State of Maryland
DEPARTMENT OF NATURAL RESOURCES
MARYLAND GEOLOGICAL SURVEY
Jeffrey P. Halka, Director

REPORT OF INVESTIGATIONS NO. 80

GEOLOGY OF THE LINGANORE NAPPE IN THE WESTMINSTER TERRANE, WESTERN PIEDMONT OF MARYLAND

by

Jonathan Edwards, Jr.

2012

Martin O'Malley
Governor

Anthony C. Brown
Lieutenant Governor

John R. Griffin
Secretary

Joseph P. Gill
Deputy Secretary

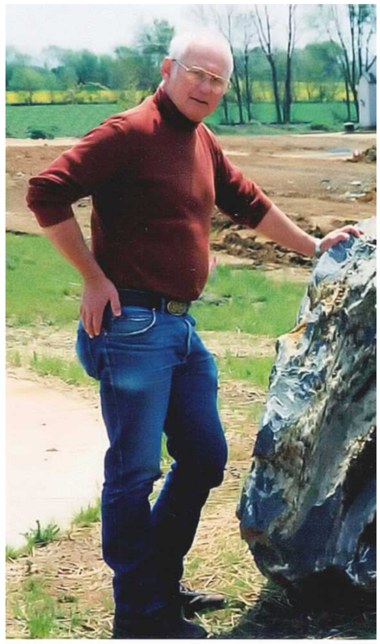
MARYLAND DEPARTMENT OF NATURAL RESOURCES
580 Taylor Avenue
Annapolis, Maryland 21401
General DNR Public Information Number: 1-800-260-8DNR
http://www.dnr.maryland.gov
Publication Number DNR 12-582012-570

MARYLAND GEOLOGICAL SURVEY
2300 St. Paul Street
Baltimore, Maryland 21218
General MGS Telephone Number: 410-554-5500
http://www.mgs.md.gov

The facilities and services of the Maryland Department of Natural Resources
are available to all without regard to race, color, religion, sex, age,
national origin, or physical or mental disability.

TABLE OF CONTENTS

FIGURES



Dr. Jonathan Edwards Jr., at Walkersville, Maryland circa 1996

***Note**: Dr. Jonathan Edwards Jr. retired in 1997 after a 31-year career at the Maryland Geological Survey where he studied and mapped the rocks of the state's western Piedmont. Dr. Edwards died nearly a year later before he could see the current study published. While some of the references may be considered dated, his observations still provide an important contribution to our understanding of the region's geology. This report was subsequently reviewed for content by Dr. Thomas Anderson (University of Pittsburgh) and then formatted and edited by Dr. James P. Reger (Maryland Geological Survey - retired) and Dr. David K. Brezinski (Maryland Geological Survey) in 2012 in advance of its release. This posthumous publication honors, in part, Dr. Edwards' many contributions to the understanding of the geology and evolution of the State.*

GEOLOGY OF THE LINGANORE NAPPE IN THE WESTMINSTER TERRANE, WESTERN PIEDMONT UPLAND OF MARYLAND

Jonathan Edwards, Jr.

EXECUTIVE SUMMARY

This report is a description of the bedrock formations exposed in the upland area of the western Piedmont of Maryland, which includes most of Carroll County, the western parts of Howard, and Montgomery Counties, and the eastern part of Frederick County. Two separate series of rocks have been identified: one is a succession of sedimentary rocks now metamorphosed to phyllite, the other is an assemblage of volcanic rocks with intermingled lenses or layers of marble.

For the sedimentary rock sequence, the following stratigraphic succession has been established: The Sugarloaf Mountain Quartzite is the oldest rock unit, and is exposed only on Sugarloaf Mountain in southern Frederick County. Successively overlying this unit are the Urbana Formation, the Ijamsville Formation, and the Marburg Formation, all of which consist primarily of phyllitic rocks, but which also contain thin beds or layers of quartzite. The Silver Run Limestone is the youngest formation in the succession, and overlies the Marburg Formation in Carroll County.

The volcanic rock sequence includes the Sams Creek Formation and the Wakefield Marble. The Sams Creek Formation originated as a volcanic island built up as a pile of basaltic lava flows and has been metamorphosed to massive metabasalt and chlorite schist. The Wakefield Marble may have originated as carbonate reef rocks but has been recrystallized to fine-grained marble.

Interpretation of the stratigraphic and structural relations of the places the assemblage of volcanic rocks and marble in a large overthrust sheet called the Linganore nappe, which overlies the sedimentary rock succession. In addition, a number of nearly vertical, presumably late, faults have been mapped across the western Piedmont. These faults strike northeast-southwest from the Pennsylvania State line in eastern Carroll County to western Montgomery County.

GEOLOGY OF THE LINGANORE NAPPE IN THE WESTMINSTER TERRANE, WESTERN PIEDMONT UPLAND OF MARYLAND

Jonathan Edwards, Jr.

ABSTRACT

The Westminster terrane in the western Piedmont of Maryland comprises two distinct assemblages of greenschist-facies metamorphic rocks: consisting of metasedimentary rocks, and an association of metavolcanic rocks and marble. The metasedimentary rocks are predominantly phyllite with subordinate metalimestone and minor beds of quartzite. The rock units include Early Cambrian Sugarloaf Mountain Quartzite, Urbana, and Ijamsville Formations, the Cambrian Marburg Formation, and the Silver Run Limestone. Included with this sequence is the Gillis Formation, an undivided phyllite unit equivalent to all the other units in the above metasedimentary assemblage. The metavolcanic rock assemblage is made up of metabasalt and chlorite phyllite of the Sams Creek Formation and includes large to small bodies of Wakefield Marble. The age of these two units has not been determined, but estimates range from as old as Early Cambrian to as young as Early Ordovician.

Structural relationships along the contact between the metasedimentary rock sequence and the metavolcanic rocks and marble suggest that the latter have been thrust over the former along the low-angle Linganore overthrust fault. The allochthonous rocks, which constitute the Linganore nappe, truncate rock layers and formation contacts in the underlying metasedimentary rocks, indicating that the footwall rocks had been folded and eroded prior to nappe emplacement.

The regional map pattern shows that both the autochthonous as well as the allochthonous rocks were folded after nappe emplacement. Regional metamorphism of all rocks in the Westminster terrane to lower greenschist facies took place after the nappe had been emplaced. The pre-nappe folding, nappe emplacement, and post-nappe folding and regional metamorphism are all assumed to be phases of the Taconic Orogeny as the youngest rock unit involved in the earliest phase of deformation is the Silver Run Limestone of possible Early Ordovician age.

The Cranberry fault system is a series of high-angle, west-verging reverse faults which cut across earlier structures in the Linganore nappe. Two of these faults define the eastern limit of the Linganore nappe. Some of these faults and appear to have a component of right-lateral, strike-slip movement. The right-lateral Pleasant Grove shear zone separates rocks of the Westminster terrane from those of Eastern Piedmont.

Extensional deformation during Early Mesozoic continental rifting produced the down-faulted Gettysburg and Culpeper Basins, which lie within the pre-existing Frederick Valley and Westminster terranes, as well as the diabase dikes and sills that intrude all terranes in the Central Appalachians. The faults along which these features formed may have been inherited from or their locations influenced by pre-existing Paleozoic faults.

INTRODUCTION

In the western Piedmont of Maryland (Figure 1), one of the problems that has historically confronted geologists is the presence of metavolcanic rocks and marble within a region dominated by metasedimentary rocks. The scope and purpose of this paper is a synthesis of the geology of the western Piedmont based on my observations during more than 25 years of geologic mapping, and on lithologic distribution patterns as displayed on geologic maps of the area. Field observations and interpretations support the hypothesis that the metavolcanic rocks and marble occur in a large thrust sheet or nappe that has overridden the metasedimentary rock sequence.

