relations by bringing distant eastern and western terranes into proximity.

To make a reasonable attempt at defining the structural and metamorphic history of the area, reference to age data and intrusive relationships elsewhere in the western Virginia Piedmont is required.
TABLE 1.

STRUCTURAL AND METAMORPHIC SEQUENCE

<table>
<thead>
<tr>
<th>Folding Event</th>
<th>Fold Type and Orientation</th>
<th>Tectonic Elements Produced</th>
<th>Metamorphism</th>
<th>Units and Locations</th>
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<tr>
<td>possible pre $F_1$</td>
<td>none identified</td>
<td>possible schistosity</td>
<td>not observed</td>
<td>Candler cf; Seneca Creek and Roanoke River</td>
</tr>
<tr>
<td>$F_1$ (Taconic)</td>
<td>isoclinal folding</td>
<td>$S_1$ schistosity</td>
<td>$M_1$, upper amphibolite; staurolite-andalusite-sillimanite</td>
<td>Candler cf-cg; Seneca Creek and Roanoke River, Rt. 641 east on Hickory Creek, 4 km</td>
</tr>
<tr>
<td>$F_2$ (Taconic)</td>
<td>isoclinal folding, type 3 refolding, 20 to 30° S 5-15 E</td>
<td>$S_2$ schistosity, parallel to $S_1$, N 10-40 E</td>
<td>$M_1$ continues</td>
<td>Candler cf-cg; Seneca Creek and Roanoke River, Rt. 641 on Hickory Creek, metavolcanics vs. R.R. tracks west, Terryville</td>
</tr>
<tr>
<td>$F_3$ (Acadian?)</td>
<td>isoclinal to open, 0°/N 40 E</td>
<td>$S_3$ penetrative to mylonitic foliation</td>
<td>$M_1$, lower amphibolite; hornblende-andesine-garnet</td>
<td>Arvonia (7); Rt. 605 and Hat Creek, lineated granite; Rt. 40 and Falling River, metavolcanics; Red Hill R.R. tracks west</td>
</tr>
<tr>
<td>$F_4$ (Alleghanian?)</td>
<td>isoclinal to open, 0°/N 40 E, type 3 refolding</td>
<td>$S_4$ foliation to ultramylonite N 40 E/30-35°SE, 1x2 0°/ N 40 E</td>
<td>$M_2$, middle green-schist grade, epidote-albite-actinolite</td>
<td>lineated granite; Rt. 40 and Falling River, Melrose granite; R.R. tracks at Melrose, Arvonia(?); Rt. 605 on Hat Creek, metavolcanics; Red Hill R.R. tracks west</td>
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<td>possible $F_5$ (Alleghanian)</td>
<td>none identified</td>
<td>$S_5$ spaced crenulation cleavage, N 76 E/30-55 SE</td>
<td>none observed</td>
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<td>$F_6$</td>
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<td>none observed</td>
<td>Candler cf-cg; Lawsons Creek and Falling River</td>
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<td>post $F_7$</td>
<td>none</td>
<td>normal faults, N 25-40 E</td>
<td>$M_3$, mineralization, epidote</td>
<td>Melrose granite; R.R. tracks at Melrose</td>
</tr>
</tbody>
</table>
First Orogenic Event

The following folding and metamorphic events are attributable to a southern equivalent of the northern Appalachian Taconic Orogeny of lower to middle Ordovician age. Rb/Sr whole rock dating of the associated metamorphism in the Fork Mountain schist of the Smith River Allochthon yields minimum ages of 450 Ma (Fig. 1, Fig. 2) (Odom and Russell, 1975). U/Pb zircon discordia ages of deformation yield ages of 500 to 450 ma (Higgins, et. al., 1977).

In the Brookneal area, the event is constrained to between upper Cambrian and middle Ordovician. The Cambrian lower age limit is imposed by the deposition of the Candler and metavolcanic sequences (Brown, 1970; Seiders, et. al., 1975) as they are involved in the folding and metamorphism. The late to post-Taconic 470 Ma, middle Ordovician Melrose-lineated granite (Sinha and Glover, personal communication, 1981) intrude and enclose enclaves of the deformed and metamorphosed units.

Possible Pre F1

The first possible folding event is recorded only in the Candler lithologies of the highest metamorphic grade in the northwestern map area (Plate 1). The possible pre S1
schistosity was transposed to another orientation during subsequent events. This schistosity overprints no other fabric so it may actually have been compositional layering with the aligned minerals formed during subsequent events. The schistosity is preserved as thin relict hinges in gneissic layers but does not relate to any large scale structures.

$F_1$

On outcrop scale the $F_1$ structures are best displayed in the aluminous schists of the Candler Formation of the northwest map area (Table 1). The folding caused transposition of possible previous structures into parallelism with $S_1$ and formation of rootless isoclines in gneissic layers.