North of latitude 39°22′30″, field data used in this paper are based on the following 1:24,000-scale geologic quadrangle maps of the western Piedmont in Carroll and Frederick Counties: Finksburg (Muller, 1994), Hampstead (Muller, 1991), Libertytown (Edwards, 1994), Littlestown (Edwards and Glaser, 1993), Manchester (Edwards, 1993b), New Windsor (Fisher, 1978), Union Bridge (Edwards, 1986), Westminster (Edwards, 1993c), Winfield (Edwards, 1996), and Woodsboro (Edwards, 1988). Unpublished geologic maps and field mapping have been done at the same scale for parts of the Lineboro and Walkersville quadrangles. South of latitude 39°22′30″ the area was mapped on a reconnaissance basis, with detailed mapping only in limited areas.

GEOLOGIC SETTING

The Piedmont Province of Maryland (Figure 1) contains the greatest variety of rocks of any geologic subdivision in the state. The eastern part of the province is made up of several separate geologic terranes, each composed mainly of medium- to coarse-grained, upper greenschist to amphibolite facies crystalline metamorphic rocks. These include: (1) fold nappes of Precambrian basement gneiss with envelopes of metasedimentary cover rocks of probable Early Paleozoic age (Crowley, 1976; Fisher and others, 1979; Muller and Chapin 1984); (2) thrust sheets of intrusive and extrusive mafic and ultramafic rocks (Crowley, 1976); (3) trench-derived olistostromes and melange (Muller and others, 1989; Higgins, 1990); and (4) metavolcanic rocks of island-arc origin (Higgins, 1990). Granitoid bodies have intruded some of the terranes and have formed by in-place anatexis in others.

The western division of the Piedmont in Maryland comprises three separate sub-provinces or terranes (Figure 2). In contrast to the coarse-grained and higher grade rocks to the east, the Westminster terrane (Muller and others, 1989) contains fine-grained, polydeformed, greenschist facies metamorphic rocks. These occur in two different assemblages: one consisting of metasedimentary rocks, predominantly phyllite and fine-grained schist, the other of metavolcanic rocks, predominantly massive to phyllitic greenstone. Quartzite and dark-colored, thin-bedded metalimestone are included within the phyllite, and light-colored, fine-grained marble is associated with the metavolcanic rocks. The Martic fault (Knopf and Jonas, 1929a; Jonas and Stose, 1938a; Southworth, 1996) separates the Westminster terrane from the terrane of the Frederick Valley to the west. The Frederick Valley is a synclinorium of unmetamorphosed, but folded and cleaved, marine carbonate rocks of Early Paleozoic age. The third terrane is made up of unmetamorphosed, non-marine, clastic sedimentary rocks of Early Mesozoic age in the Gettysburg and Culpeper Basins which unconformably overlie the other two terranes. All three terranes in the Western Piedmont have been intruded by dikes and sills of Lower Jurassic diabase.

The Piedmont has traditionally been subdivided on physiography, and was placed along the drainage divide between streams that drain directly to the Chesapeake Bay or to the Potomac River and those that flow westward to the Monocacy River (Figure 1). This divide into eastern and western parts follows Dug Hill Ridge and Parrs Ridge across Carroll County in a northeast-southwest direction, roughly parallel to regional strike, and swings across western Montgomery County to the Potomac River. The actual geologic and structural boundary, however, is the Pleasant Grove shear zone (Muller and Edwards, 1985; Krol and Muller, 1995) that crosses the state a few miles farther to the east (Figure 2). This narrow belt of fine-grained, phyllonitic rocks is a major lithologic and tectonic discontinuity that separates the Maryland Piedmont into two regions with different sedimentologic, structural, and metamorphic histories (Muller and Edwards, 1985; Valentino and others, 1994; Krol and Muller, 1995).

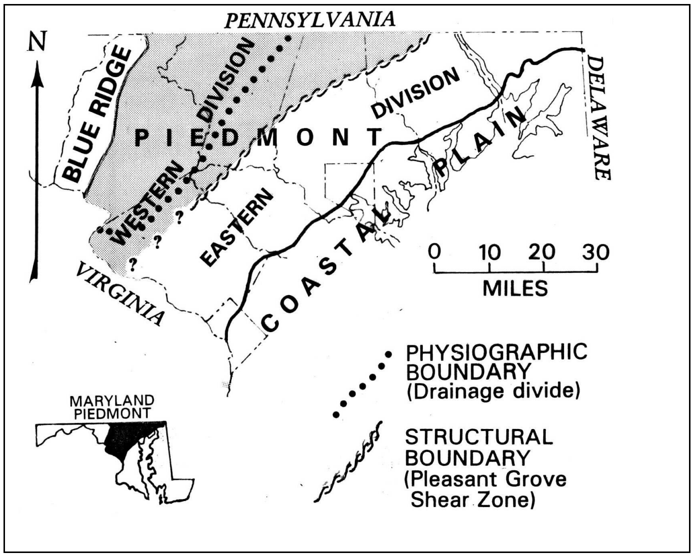


FIGURE 1.–Piedmont Province in Maryland.

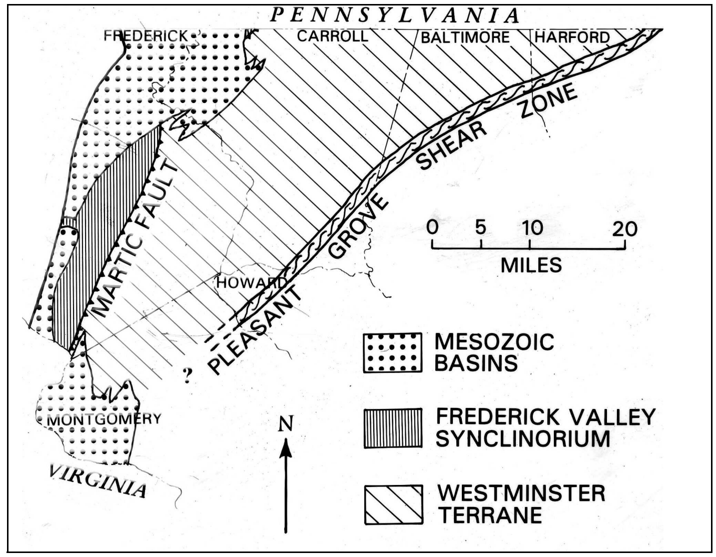


FIGURE 2.– Geologic terranes in the western Piedmont of Maryland.

HISTORY OF INVESTIGATIONS

The first geologic mapping program in Maryland was conducted between 1834 and 1840 by J.T. Ducatel. His reports to the Maryland legislature dealt with the mineral resources of the State, but were never published (Mathews, 1898). The first geologic map of Maryland was produced at a scale of 1:600,000 by Philip T. Tyson in 1859 to accompany his reports (Tyson, 1860; 1862), which also emphasized the mineral resources and agricultural uses of the various rock units in the state.

Detailed studies of the geology of the Piedmont and interpretations of its structure and age began with G. H. Williams (1891). Further work by Keyes (1891), Mathews (1904; 1905), and Clark and Mathews (1906) led to the concept of a broad synclinal structure to the Piedmont.

The metavolcanic and metasedimentary rocks of the western Piedmont were first described by Mathews and Grasty (1909) in their report on the limestone resources of Maryland. However, the first detailed geologic mapping and analysis of the stratigraphy and structure of the region were performed by Anna Jonas (1928) in Carroll County. Later, Jonas and Stose (1938a; 1938b) revised the stratigraphy of the phyllites and metavolcanic rocks in western Carroll and eastern Frederick Counties.

Cloos (1941) reported on studies of the structural geology in the western Piedmont. Scotford (1951) and Thomas (1952) reinterpreted the stratigraphy and structure of the Sugarloaf Mountain area. A ground-traverse magnetic survey of the Sugarloaf Mountain area conducted by Tucker (1983) supported the conclusions of Scotford and Thomas.

Fisher (1978) made a detailed stratigraphic and structural study of western Piedmont rocks in the New Windsor Quadrangle, Carroll County, Maryland. An interpretation of the stratigraphy and structure of the entire Piedmont Province between northern Virginia and New Jersey, based on regional aeromagnetic maps, was made by Fisher and others (1979).

The Maryland Geological Survey has issued a number of quadrangle geologic maps that cover the western Piedmont area (Edwards, 1986; 1988; 1993b; 1993c; 1994; 1996; Edwards and Glaser, 1993; and Muller, 1991; 1994).

Southworth (1996) described the structural relations along the Martic fault in Frederick County. Regional mapping in the southern part of the western Piedmont of Maryland has been conducted by Scott Southworth and Avery Drake of the U.S. Geological Survey (see Southworth, 1996, for references).

STRATIGRAPHY

A stratigraphic succession for rock units exposed in the Westminster terrane is presented in

Figure 3, and is based on the following criteria: (1) the recognition by Scotford (1951) and Thomas (1952) that Sugarloaf Mountain in southeastern Frederick County is an anticlinorial structure with the Sugarloaf Mountain Quartzite the oldest exposed metasedimentary unit; and (2) my interpretation that the Sams Creek Formation and Wakefield Marble have been thrust over the Silver Run, Marburg and Ijamsville Formations, and therefore, are assumed to be older (Edwards, 1984; 1986).

SAMS CREEK FORMATION

Name and previous work

The metamorphosed basaltic volcanic rocks or greenstones that crop out across Carroll, eastern Frederick, and western Montgomery counties, Maryland, were first described by Mathews and Grasty (1909). In central Carroll County, Jonas (1928) considered them to be interbedded with the marble, which she identified as the Cockeysville Marble. Mathews (1933) followed this designation. The volcanic rocks were named Sams Creek Metabasalt by Stose and Stose (1946) for exposures at the village of Sams Creek, on the Carroll/Frederick County line. No specific type locality was given, but the *de facto* principal reference section as established by Smith and Barnes (1994) is the large outcrop at Englars Mill on the south side of Maryland Route 31 in Frederick County, just west of the county boundary along Sams Creek. The unit was renamed Sams Creek Formation by Fisher (1978), who described it as consisting of a massive metabasalt facies and a phyllitic metabasalt facies.

Lithologic description

The Sams Creek Formation consists of dark bluish-green to green, massive to foliated metabasalt, lustrous green chlorite phyllite, and reddish-purple to gray phyllite. Yellow-green epidotized nodules up to six inches long occur locally within the metabasalt. All lithologies of the Sams Creek may contain calcareous material, such as blebs or amygdules between 1/8 and 1 inch in size, thin laminae or layers, or lenses and masses of marble several tens of feet thick and up to several miles long. The larger bodies of marble are mapped as the Wakefield Marble. The Sams Creek Formation has been extensively deformed by folding and the true thickness is unknown, but is estimated to range up to at least 1,000 feet.

Green, purple, and gray phyllite in the Sams Creek Formation are interlaminated and commonly contain flattened blebs of chlorite or aggregates of sericite on cleavage surfaces. They resemble phyllites in the Ijamsville Formation, but are more lustrous, include or are associated with calcareous material as described above, and contain none of the sand detritus, sandy or silty beds, or quartzite layers that are so prevalent in the phyllites mapped as Ijamsville. The intrinsic features of the Sams Creek phyllite indicate that it probably originated as basaltic tuff or may be metabasalt that was phyllonitized by intense shear during deformation.

Narrow, elongate masses of metabasalt crop out along the traces of the Cranberry, Winfield, and Hyattstown fault zones which delineate the eastern limits of Sams Creek outcrops in Carroll, Frederick, and Montgomery Counties. Some of these masses contain coarse-grained ophitic or diabasic texture, whereas others are coarse-grained phyllite and schist.

	WESTMINSTER TERRANE		
			LINGANORE NAPPE
CAMBRO-ORDOVICIAN	Silver Run Limestone		
	Marburg Formation		
	Ijamsville Formation	Gillis Formation	
EARLY CAMBRIAN	? Araby Formation ?		
	Urbana Formation	?	
	Sugarloaf Mountain Quartzite ?	? Prettyboy Schist	
EARLY CAMBRIAN – LATE PROTEROZOIC			Sams Creek Formation and Wakefield Marble

FIGURE 3.– Stratigraphic succession of rock units in the Westminster Terrane.

Pale, purple-gray or dark reddish-purple phyllite of the Sams Creek Formation mapped by Jonas and Stose (1938a) as metarhyolite and meta-andesite and subsequently named Libertytown Metarhyolite by Stose and Stose (1946) are massive Sams Creek metabasalt that has been oxidized.

Distribution

The Sams Creek Formation forms a discontinuous belt of elongate to irregularly shaped bodies that crosses Maryland from the Pennsylvania State line in Carroll County southwestward across Frederick County and into western Montgomery County, where it passes beneath Mesozoic rocks in the Culpeper Basin (Figure 4). North of Westminster, Maryland, the belt is approximately 3 miles wide and consists of long, narrow, bodies of metabasalt and chlorite schist. Between Westminster and New Market in Frederick County, the Sams Creek Formation is more widespread and is associated with many large to small bodies of Wakefield Marble. South of New Market, the Sams Creek again crop out as isolated bodies in a belt that narrows southward until it is only half a mile wide at its termination at Beallsville in Montgomery County. Throughout its distribution, the Sams Creek Formation is in contact with rocks of the Marburg, Ijamsville, Silver Run, and Gillis Formations.

Environment of deposition

On the basis of trace-element geochemical analyses of six rock samples from Maryland, Smith and Barnes (1994) determined that the Sams Creek Formation was enriched or plume ocean-floor basalt, and that it appeared to represent the main stage of development of Iapetan seafloor generation. The unit may have formed as a seamount or volcanic island built on oceanic crust of a passive continental margin.

WAKEFIELD MARBLE

Name and previous work

Exposures of crystalline marble in the western Piedmont were named Wakefield Marble by Jonas and Stose (1938a; 1938b) for the Wakefield Valley in Carroll County where it is typically exposed. These rocks had initially been considered to be the Cockeysville Marble of Precambrian age (Jonas, 1928), a geologic unit of the eastern Piedmont that crops out adjacent Baltimore and Howard Counties (Cleaves and others, 1968).

Jonas and Stose (1938a) and Stose and Stose (1946) regarded the Wakefield Marble and Sams Creek Formation as separate formations, with the metavolcanic rocks overlying the marble. Fisher (1978; *in* Higgins, 1987) also considered them to be separate units but placed the Wakefield above the Sams Creek. Edwards (1986) mapped the Wakefield as a member of the Sams Creek because it is almost always associated with that unit. However, as the Wakefield is a distinct and separately mappable formation, it is here removed from the Sams Creek Formation and restored to full formational rank.

Lithologic description

The Wakefield Marble consists primarily of white to gray, massive to banded or bedded, crystalline, calcitic and dolomitic marble, but includes areas of dark gray, blue-gray, pale green, and purple marble and interlayers of green and purple phyllite. Reddish-purple brecciated zones, boudinage layers, and complex internal folding occur throughout the unit. Because of the complex internal deformation the true thickness is unknown but is estimated to range from 3 to as much as 500 feet.

Distribution

The Wakefield Marble is invariably found associated with metabasalt or phyllite of the Sams Creek Formation. The main outcrop belt lies between Westminster, Carroll County and New Market, Frederick County (Figure 4), where the unit occurs as lenses or belts that range from a few tens to several hundred feet thick and up to several miles in length. Small outcrop-size pods may be found as far northeast as Ebbvale. Only two small outcrops are known to occur south of New Market, both of which are surrounded by phyllite of the Sams Creek Formation. One crops out in the roadbank on the north side of Maryland Route 75 about 200 feet east of where the road makes a right-angle bend to the south at New Market. The other outcrop is a ledge of dark, purple-gray marble in the west bank of a small tributary stream north of Bush Creek, about one mile west of Monrovia and several hundred feet north of the CSX railroad tracks.