The deformation is best demonstrated by isoclinal folding and segregation of minerals into $S_1$ gneissic bands. The folds generally plunge moderately to the southwest but are not identifiable on map scale. Amplitude and wavelength cannot be determined because of a lack of marker beds and scarcity of outcrop. The present northeasterly structural trend may have been caused by subsequent tectonic rotation of the folds.

In the metavolcanic sequence of the extreme southeastern map area, intrafolial isoclinal folding may
also have been the result of F₁ (Table 1). Unfortunately they are not rigidly constrained to an definite position in the structural sequence by dating or intrusion. If these structures are Taconic in age, then they would be attributable to either the F₁ or F₂ folding events.

**F₂**

The F₂ event folded the Candler Formation of the northwest map area (Plate 1) into a series of tight to isoclinal northeast trending structures. The folds are overturned sharply to the northwest and locally nearly recumbent. The wavelength of the major folds is on the order of 1 km. The event apparently brought rocks of high metamorphic grade into proximity of units exhibiting a lower grade as upper amphibolite grade schists border on lower amphibolite grade rocks (see M₁ section). The event appears to have been coaxial with F₁ since only type 3 refolded folds (Ramsay, 1967) are observed in Candler schists.

This event probably included thrust faulting that was later obscured by granite intrusion. These thrust faults may have brought the metavolcanic and metasedimentary units together. It was certainly responsible for generation and mobilization of anatectic type granites (White and Chappell, 1976) in the Candler units. Upper amphibolite
grade metamorphism accompanied the event causing sillimanite and staurolite to define the \( S_2 \) foliation and cut across early gneissic banding. Isoclinal folding caused \( S_2 \) to form parallel to \( S_1 \) in most cases. Thermal effects produced an \( S_2 \) strain free mineralogy replacing the highly deformed \( S_1 \) schistosity the northwestern map area (Plate 1).

\[ M_1 \]

The first major metamorphic event occurred during the Taconic Orogeny. Evidence of the event is preserved in those Brookneal Candler aluminous schists that remained unaffected by later retrograde events. An aligned, but strain free, mineralogy was produced indicating that the thermal effects either ended simultaneous with or outlasted deformation.

The assemblage of the highest grade metamorphic aluminous Candler rocks is indicative of the upper amphibolite facies (Table 1). Strain free sillimanite is a stable phase incorporating only a few cores of other possible aluminumsilicates. Staurolite is stable with only local retrogression to strained biotite in thin cleavage bands. The mineral assemblage of stable muscovite, staurolite and sillimanite is indicative of temperatures between 575° and 650° C and pressures ranging from 3.7 to
5.8 kilobars (Fig. 4) (Greenwood, 1976). A two mica, concordant granite and associated coarse pegmatite labelled g on the Brookneal geologic map (Plate 1), commonly intrude the high grade Candler schists. The high quartz and low plagioclase, first melt composition indicates derivation from a deeper but local level because higher temperatures than those indicated in the schists are required for granite production (Fig. 4) (White and Chappell, 1976).

Rocks of the lower grade intervening areas labelled cg and located in the northwestern map area yield a biotite-almandine assemblage where they have not been totally retrograded. Though no rigid pressure-temperature constraints exist on the rock, an upper greenschist to lower amphibolite facies metamorphism is suspected because of the moderate mica content and absence of kyanite or sillimanite. Mineral strain and sedimentary features are locally preserved in the pebbly biotite schists, indicating that the less intense or later deformation outlasted thermal effects.

In the Candler aluminous rocks, deep stratigraphic levels were mobilized, faulted and isoclinally folded, yielding local anatetic granites and narrow zones of peak metamorphism in belts across the northwestern map area (Plate 1). The metamorphic grade appears to decrease sharply away from the peaks suggesting fault contact of the
Figure 4: Pressure-temperature diagram with the stability fields for common aluminosilicates and assemblages (after Greenwood, 1976). Shaded area indicates the stability field for the formation of the Candler schist and gneiss.
terranes. The intervening areas exhibit a much lower grade assemblage, indicating that peaks are probably emplaced by isoclinal folding or thrust faulting.

Whether or not the metavolcanic sequence was affected by the Taconic metamorphism is a question that has not been unequivocally answered. All metamorphic ages from the Chopawamsic Volcanic Sequence have been of Devonian late-Acadian events (Fullager, 1971; Glover, in preparation). Some mobilization of stratigraphic levels in the eastern areas however may also occurred during Taconic deformation.

In the Brookneal area, the lineated granite intrudes the foliated metavolcanic sequence in a semi-concordant manner similar to the Shelton Granite of the Danville area (Henika, 1980). The granite encloses apparently schistose enclaves that were deformed and metamorphosed prior to Melrose granite intrusion.