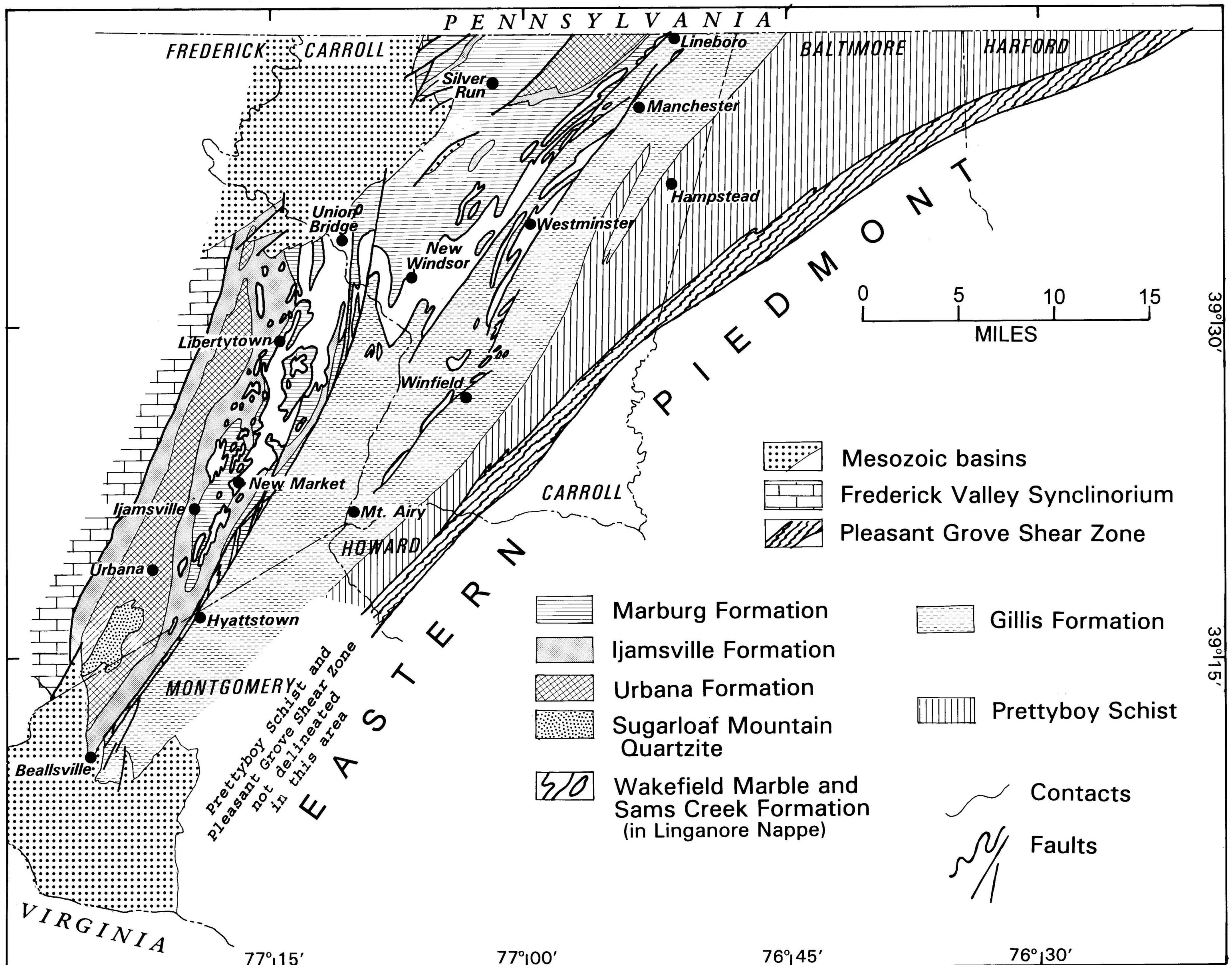


FIGURE 4.—Generalized geologic map of the Westminster terrane. (Adapted from Cloos and Cooke, 1953; Edwards, 1986, 1988. 1993a, 1993b, 1993c, 1993d. 1994, 1996, and unpublished data; Fisher, 1978; Froehlich, 1975; Jonas and Stose, 1938a; Muller, 1985, 1991, 1994; Muller and others, 1989; Southwick and Owens, 1969; Southworth, 1996; and Tucker, 1983.)

Environment of deposition

The occurrence of the Wakefield Marble with metavolcanic rocks of the Sams Creek suggests that the formation probably originated as a shallow-water reef complex surrounding and capping basaltic volcanic islands (Fisher, 1978; Smith and Barnes, 1994). The apparent envelopment of marble within the volcanic rocks may be of stratigraphic origin, in which reefs built during periods of volcanic quiescence were later buried by renewed volcanic activity. On the other hand, the association may be tectonic, in which the fringing and capping reef limestones were incorporated into the volcanic rocks as pods and lenses during the deformation that accompanied nappe emplacement.

SUGARLOAF MOUNTAIN QUARTZITE

Name and previous work

The thick quartzite that caps Sugarloaf Mountain, a prominent topographic landmark in southeastern Frederick County, Maryland, was originally named Sugarloaf Sandstone by Keyes (1891), who correlated it with the Lower Cambrian Weverton Quartzite of the Blue Ridge Province. As the name had been preempted elsewhere, Jonas and Stose (1938b) renamed the formation Sugarloaf Mountain Quartzite and gave its age as Cambrian (?). Scotford (1951) called the unit Weverton Formation, but Thomas (1952) referred to it as the Sugarloaf Group, consisting of a lower Stronghold Quartzite and an upper Sugarloaf Quartzite. Cloos and Cooke (1953) referred to the formation as Sugarloaf Quartzite, but Hopson (1964) and all subsequent workers have called it the Sugarloaf Mountain Quartzite.

I did not map the Sugarloaf Mountain Quartzite nor interpret the structure of the mountain during the course of my field work in the western Piedmont. The following data on the formation are that of previous authors, as cited.

Lithologic description

According to Stose and Stose (1946), the Sugarloaf Mountain Quartzite consists of two thick, hard, quartzite layers: about 200 feet of massive, white, cliff forming quartzite that caps the main peak of the mountain, and a lower, medium-bedded to laminated, white to reddish, ledge-making quartzite, about 100 feet thick, that forms the subsidiary ridges that surround the central peak. The two quartzite units are separated by poorly exposed, interbedded, softer, sericitic quartzite and slate beds. Scotford (1951) described the entire unit as a massive, medium-grained, light tan to rusty brown, maroon, and purple quartzite. Thomas (1952) traced four mappable quartzite beds of similar lithology in each of the Stronghold and Sugarloaf Quartzites of his Sugarloaf Group. Stose and Stose (1946) gave the thickness of a composite section as approximately 370 feet.

Distribution

The Sugarloaf Mountain Quartzite corresponds to the core of the Sugarloaf Mountain anticlinorium (Figure 4) and forms the peak of Sugarloaf Mountain, as well as the crests of the parallel ridges that join in a north-plunging nose just south of Bennett Creek. A ground-traverse magnetic survey of the Sugarloaf Mountain area by Tucker (1983) traced the south-plunging nose of the structure beneath Mesozoic rocks in the Culpeper Basin.

Environment of deposition

Schwab (1972; 1986) concluded that the Early Cambrian Weverton Formation in the Blue Ridge of Virginia was deposited as a series of shallow-water, marine and non-marine deltas in a subsiding coastal plain along the eastern margin of the Early Paleozoic North American continent, Laurentia. Because the Sugarloaf Mountain Quartzite has been generally accepted as correlative with the Weverton (Keyes, 1891; Jonas, 1924; Cloos, 1941; Scotford, 1951; Thomas, 1952; Cloos and Cooke, 1953; Hopson, 1964), it is considered to represent a similar environment of deposition.

URBANA FORMATION

Name and previous work

Jonas and Stose (1938a; 1938b) gave the name Urbana Phyllite to green, quartzose phyllite with interbedded slaty layers crop out near Urbana, Frederick County, Maryland. No specific type locality was identified, but the formation is well exposed along Peters Road, which parallels Bennett Creek across the north-plunging nose of the Sugarloaf Mountain anticlinorium between Thurston Road and Park Mills Road.

All of the western Piedmont phyllitic units, including the Urbana, were called Loudoun Formation on the map by Mathews (1933). Scotford (1951) called the unit Harpers Phyllite based on its lithologic similarity with typical Harpers in the Blue Ridge region. Cloos and Cooke (1953) and Hopson (1964) adopted Scotford's ideas. Thomas (1952) revived the name Urbana in his dissertation but divided the unit into several separately named formations and members. The metabasalts of the Sams Creek Formation were included as an unnamed member of the Urbana.

Lithologic description

The Urbana Formation consists mainly of dark gray, tan to grayish-green, and bluish-gray, ferruginous, chlorite-muscovite-quartz phyllite that weathers to a pale, orange-tan soil. Included grains of quartz sand give the phyllite a gritty appearance, and relict bedding defined by thin interbeds or laminations of tan silty phyllite and dark green-gray chloritic phyllite characterize many outcrops. Thin zones of pale purple phyllite are exposed along Ijamsville Road south of Interstate Highway 70, near the contact of the Urbana with the Ijamsville Formation. These fine-grained units are interpreted as being near the top of the unit and suggest a gradational contact with the Ijamsville. Thickness of the formation is not known.

Layers and lenses of gray, tan, and brown, fine to medium-grained quartzite are present throughout the formation. The quartzites are composed of round quartz grains, between 1/32 and 1/8 inch in diameter, in a matrix of finer-grained quartz sand. The individual layers ranges from 1 to 50 feet. Some quartzites are conglomeratic with pebbles up to one inch in diameter in places. Finely crystalline, pale greenish-gray to white limestones and calcareous layers with interbeds or laminations of greenish-gray to bluish-gray phyllite are exposed in a roadcut on Maryland Route 355 at Price Road, 2 miles north of Hyattstown, and east of Mt. Ephraim Road on the northwest flank of Sugarloaf Mountain (Southworth, personal communication, 1993).

Distribution

As currently defined and mapped, the Urbana Formation (Figure 4) is distributed around Sugarloaf Mountain and overlies the Sugarloaf Mountain Quartzite in Frederick County. Jonas and Stose (1938a) mapped three belts of the Urbana between New Market and Bartonsville that extend southward from the vicinity of U.S. Route 40 (Interstate Highway 70) into Montgomery County. I recognized the Urbana to be present only in the Sugarloaf Mountain anticlinorium (Edwards, 1988; and unpublished data, Walkersville quadrangle). The unit extends north along the axis of the anticlinorium to Ladiesburg, where it is unconformably overlain by Mesozoic sedimentary rocks in the Gettysburg Basin.

In Carroll County, the Urbana crops out in the core of the Deep Run anticlinorium, northeast of Union Mills. Good exposures of this unit are along Deep Run Road, Kridlers Schoolhouse Road, and Maryland Route 30 in the vicinity of Wentz.

Environment of deposition

Hopson (1964) considered the Urbana (his Harpers) to have been derived from the metamorphism of silty shales and fine-grained sandstone. Schwab (1971; 1986) interpreted the Harpers to be a near-shore to deep-water sequence of shale, siltstone, and sandstone deposited off the coast of Laurentia in Early Cambrian time. The Urbana may have been a deeper water facies of the Harpers that accumulated down the continental slope. Subsequent metamorphism has altered the fine-grained rocks in the formation to phyllite.

ARABY FORMATION

Name and previous work

Gray quartzite and quartz schist that underlies the low hills and ridges on the east side of the Frederick Valley were identified as Antietam Formation by Mathews (1933), Jonas and Stose (1938a), and Stose and Stose (1946). However, the Antietam was originally described in the Blue Ridge region as a white sandstone (Williams and Clark, 1893). In light of this disparity, Reinhardt (1974) renamed the unit Araby Formation for exposures in the vicinity of Araby, a former village located at Frederick Junction on the Monocacy River about 3 miles southeast of Frederick, Maryland.

Lithologic description

The Araby along the eastern edge of the Frederick Valley, as originally described by Reinhardt (1974), is comprised of about 330 feet of greenish gray phyllite and very fine-grained metasiltstone with traces of horizontal and vertical burrows. Edwards (1988) described the unit as gray to tan siltstone and silty shale with layers of dark gray to black, fine- to medium-grained quartzite. Black slaty shale or phyllite, which Reinhardt included within the Araby, was designated as the overlying Cash Smith Formation by Edwards (1988).

The Araby mapped in the northwest corner of the Westminster terrane in Carroll County (Edwards and Glaser, 1993) is grayish metasiltstones.

Distribution

Within the Westminster terrane, the only known outcrop of the Araby Formation is in the extreme northwest corner of the terrane. Just south of Blacks Schoolhouse Road, a narrow belt of the unit underlies a low ridge that runs east-northeast from the edge of the Gettysburg Basin (Edwards and Glaser, 1993). The stratigraphic relationship of this rock with the surrounding Ijamsville Formation is uncertain.

The main exposures of the Araby are outside the Westminster terrane. Ridges and hills underlain by the unit define the eastern boundary of the Frederick Valley (Reinhardt, 1974; Edwards, 1988), and are separated from the Westminster terrane by the Martic fault (Southworth, 1996). In northwestern Carroll County, a small area of Araby lies west of the Martic Fault between the Mesozoic rocks and the Pennsylvania State line (Edwards and Glaser, 1993). This was mapped as Antietam by Jonas (1928), but Mathews (1933) showed it as Loudoun Formation.

Environment of deposition

Schwab (1970) described the Antietam Formation as a near-shore, shallow-water, marine platform deposit. Reinhardt (1974) postulated a low energy environment for the site of Araby deposition, probably with a moderate sedimentation rate in a quiet marine basin well below wave base. This suggests that the Antietam sands interfinger offshore with finer grained sediments of the Araby.

Unequivocal outcrops typical of the Araby lithology have not been found within the Westminster terrane. This may indicate that the unit was deposited no farther offshore than the base of the continental shelf (Reinhardt, 1974).

IJAMSVILLE FORMATION

Name and previous work

The Ijamsville Formation was originally named Ijamsville Phyllite by Jonas and Stose (1938a; 1938b) for blue, green, and purple phyllitic slates exposed at Ijamsville, Frederick County, Maryland, where the rock was locally quarried for roofing slate. Although not previously specified, the abandoned and water-filled quarry on the north side of the CSX railroad tracks just west of Ijamsville Road is assumed to be the type locality.

Edwards (1986) determined that reddish-purple, purple, and green-gray phyllites, mapped as Ijamsville Phyllite by Jonas and Stose (1938a), actually comprise two separate geologic units. The phyllite in the outcrop belt that includes the Ijamsville type locality is of sedimentary origin and contains quartzites and thin sandy layers. For this lithology the name Ijamsville was retained. The other phyllite is associated with metavolcanic rocks of the Sams Creek Formation, as described above, and has been mapped as such. Phyllites of the Sams Creek contain small carbonate blebs, laminae or layers, to various size pods or masses that are associated with bodies of Wakefield Marble, whereas no calcareous material has been found in the phyllites that I have mapped as Ijamsville.

The Ijamsville Formation, as shown on the maps of Cloos and Cooke (1953), Hopson, (1964), Fisher (1978), and Fisher and others (1979) includes areas that Edwards (1986; 1993b; 1993c; 1994) and Edwards and Glaser (1993) mapped as either the Marburg or the Gillis Formations.

Lithologic description

The Ijamsville Formation consists of intercalations dull to lustrous, purple to reddish-gray, hematitic muscovite phyllite and tan to green chlorite-muscovite phyllite. Zones of reddish-gray to tan, medium-grained, sandy phyllite are common. Sporadic layers and lenses of gray, tan, and brown, medium-grained quartzite from a few inches to as much as 10 feet thick occur. Locally, bedding and cross-bedding have been preserved in some of the quartzite layers and sandy phyllite zones. Bedding in the phyllite has been obliterated by the pervasive foliation and a later spaced cleavage. The thickness of the unit cannot be determined.