**Second Orogenic Event**

The following folding event is assigned to the second orogenic episode. The late-northern Appalachian Acadian event is constrained in Brookneal to between upper Ordovician and pre-Triassic times by the deformed Arvonia (Tillman, 1970) and undeformed Danville Basin (Henika and Thayer, 1977) sedimentary sequences. Rb/Sr whole rock and mineral dating in the central and northern Virginia
Chopawamsic volcanics and Columbia granite suggests a 342 ± 28 Ma, Devonian age for orogeny (Fullagar, 1971, Higgins, et. al., 1971; Glover, in preparation). These ages define an event commonly called Acadian in the central and southern Appalachians but is 30 to 40 Ma younger than the Acadian of the northern Appalachians (Naylor, 1971). This problem needs clarification as to whether two separate events or some degree of diachroneity is involved. Because this problem is outside of the scope of this study, the approximate 350 Ma event in Brookneal will be referred to as the late-Acadian event.

$F_3$

The late-Acadian $F_3$ event formed an $S_3$ foliation in the late to post-Taconic Melrose and lineated granites (Table 1). Strain features increase to the southeast edge of the Arvonia(?) syncline where a mylonitic to ultramylonitic ductile detachment zone developed. The ductile deformation zone intersected the lineated granite and overlying metavolcanic and Arvonia(?) graphitic schist units.

The $F_3$ event isoclinally folded the Arvonia(?) units and metavolcanic lithologies. Some folding and faulting may have occurred in the eastern portions of the Candler Formation but most of this deformation is attributable to
later events. The northwesterly overturned structures trend N40E and have horizontal fold axes with all observed deformation in the ductile regime.

The most intense deformation is exhibited in the graphitic "button" schist. Mica folia and intrafolial quartz veins were stretched into ribbons. Lineated Granite also underwent mylonitization beneath the Arvonia(?) units. Away from the ductile zone, strain features of this event taper off over a short distance westward in the Melrose Granite and increase eastward. In the schistose, less deformed rocks, structures similarly become progressively more open.

\[ M_2 \]

The second metamorphic event peaked far to the east of the earlier Taconic metamorphism as indicated by the high grade assemblages to the east and the absence of overprintng in the western Melrose granite and Candler lithologies. The metamorphism mainly affected rocks of the metavolcanic sequence, lineated granite and the Arvonia(?) sequence (Table 1).

Relict minerals of the highest grade metamorphism (as yet undated in the Brooknel area) occur in the easternmost portion of the map area (Plate 1). Although these hornblende-andesine assemblages do not constrain the
pressure-temperature conditions of formation, comparison with lower grade indicator minerals of the same rock type indicate that conditions of lower amphibolite facies metamorphism prevailed. Studies from the volcanic rocks in Danville also report eastward increasing metamorphism where locally the rocks achieve the first sillimanite isograd (Henika and Thayer, 1977; Tobisch and Glover, 1971). The metamorphic grade apparently decreases westward to the \( F_3 \) ductile deformation zones associated with the event. Though commonly overprinted by a later event, relict phases in lineated granite and metavolcanic rocks indicate an andesine-allanite-garnet assemblage. These minerals are characteristic of upper greenschist to lower amphibolite facies metamorphism (Greenwood, 1976).

West of the late-Acadian \( F_3 \) ductile detachment zone, on the east side of the Arvonia (?) (Plate 1), retrogression from the \( M_2 \) event appears to have been minor. Even if produced, the effects would probably have been obliterated by the later strong deformational event. In the western map area, granite underwent later ductile deformation that recrystallized most of the previous phases.

**Third Orogenic Event?**

The following events are attributed to a second phase of the late-Acadian or to the Alleghanian Orogeny but few
time constraints are available for them. K/Ar mineral age determinations yield 300 Ma, Missippian minimum ages for the cooling of the rocks (Harper, et. al., 1973) in the Arvonia Syncline. These ages however may be on the earlier event.

In Brookneal, the event is constrained to being after the first phase of the late-Acadian event and prior to the brittle deformational events by overprinting relations. In relative time, it is constrained to between upper Ordovician by Arvonia (?) and Triassic by the Danville Basin.

$F_4$

The $F_4$ event appears to have resulted in a westward shift in the metamorphism and deformation. This second event of mylonitization overprinted the $S_3$ foliation, reactivated the $F_3$ mylonite zone and developed additional mylonite zones just west of the Arvonia(?) basin and at the west end of the Melrose Granite. Strain features shifted to a new peak and new zones of mylonitic foliation developed while some of the eastern strain features began to recover (Table 1).

The $F_4$ event caused isoclinal folding that is localized to the mylonite zones. The non-plunging folds are overturned sharply to the northwest and fold axes trend
N40E. All deformation was in the ductile regime.

The F₄ event is coaxial to the F₃ event but not coplanar. The F₄ folds therefore cause type 3 interference patterns and foliation overprinting in the Arvonia (?) and metavolcanic units.

The F₃ event formed a minor S₃ foliation in the Melrose Granite. West of Arvonia(?) syncline, S₄ developed by the F₄ event formed subparallel to the weakly developed S₃ yielding poorly developed lineations in strongly planar fabric. East of the new major detachment zone, the anisotropic granite resulting from F₃, was folded into F₄ asymmetric overturned structures. The S₄ foliation intersects the S₃ foliation yielding a strong, horizontal lineated fabric trending N40E.

The S₃ mylonitic foliation in the graphitic schist was transposed into parallelism with the S₄ mylonitic foliation, leaving remnant hinges as the only record of the F₃ event. The transposition caused boudinage in the intrafolial quartz veins. The small quartz pods were folded into rootless isoclines characteristic of large scale structures in the metavolcanic sequence.

M₃

The characteristic M₃ assemblages that overprinted all units of the map area except the Candler M₁ granites,
include: chlorite, albite, epidote, actinolite and in some places biotite. These minerals are characteristic of lower to lower middle greenschist grade metamorphism making the event one of retrogression from previous metamorphic highs (Table 1). Hornblende and biotite were altered to chlorite, actinolite, epidote and green biotite. Plagioclase exhibiting relict andesine composition has been alбитized and sericitized. In the M₁ metamorphic peaks of the Candler Formation, small veins of aligned muscovite and chlorite cut and replace sillimanite and staurolite.

The M₃ indicator of highest metamorphic grade is olive-brown biotite occurring commonly in the ultramylonite zones. It defines a spaced cleavage in the far eastern areas of the metavolcanic sequence with epidote in hornblende-andesine schist. In the pebbly biotite schists, biotite forms the schistosity in small highly deformed laths.

The third metamorphic event is intimately related to the F₄ faulting and folding phase affecting those rocks in the vicinity of the mylonite zones. The metamorphism strongly affected all lithologies except the Evington Group granite and associated aluminous schists on which it had only a slight effect. Where not in contact with the local granite, the aluminous schist is completely retrograded. Major deformation and metamorphism appear to have ended
nearly simultaneously.

The M3 thermal effects peak in the Arvonia(?) lithologies and again at the western edge of the Melrose Granite. The metamorphic effects decrease over a short distance away from the peaks with only a slight overprint on some of the aluminous Candler unit. This distribution suggests faulting of deeper thermal regimes over shallow cooler rocks. The event probably did not extend much beyond the map area to the east as the effects taper off.

Events not assigned to Orogenic Episodes

Possible F5

A late, spaced, crenulation cleavage developed as a conjugate surface to the major S4 schistosity developed by the F4 event (Table 1). No mineral growth is associated with this surface and a right lateral movement sense is inherent. The S5 cleavage forms with approximately the same dip as the S4 major foliation but with a +35° deviation in strike. The cleavage is best documented in the mylonitic graphite schist on the southeast side of the Arvonia (?) belt where foliation is locally transposed. It also occurs in the ultramylonite zones of the Melrose granite, indicating that the fault zones were reactivated during this event.
The Brookneal area lies at the north end of a southward widening allochthonous plate (Fig. 2). Therefore to the south, a large amount of westward travel of the block is required. To account for the difference in westward movement between the Brookneal area and that to the south, a large component of strike slip motion is required. In moving part of the overriding plate farther westward than the rest, the rocks are required to extend along their length to accommodate the increased travel distance. This extension could be taken up on the conjugate crenulation cleavage with a right lateral strike slip motion (Platt and Vissers, 1980). Since a thrusting plate is constantly being uplifted, deformation may be transitional into the brittle regime. The reduced temperature would account for the lack of mineral growth along the slip planes and the retrogression near them.

This event may be the Brookneal, Virginia record of the Alleghanian Orogeny.

$F_6$

A series of coaxial, coplanar, extensional folds and associated faults were formed on the southeast side of the Arvonia (?) syncline and in the metavolcanic sequence (Table 1). These are now observed as folds that verge in a reverse sense relative to the $F_4$ structures. Faults with
slickenside surfaces and thin hematite filled veins form parallel to the $S_4$ foliation. The present level of observation was at that time just deep enough to experience some ductile behavior.

Possible $F_7$

A gentle warp perpendicular to the major structural trend may be the result of an $F_7$ event (Table 1). It is documented by the tilting of the Melrose Granite N40E lineations from horizontal to plunges ranging from $13^\circ$ NE to $12^\circ$ SW. The warp creates a slight doming of the structures well documented in the Chopawamsic units to the north.

In the Candler rocks, cylindrical kink folds trend nearly perpendicular to regional strike with plunge approximately equal to the foliation dip. These structures however, may have been caused by reclined folding in earlier nappe movement like those exhibited in the Charlotte Belt (Tobisch and Glover, 1971).

Taphrogenic Event

Post $F_7$

The Jurassic-Triassic rifting event, as dated by fossils in the Danville Basin (Thayer, 1977), produced a
series of N25-40E trending normal faults across the area (Table 1). Many of these faults are the result of reactivation of old ductile shear zones (Glover, et. al., 1980). The Jurassic-Triassic rifting may have been related to the F₆ extensional event. The reactivation of shear zones generally causes extreme epidotization of the Melrose mylonite. Faults that were not reactivations of old planes of weakness exhibit zones of cataclasite in Melrose and Candler rocks. The most prominent feature formed by the taphrogeny, is the rift generated, Danville Basin.