Distribution

The Ijamsville Formation (Figure 4) crops out on both flanks of the Sugarloaf Mountain anticlinorium in Frederick and Montgomery Counties. To the north and south, the formation passes beneath the Gettysburg and Culpeper Basins. On the west limb, the phyllite is exposed along many of the roads that cross the outcrop belt north of Interstate 270. Possibly the best exposure in this area is the borrow pit/quarry on the south side of Maryland Route 80, one mile west of Park Mills Road. On the east side of the anticlinorium the unit is less well exposed, but outcrops can be seen along the CSX railroad tracks west of Ijamsville and also along Ijamsville Road both north and south of the village.

East of Mussetter Road at Ijamsville, the rock ledges exposed in the abandoned quarries along the CSX tracks are assigned to the Marburg Formation. These quarries were not included in Mathews' (1898) description of the slate quarries at Ijamsville and may have been borrow pits for railroad fill when the Baltimore and Ohio Railroad was straightened and upgraded.

The Ijamsville also crops out in a belt that extends north from Hyattstown to just east of Monrovia and New Market, where it terminates against the Sams Creek Formation. Another belt of Ijamsville begins at Bens Branch east of Detrick Road and is exposed north almost to Clemsonville, where it is also cut off by the Sams Creek Formation. Between Unionville and Clemsonville, the Sams Creek borders the west side of this belt.

In Carroll County, the Ijamsville Formation crops out on the southeast flank of the Deep Run anticlinorium between the Urbana and Marburg Formations. This outcrop belt gradually decreases in width northeast of Union Mills until at the Pennsylvania State line it is less than 1,000 feet wide. Other small belts of the Ijamsville occur east of Pleasant Valley as well as in the northwestern corner of the Westminster terrane between Silver Run and Blacks Corner.

Environment of deposition

Edwards (1986) proposed that the sediments that formed the Ijamsville Formation originated as oxidized soils on the exposed surface of the Laurentian continent in Late Precambrian and Early Cambrian time. During the Early Cambrian marine transgression, these materials were eroded, transported, and deposited offshore in a deep basin as red muds, in the manner described by Ziegler and McKerrow (1975) for the origin of marine redbeds. These sediments are now represented by the purple, green, and tan phyllites of the Ijamsville. Quartzites layers in the Ijamsville represent influxes of sand that were transported down the continental slope and into the basin.

Eastward across the Westminster terrane, the outcrop belt of the Ijamsville Formation narrows, suggesting that the marine redbed unit pinched out into the marine basin. Zones of reddish phyllite occur sporadically within the Gillis Formation to the east, but these can no longer be mapped as a separate unit.

MARBURG FORMATION

Name and previous work

The Marburg Formation originally was named Marburg Schist by Jonas and Stose (1938a; 1938b) for exposures near the town of Marburg, York County, Pennsylvania. However, the type locality is no longer accessible as it lies beneath Lake Marburg Reservoir. Fisher (1978) abandoned the name and placed all lithologies that had formerly been assigned to the Marburg in Maryland into his Ijamsville Formation, as he considered the two units to be redundant. Edwards (1986) revived the name because the Marburg and Ijamsville are separate and distinct mappable units in the Westminster terrane. He called it Marburg Formation because the lithology is primarily phyllite, not schist, and it also contains subordinate quartzite lenses, calcareous phyllite layers, and thin lenses of dark blue-gray, thin-bedded metalimestone.

As here defined, the Marburg Formation includes rocks formerly mapped as the albite-chlorite facies of the Wissahickon Formation (Jonas, 1928; Jonas and Stose, 1938a; Stose and Stose, 1946), Harpers (Jonas, 1924; 1928) and Loudoun (Mathews, 1933) Formations, and Ijamsville Phyllite (Cloos and Cooke, 1953; Hopson, 1964; Fisher, 1978; Fisher and others, 1979).

Lithologic description

The Marburg is predominantly a grayish-tan, pale olive-tan, to pale bluish-green quartz-chlorite-muscovite phyllite with abundant laminae of very fine-grained quartz. Foliation surfaces have a waxy or silvery sheen. In places, the unit contains abundant small limonite cubes pseudomorphic after pyrite. Zones of pale, purplish-gray phyllite and dark gray to black, calcareous, muscovite phyllite occur locally. Foliation obscures bedding as well as most other original sedimentary features. The unit has been further deformed by isoclinal folds, spaced cleavage, and probable intraformational thrust faults; therefore, the thickness cannot be determined.

Thin lenses and layers of light gray to tan, medium-grained phyllitic quartzite are widely distributed throughout the formation. These contain round grains of quartz up to 1/16 inch in size in a very fine-grained phyllitic matrix of quartz and sericite. In the Linganore Hills region of Frederick County, thick-bedded, medium to dark gray and brown, medium-grained quartzite, in lenses up to 50 feet thick, forms prominent ridges along Maryland Route 75 between Union Bridge and Urbana. Lenses of very dark green to greenish-gray-brown quartzite up to 50 feet thick also crop out in northern Carroll County east of Old Hanover Road about 2 miles northeast of Union Mills.

Lenses of thin-bedded, dark bluish-gray metalimestone with laminae of dark gray phyllite occur sporadically within the Marburg in Carroll County, mainly in the area north of Maryland Route 140. In Frederick County, an outcrop of metalimestone crops out along a small, north flowing tributary to Linganore Creek north of Old Annapolis Road and two miles east of Maryland Route 75. Another small exposure was found in a field east of the farm road which extends east from Maryland Route 75 south of Linganore High School, between Old Annapolis Road and Lime Plant Road. Similar lenses of metalimestone occur along a line extending from just north of Harrisville Road at Glissans Mills Road to east of the intersection of Lime Plant Road with Detrick Road, near the eastern margin of the Marburg Formation. All of these exposures may actually be very small lenses or tongues of the Silver Run Limestone.

Distribution

Although the Marburg Formation (Figure 4) is poorly exposed throughout the Westminster terrane, it underlies a large area north and west of the Sams Creek Formation and east of the Mesozoic sedimentary rocks of the Gettysburg Basin. The most accessible outcrops are along Maryland Route 97 between Old Hanover Pike at Union Mills and Humbert Schoolhouse Road north of Silver Run. On the southeast flank of the Deep Run anticlinorium, the Marburg overlies the Ijamsville Formation. It is well exposed in roadcuts along Saw Mill and Rinehart Roads between Maryland Route 496 and Big Pipe Creek.

In Frederick County, the Marburg occupies a belt up to 5 miles wide south of the Gettysburg Basin between the Ijamsville Formation to the west and the Hyattstown fault on the east. This outcrop belt gradually narrows to the southwest until it is cut off by the Hyattstown fault south of Green Valley. On the north side of Glissans Mill Road, three miles east of Maryland Route 75, ledges of typical Marburg form a large outcrop just east of Dollyhyde Road. The formation is not present on the west flank of the Sugarloaf Mountain anticlinorium.

The eastern limit of the Marburg Formation in Carroll, Frederick, and Montgomery Counties has been drawn along the traces of the Avondale and Hyattstown fault zones. The metasedimentary rocks exposed east of these faults have been mapped as Gillis Formation, an undivided unit made up of phyllites identical with lithologic units found in the Urbana, Ijamsville, and Marburg Formations.

Environment of deposition

The Marburg Formation was deposited as shale and silt in a deep, marine basin, marginal to the continent. Lenses of metalimestone and quartzite within the unit indicate that sporadic influxes of carbonate debris and sand were transported across the continental shelf and down the adjacent slope into the basin.