The final metamorphic event occurred in thin, discrete zones (Table 1). The age of the event has not been documented in this area but due to its localization to the late brittle faulting, a Jurassic-Triassic age is suspected. The event affects the Melrose Granite and Candler Formation but in both only locally. Thermal effects appear to be related to the flow of fluids along discrete planes or zones.

The effects of the event lasted only as long as faulting. The mineralogical changes include some retrogression of strained biotite to strain free chlorite, the creation of some epidote rich zones and hematite staining. A few samples of float around the Danville basin
contain only sericite, pyrite and quartz and appear to have undergone extreme hydrothermal alteration.
Microstructure

Introduction

The microstructural distribution in Brookneal directly reflects the deformational and metamorphic processes and their extent. They prove the major structural and metamorphic break on the east side of the Arvonia (?) syncline with an abrupt change from preserved strain features to the west to recovered strain features to the east. Included in the delineation of this break is the approximate western limit of the first phase of the late-Acadian event.

The Pre-Triassic, Brookneal area can be divided into three microstructural domains (Fig. 5): (1) the domain of undeformed hornblende metagabbro and Melrose Granite west of the map area; (2) the western high strain domain including all areas west of the Arvonia(?) syncline except those assigned to other domains; (3) the eastern partially recovered high strain domain including all areas east of the Arvonia(?) syncline and the totally recrystallized domain in the discrete metamorphic peaks of the Candler Formation.
Figure 5: Microstructural domains of the Brookneal area: 1) undeformed to slightly strained, 2) highly strained, 3) variably recovered high strain features.
Low Strain Features

The only undeformed Pre-Triassic rocks are part of the hornblende metagabbro body and the Melrose Granite outside of the map area. The initial strain features in the granite result from the F₄ event and include kink banding of the biotite, undulose extinction of quartz and brittle fracturing of the titanite grains. The initiation of plagioclase deformation is enhanced by retrogressive processes of the M₃ event.

In mafic units the hornblende fractured allowing the infiltration of metasomatic fluids that altered the grain. Once alteration began, the deformation and further breakdown of hornblende was rapid, yielding small epidote, actinolite, biotite and chlorite produced during the M₃ metamorphism and oriented parallel to the major strain directions.

High Strain Features

In the Melrose Granite, segregation of minerals is common only at the F₄ mylonite to ultramylonite conditions because the ductility contrast between most of the phases is low. Except for the remnant grains of microcline and less commonly plagioclase, all phases are recrystallized. On the west side of the Arvonia(?) syncline, strain
features of the F₄ event are generally preserved. Quartz exhibits undulose extinction, extinction bands, Boehm lamellae, sutured boundaries, subgrain growth and new grain growth. The .2 mm grains are segregated into S₄ ribbons with axial ratios of up to 40:1. In zones of pure quartz, the grain size is commonly three times greater than that of mixed phase zones. Albite generally exhibits the same strain features as quartz but was not segregated into ribbons.

Biotite, muscovite and chlorite produced by the M₃ metamorphism, form minute .2 mm spindle-like laths that also segregate into thin ribbons. They wrap tightly around large grains and form pressure shadows with quartz. The pressure shadow trails show rotation of the microcline and plagioclase grains.

The pebbly biotite schists of the Candler Formation show many of the same features as the Melrose Granite. Deformation from F₄ is generally not as intense but locally the quartz pebbles are stretched into ribbons with axial ratios of 18:1. Segregation of biotite into ribbons commonly defines the S₄ schistosity. Because so few rigid minerals exist in this lithology, where the quartz pebbles were recrystallized, a fine grain size was formed.

In the Arvonía(?) graphitic schists, the S₄ mylonitic fabric is defined by stretched muscovite and disseminated
graphite. The interlayered quartz veins formed $S_3$ ribbons but they were broken and folded by the $F_4$ event. The more rigid phases like the small, euhedral titanite grains appear to have floated unhampered through the deforming matrix.

In response to the intense stress imposed by the $F_3$ event, 1 mm amphibole and micaceous minerals were oriented in the mafic rocks. Where a moderate felsic component exists in the rock, minerals segregated to form banded gneisses. In interbedded felsic and mafic sequences, the less competent mafic units exhibit pinch and swell or boundinage while the felsic units are only weakly deformed. In the most intensely deformed areas however, both lithologies became highly strained.

**Recovered Strain Textures**

Where thermal effects outlasted deformation or subsequent deformational events were of lower strain than preceding ones, strain features recovered. In the $M_1$ metamorphic peaks of the Candler Formation, the rocks remained hot even after deformation ceased. The result is an $S_2$ gneissic fabric exhibiting only recovered microstructural strain features. Large, euhedral mica laths are aligned but strain free. $S_2$ ribbons of quartz have triple junctions between the clear grains. All other
phases are euhedral and free of strain.

Mineral strain recovery in the other areas however, is usually not as complete as in the Candler rocks. In the eastern, lineated granite and metavolcanic sequence, early F$_3$ peak deformation was overprinted by the marginal effects of the later F$_4$ event. S$_3$ ribbons of quartz exhibit undulose extinction, sutured boundaries and deformation lamellae but the maximum strain direction is not always consistent with the direction of the individual features. Interspersed with the strained minerals are some bounded by equilibrium type triple junctions. S$_3$ mylonites of the lineated granite have M$_2$ mica spindles aligned with the foliation and M$_3$ laths nearly perpendicular to it. In some of the metavolcanic rocks, the M$_3$-F$_4$ recovery event was so efficient that only the uniformly small grain size and general alignment of the features reveal that they once were strained.
GEOLOGIC HISTORY

The oldest units exposed in the Brookneal area, by structural position, contact relations and age determinations to the north are the metavolcanic sequence and the Candler Formation (Plate 1). The volcanically derived Candler muds were deposited below wave base on crust of questionable origin, possibly as rear arc sedimentation (Bland and Brown, 1977) (Fig. 6). The muds stratigraphically overlie the late Precambrian Catoctin Volcanics in the Lynchburg quadrangle (Brown, 1958) making them Eocambrian to Cambrian in age. The Candler was deposited on the west side of a basin which lay to the east of the time equivalent Chilhowee shelf sequence (Brown, 1970), possibly separated by a proto-Atlantic ocean basin (Rankin, 1975).

To the east of the Candler deposition, a volcanic complex was also being deposited (Fig. 6). The volcanic rocks of the metavolcanic (Charlotte Belt) sequence include basalts, andesite, dacites, and tuffs that are interlayered with volcanoclastics. Ages of vulcanism range from about 570 to 540 Ma (Higgins, et. al., 1971; Seider et. al., 1975; Higgins; et. al., 1977; Tilton, et. al., 1970). The two sequences are therefore at least in part time equivalent.
Figure 6: Cross-sections depicting the geologic history of Brookneal, Virginia.
Succeeding the Candler muds are much coarser, more quartz rich graywacke units that are now represented by the Brookneal pebbly biotite schist (Fig. 6). The coarser unit succeeding the finer is probably the result of submarine turbidite fans prograding over the western edge of the basin. The high energy environment required for the formation of these lithologies may have resulted from the building out of the Chilhowee-Shady shelf sequences of lower to middle Cambrian time. The turbidites are the result of instabilities at the shelf-slope boundary created by the rapid sediment buildup.

The Brookneal metagraywacke contains coarse grains in a fine grained matrix (Plate 1). The pebbles are dominantly clear quartz with lesser amounts of plagioclase, rutilated quartz and microcline. The unit locally contains small pockets of calcite that may have been grains. Except for the plagioclase, the pebble type and distribution is similar to that of the Valley and Ridge, Cambrian units. It is also similar to the Mount Athos Formation of the Evington Group (Brown, 1958) but the Mount Athos has not been extended to the Brookneal area.

Clastic deposition apparently filled the basin from both sides (Fig. 6). Volcaniclastics derived from the volcanic pile commonly contain amphibole, a high plagioclase content, and no rutilated quartz or microcline.
They form well bedded units with scoured tops and a slightly gradational character. Similar volcaniclastic aprons bound the eastern side of the Chopawamsic volcanics in northern central Virginia (Pavlides, 1978).

The eastern volcanic and western sedimentary sequences probably interfingered or had an intermediate lithology between them but neither feature exists in the Brookneal area. The Brookneal lithologies are either completely metavolcanic or completely metasedimentary. At one point, there must have been a large distance between the two units but subsequent tectonic activity has removed it.

**Taconic Orogeny**

Late in the depositonal history of the basin, the Taconic F₁ and F₂ deformational and M₁ metamorphic events began (Table 1, Fig. 6). Evidence for both aspects of the orogeny are best documented in the western units of the basin. The eastern, volcanic units are also deformed and metamorphosed but the amount of mobilization of strata is less than that of the sedimentary pile.

The intensity of the Taconic deformation and metamorphism of the sedimentary units generally increases to the south. In the Brookneal area, the intensity of the metamorphism and deformation cause the mobilization of strata into isoclinal folds and westward directed nappes.
The proximity of lower and upper amphibolite terranes indicates upwelling during this event (Plate 1).

The event apparently closed the Evington Group-Charlotte Belt basin along a fault that was later intruded by the Melrose Granite in the Brookneal area (Fig. 6). The fault zone was reactivated during every other deformational event in the Appalachians, supporting its importance as a major Piedmont juncture (fig 1).