SILVER RUN LIMESTONE

Name and previous work

Thin-bedded, fine-grained, blue-gray metalimestone exposed in several small quarries in the valley of Silver Run, Carroll County, Maryland, was named Silver Run Limestone by Jonas and Stose (1938a; 1938b). Previously, limestone in the phyllitic rocks north and west of Westminster had been mapped as Conestoga Limestone (Jonas, 1924; 1928) and as Cockeysville Marble (Mathews, 1933). Edwards (1986) considered the Silver Run to be a member of the Marburg Formation, but as it is a distinct mappable unit it should remain classed as a formation.

Lithologic description

The Silver Run is thin-bedded to thinly laminated, medium-grained, medium bluish-gray, metalimestone to fine-grained, dark bluish-gray to black metalimestone interbedded or interlaminated with gray and dark gray to black phyllite. White, calcite filled fractures and joints are common. Clay minerals in the limestone and in the phyllite laminae have been altered to fine-grained mica flakes. The unit is nowhere well exposed naturally. Where exposed in roadcuts, quarries, or excavations, the beds are composed of thin laminae ranging from less than 1/16 inch to 3 inches in thickness. In many places these thin strata have been isoclinally folded. The thickness of the unit is impossible to determine, but outcrops range from less than 10 feet to greater than 100 feet.

Distribution

The Silver Run Limestone crops out in association with the Marburg Formation in the area northwest of the belt of Sams Creek Formation in Carroll County. Exposures of unit range from small lenses or layers a few tens of feet in length to belts up to half a mile wide and several miles long. The presumed type locality is the small quarry opening in the hillside that forms the south wall of the valley of Silver Run, about 1 mile west of the village of Silver Run. However, the formation is best exposed in the diversion channel for Sams Creek that was cut by the Lehigh Portland Cement Company along the Carroll/ Frederick County boundary south of Union Bridge. Small outcrops can also be seen in fields and in roadcuts along Pipe Creek Road where the unit occurs between Linwood and Weller Mill, west of New Windsor. Elsewhere in Carroll County, the presence of this unit usually is indicated only by chips and fragments in recently plowed fields. The small bodies of metalimestone mapped in the Marburg Formation may actually be Silver Run Formation.

Three small pods of carbonate rock contained within a narrow belt of Sams Creek Formation that passes through Fountain Valley, west of Westminster, were mapped as the Silver Run by Fisher (1978). However, two of these pods contain quarries that expose light gray marble typical of the Wakefield.

Environment of deposition

The dark metalimestone of the Silver Run Formation, as well as the small metalimestone outcrops within the area mapped as Marburg Formation, may represent tongues of deep-water carbonate sediment that extended eastward from the shelf carbonates of the Frederick and Grove Formations into the Cambro-Ordovician marine basin as suggested by Reinhardt (1974) and Fisher (1978). It is not known if all these metalimestone outcrops are stratigraphically equivalent or if several horizons are represented.

GILLIS FORMATION

Name and previous work

The Gillis Formation was named by Edwards (1986) for the phyllite exposed along Gillis Road, west of Gillis Falls in southwestern Carroll County, Maryland. However, the exposure of phyllite beneath the Potomac Edison Transmission Company power line where it crosses Maryland Route 144, 0.2 mile east of the intersection with Bartholows Road, Frederick County is designated as the reference outcrop (Figure 5). The Gillis Group, hereby abandoned, was formerly used for the undifferentiated phyllites within the large expanse of the Westminster terrane east of the Avondale and Hyattstown fault zones (Muller, 1991; 1994; Edwards, 1993a; 1993b; 1993c; 1994; and Edwards and Glaser, 1993) and as an inclusive term for the stratigraphic assemblage of the Urbana, Ijamsville, and Marburg Formations to the West (Edwards, 1993b; 1993c; 1994).

Much of what is here called Gillis Formation has been previously included in various facies of the Wissahickon Formation or Wissahickon Group: namely, the albite-chlorite schist or western facies (Jonas and Knopf, 1925; Jonas, 1928; Knopf and Jonas, 1929b; Jonas and Stose, 1938b; Cloos and Broedel, 1940; Cloos and Cooke, 1953), the western sequence (Hopson, 1964), the upper pelitic schist facies (Cleaves and others, 1968; Fisher, 1970), and the pelitic schist facies (Higgins and Fisher, 1971; Fisher and others, 1979). It has also been mapped as Marburg Schist (Jonas and Stose, 1938b) and Ijamsville Phyllite (Cloos and Cooke, 1953; Hopson, 1964). Fisher (1978; Fisher *in* Higgins, 1987) called it both Wissahickon albite phyllite and Ijamsville Phyllite.

Lithologic description

The Gillis Formation is composed primarily of dark to light silvery-gray, tan, and greenish-gray quartz-chlorite-muscovite phyllite, some with thin interbeds or laminae of white to pale green or tan quartz metasiltstone. Small cubic pseudomorphs of limonite after pyrite are common. Zones of bluish-green muscovite-chlorite phyllite and reddish-purple to pale purplish-gray muscovite phyllite occur throughout the unit. The formation includes numerous layers of medium-gray, gray-tan, and brown, fine- to medium-grained quartzite from 3 to 20 feet thick which contain rounded quartz grains up to 1/16 inch in size.