On the east side of the closed basin, Taconic effects are fairly uniform. Intrafolial, isoclinal and related folding contain an axial planar schistosity. No Taconic metamorphic ages have been recovered from the volcanic units. Rb/Sr systems were closed during the Taconic Orogeny but due to good migration of fluids in the pile, many isotopic systems stabilized at new levels that were uplifted during later events. Metamorphic age dating has only yielded the younger ages thus far. Rb/Sr whole rock dating in Martinsville indicates that peak metamorphism had ended by 450 Ma (Odom and Russell, 1975). In central Virginia, an episodic lead loss in zircons also occurred at 450 Ma (Tilton, et. al., 1970, Higgins, et. al., 1977) as a result of Taconic deformation.

During the final stages of the Taconic event, a series of granite plutons and contemporaneous mafic bodies intruded the western Piedmont along probable fault zones
since they were active during subsequent events (Fig. 6). In Brookneal, the Melrose-lineated granite intrudes a foliated terrane in a semi-concordant manner. It intrudes both the volcanic and Candler sequences, obscuring their juncture (Plate 1). A large mafic body in the northwest map section appears to be closely tied in sequence, to the intrusion of the Melrose Granite.

Either simultaneous with or just after the intrusion of the post-Taconic plutons, deposition in the area was renewed (Fig. 6). The resulting basin was shallower than the earlier one. The Arvonia Sedimentary Sequence filled the basin that extended from at least north central Virginia to Brookneal, its farthest southerly documented occurrence.

In Brookneal, deposition of thin clean limestone and sandstone units in carbonate mud dominated the western edge. The bedded units grade eastward into very fine, massive, black, carbonaceous mudtone, characteristic of an euxenic basin. The energy requirements for the production of such lithologies indicate that the basin was protected. The bounding topographic promontories to the basin were the uplifted Blue Ridge and Piedmont to the west (Brown, 1970) and the metavolcanic pile to the east. The lithologic distribution in the basin also results from the differing bounding terranes. Reworking of the Cambrian turbidites
supplied the clastic influence from the west and the chemical weathering of the mafic units supplied the mud to the east.

As dated by fossils in the Arvonia slate (Tillman, 1970), the deposition was active during the upper Ordovician through lower Silurian. Duration of sedimentation is constrained by the earlier Taconic event and the succeeding late-Acadian.

Late-Acadian Event

The ensuing late-Acadian event included the F₃ folding and M₂ metamorphism (Table 1, Fig. 6). The major results of the event were upwelling of the metavolcanic belt to the east of the Arvonia basin and renewed movement on old fault zones. The late-Acadian event appears to have been simpler than the Taconic with only one major folding phase. Its effects were localized to the central Piedmont. Areas west of Brookneal were apparently not involved in the folding or metamorphism.

Aplitic, pegmatitic and mafic dikes may have been late stages of the post-Taconic intrusions. Thin, sheetlike, aplite, gabbro and pegmatite bodies that were injected into the Melrose and lineated granites concordant with the major structural trend (Plate 1). Pegmatite was also injected along compositional layering in the metavolcanic sequence.
In both northern Virginia and the Danville area, age determinations on similar pegmatites yield 300-340 Ma ages (Pavlides, 1979; Deuser and Herzog, 1962). No correlation however, is proposed between these bodies because too few age constraints exist.

The metamorphic grade and deformational intensity in the Arvonia and metavolcanic rocks generally increases eastward. The metavolcanic rocks appear to have been thrust over the Arvonia basin, folding it into a westward overturned syncline and causing the eastward prograding metamorphism and intensifying deformation. Metamorphism was apparently caused by the thrusting of the hot eastern block over the cooler western block. In the Dillwyn quadrangle, the west side of Arvonia contains weakly deformed slates that become highly deformed kyanite schists towards the east (Fig. 1).

In Brookneal, ductile deformation caused mylonitization of the eastern lineated granite and isoclinal folding of the Arvonia(?) units (Plate 1). The metamorphic grade increases eastward across the area into the metavolcanic sequence where at least lower amphibolite facies prevailed. West of the major detachment zone located at the eastern edge of the Arvonia(?) syncline, effects of the late-Acadian phase are weak and usually obscured by later events. Similarly in Danville, the
Charlotte Belt rocks attained upper amphibolite grade metamorphism to the east, near the Shelton Granite (Fig. 1).

The late-Acadian uplift terminated all deposition by fully exposing the Virginia Piedmont to erosional processes. Therefore, no sedimentary record of the Piedmont is preserved between the late-Acadian and Jurassic-Triassic times.

Second Late-Acadian or Alleghanian Event

The compressional, second phase late-Acadian or more likely Alleghanian event is represented by the \( F_4 \) deformation and the \( M_3 \) metamorphism (Table 1, Fig. 6). The lower to middle greenschist grade of metamorphism caused retrogression of the units. Many old faults were reactivated during this event. Isoclinal folding was localized to the ductile deformation zones where the late-Acadian fabric was reoriented, overprinted or destroyed. The structures range from isoclinal to open depending on location.

Fault generated, late-Acadian mylonitic fabric in the Arvonia(?), graphitic schist was transposed to a new orientation during this succeeding event. The late-Acadian fault planes however were not the only major movement zones. The major detachment surface was renewed but new
zones also emerged a few hundred yards west and to the west end of the Melrose Granite (Plate 1).

The main effects of the second phase or Alleghanian event were westward of the late-Acadian peaks. Cleavage planes of retrogression cut the major schistosity of the metavolcanic units of the eastern Brookneal map area. Towards the Arvonia(?) syncline however, all previous mineral relationships were obscured. The second foliation cuts the eastern Melrose-lineated granite at a high angle to the first, giving it the lineated appearance. The previously weakly deformed western Melrose developed a strong, locally ultramylonitic foliation that weakens westward to a pocket of undeformed granite. At the western detachment zones, retrogression of the Candler Formation and Melrose Granite is intense.

In the laterally equivalent areas of the Piedmont, recognition of second phase late-Acadian or Alleghanian deformation is sparse. In the Dillwyn Quadrangle, superposed folding of the Arvonia slates is recognized in the eastern side of the syncline (Brown and Griswold, 1970) (Fig. 1).

If the deformation is laterally continuous and progressive along the belt, then Alleghanian or second phase effects may increase in the Danville-Martinsville area (Fig. 1, Fig. 2). In Brookneal, the late-Acadian
shortening occurred in the eastern portions of the map area (Plate 1). Second late-Acadian or Alleghanian deformation was more intense to the west of the previous detachment zones. If the Ridgeway fault on the east side of the Smith River Allochthon is the extension of the eastern Brookneal fault, then it was active during the late-Acadian event. The second late-Acadian or Alleghanian activity was westward on the Bowens Creek fault. The Smith River Allochthon then may in part be the result of the late-Acadian and Alleghanian events. The axis of deformation pivots from the north and intensifies to the south just like the Alleghanian faults of the Valley and Ridge and Blue Ridge (Brown, 1970).

The final compressional event formed the F₅ crenulation cleavage in the Arvonia (?) mylonite and Melrose ultramylonite, once again activating the fault zones (Table 1). The event has not been dated but an Alleghanian age of formation is suspected. The deformation however, involves no mineral growth so dating may be difficult.

At the end of the Alleghanian Orogeny, compression of the rocks ceased. The piling of thrust slabs on top of one another during the compression now resulted in a gravitationally unstable situation. To alleviate the instability, structurally raised units backslid into an
equilibrium configuration, yielding the normal faults and folds of the F₆ event (Table 1).

The final phase of Piedmont deformation is the Jurassic-Triassic rifting event (Fig. 6). The tensional regime imposed on the area caused reactivation of many of the ductile deformation zones (Glover, et. al., 1980). The previously compressional faults now acted as brittle normal faults that created grabens along the Piedmont belt. The deposition filling the basins was in the form of alluvial fans and red beds.

The Danville Triassic Basin was formed by the reactivation of the Chatham fault and another minor fault on the east side of the basin. The resulting basin extends from northern North Carolina through the Brookneal area.

Reactivation of the faults caused local mineralization of rocks along the edge of the basin. They were epidotized, locally producing unakite in the Melrose Granite. The hydrothermal fluids responsible for forming the epidote also caused local retrogression of the Candler schists. Where brittle faults are not reactivations of old shear zones, zones of cataclasite are also mineralized with epidote or hematite.

The other major features attributable to the tensional event are a series of closely spaced diabasic to basaltic dikes. The dikes trend essentially north-south and
commonly induce a positive magnetic anomaly.

Since the Triassic, the Piedmont has remained relatively stable. Local river deposition is common but the most prolific geologic process is the erosion that continues today.
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Geology of the Western Boundary of the Charlotte Belt at Brookneal, Virginia

by

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(ABSTRACT)

The western boundary of the Charlotte Belt near Brookneal, Virginia lies midway along a 100 km length of the boundary previously mapped by reconnaissance methods only (Jonas, 1928). This study concludes that the metavolcanic Chopawamsic Formation of northern and central Virginia is the extension of the Charlotte Belt. The Charlotte Belt is bounded to the west by the metasedimentary Evington Group that extends from northern Virginia southward into the Smith River Allochthon as the Fork Mountain Schist. In Brookneal, the boundary between the eastern metavolcanic and western metasedimentary units is obscured by the intrusion of the 470 Ma Melrose Granite. The abrupt change in lithology and multiple fault generation across the granite indicates that the boundary between the metasedimentary and metavolcanic units is tectonic.

Unconformably overlying both the metavolcanic and metasedimentary units is the Arvonia sequence, previously not documented in the southern Virginia Piedmont.
The Brookneal terrane has undergone three metamorphic events and localized hydrothermal retrogression. The metamorphism is tied in sequence to seven folding episodes. The metamorphism and deformation are results of the regional Taconic event, the late-Acadian event which terminates to the west in Brookneal, and the fault localized Alleghanian? event, each of which resulted in faulting.