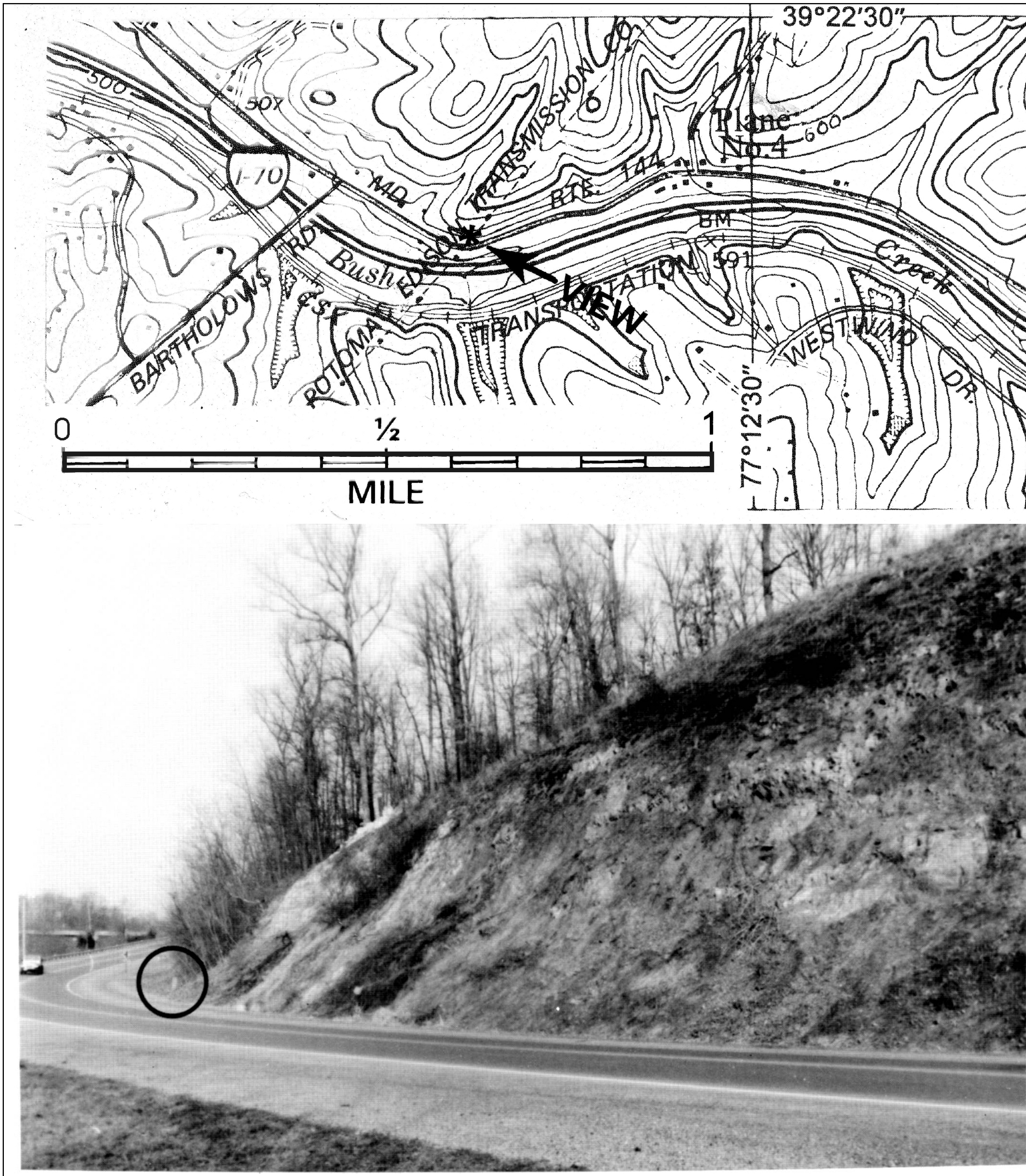


Figure 5.– Reference outcrop of the Gillis Formation, view to north-northwest. Exposure lies under the Potomac Edison Transmission Company power line on Maryland Route 144, 0.2 mile east of the intersection with Bartholows Road, Frederick County (Damascus Quadrangle). Circle at west end of outcrop indicates milepost #34 of the Baltimore National Pike.

Thin layers of sheared and phyllitic quartzite with interlayered phyllite are also present. Small lenses of metalimestone or marble may be contained within the Gillis Formation in Carroll County. The thickness of the unit is indeterminate because the rocks have been strongly deformed by folding and pervasive cleavage.

The predominant lithology appears to be identical to that of the Marburg, but all lithologies that have been described in the Marburg, Ijamsville, and Urbana Formations may be found within the Gillis Formation. The presence of isoclinal folds, spaced cleavage, and probable intraformational thrust faults, as well as the poor exposure of the unit, precludes further subdivision with any degree of certainty.

Distribution

The Gillis Formation (Figure 4) includes all the undifferentiated phyllitic rocks of the Westminster terrane that extend from the northwestern corner of Baltimore County, through central Carroll, southeastern Frederick, and western Howard Counties, into northwestern Montgomery County. The Avondale and Hyattstown fault zones have been arbitrarily chosen as the boundary between the Gillis and Marburg Formations. In the area between these fault zones along the Carroll County/Frederick County border, the boundary is the trace of the Linganore overthrust along the south side of the Sams Creek Formation.

The phyllite of the Gillis Formation grades into the Prettyboy Schist to the east across a zone several hundred feet wide. The contact on the geologic map is drawn at the first eastward appearance of coarser grained schist layers within the phyllite.

A deep reentrant in the Prettyboy/Gillis contact between Carrollton and Greenmount in eastern Carroll County (Edwards, 1993c) outlines a long, south-pointing wedge of Gillis surrounded by the Prettyboy Schist.

Topographic relief throughout the area of the Gillis is low to moderate and natural exposures of the unit are poor. The formation is best exposed in a series of cuts along a 10-mile traverse along the CSX railroad tracks between Woodbine in Carroll County and New Market in Frederick County. At the western boundary of the unit, fragments of sheared metabasalt exposed in the railroad cut behind the Maryland State Police truck inspection facility on Interstate Highway 70 east of New Market mark the location of the Hyattstown fault zone.

Outcrops of schistose marble or metalimestone within the Gillis Formation lie along a northeast-southwest alignment in the area east of Manchester between Maple Grove and Alesia, as well as in the wedge of Gillis that extends into the Prettyboy Schist between Greenmount and Patapsco west of Hampstead. These bodies were mapped as Cockeysville Marble by Jonas (1928) and Mathews (1933), but Stose and Stose (1946) called them Wakefield Marble. However, except for being more crystalline and coarser grained, the rock more closely resembles the metalimestone of the Silver Run in lithology and in its association with phyllite.

Thin layers of white to light gray schistose marble or metalimestone in weathered Gillis phyllite were found in an excavation for a borrow pit in the northeast corner of the intersection of Cranberry Road and Maryland Routes 97 and 140 in Westminster. In southern Carroll County, about three miles north of Winfield, an outcrop of phyllite in the driveway to a lumber yard on Salem Bottom Road contained a foot thick bed of white to light gray marble. A thin ledge of light to medium gray marble or metalimestone was exposed 0.3 mile west of the intersection of Salem Bottom and Bloom Roads in a small, abandoned pit on the south side of Morgan Run.

PRETTYBOY SCHIST

Name and previous work

Crowley (1976) named the Prettyboy Schist for outcrops of uniform, fine-grained schist near the dam at Prettyboy Reservoir on Big Gunpowder Falls in northern Baltimore County. The schist previously the albite-chlorite facies or albite-chlorite schist of the Wissahickon Formation (Knopf and Jonas, 1923; 1929a; 1929b; Jonas, 1924; 1928; Jonas and Knopf, 1925; Cloos and Broedel, 1940; Stose and Stose, 1946; Cloos and Cooke, 1953); the western sequence of the Wissahickon Formation (Hopson, 1964); or the upper pelitic schist facies of the Wissahickon Formation (Southwick and Fisher, 1967; Cleaves and others, 1968; Southwick and Owens, 1968; Southwick, 1969). Higgins and Fisher (1971) and Fisher and others (1979) included it within their pelitic schist facies of the Wissahickon.

Lithologic description

The Prettyboy is a greenish gray-tan to medium gray, fine-grained, albite-quartz-muscovite-chlorite schist (Muller, 1985). Minute, individual flakes of muscovite mica can be discerned on the foliation surfaces, whereas foliation surfaces in the Gillis Formation have a uniform, metallic sheen because the mica grains are too small to be perceived by the unaided eye. The Prettyboy commonly, but not ubiquitously, contains small porphyroblasts of albite that may range up to 1/16 inch across, although larger crystals are locally present. Magnetite crystals up to 1/16 inch in size are present in some samples. Light gray to tan, thinly laminated to slabby, fine-grained, schistose, muscovite bearing quartzites up to 20 feet in thickness are locally present throughout the formation. Lenses and pods of milky white vein quartz are also common. The thickness of the formation is not known.

Distribution

The Prettyboy Schist is bounded on the east by the Pleasant Grove shear zone, and on the west by the Gillis Formation (Figure 4). It has been mapped under various names (see above) across the western Piedmont of Maryland from the Pennsylvania State line in Harford and Baltimore Counties to the Patuxent River in western Howard County. The unit has not been traced across Montgomery County.

Environment of deposition

The relation of the Prettyboy Schist to the Gillis Formation to the west is uncertain. If the Gillis is younger than the Prettyboy, as proposed by Muller (1991; 1994) then the Prettyboy may have been a deep-water marine deposit upon which distal continental margin deposits of the Gillis were prograded.

CORRELATION AND AGE

INTRODUCTION

The geologic units now present in the western Piedmont and adjacent Blue Ridge and Appalachian regions were deposited in widely separated environments that lay roughly parallel to the Late Proterozoic/Early Paleozoic continental margin. The transitional lithologies that formerly lay between these tectonostratigraphic packages of rocks are now missing, which hampers correlation of strata between terranes.

My attempts toward regional correlation and assignment of geologic ages of formations in the Westminster terrane are shown in Figure 6. These have been made on the basis of the stratigraphic position of certain key lithologies in the sequence, and their similarity to formations of known geologic age in the Appalachian and Piedmont Provinces.

SAMS CREEK FORMATION

The lithologic similarity between metabasalts of the Sams Creek Formation and those of the Late Proterozoic Catoctin Formation in the Blue Ridge was noted early by Clark (1897), Clark and Mathews (1906), Mathews and Grasty (1909), and Jonas (1924). Basalt flows of the Catoctin Formation were extruded during the rifting phase in the initial break-up of a continent in the Late Proterozoic (Rankin, 1975; Smith and Barnes, 1994). Radiometric dates from volcanic and hypabyssal rocks associated with the Catoctin (Odom and Fullagar, 1984; Badger and Sinha, 1988; Aleinikoff and others, 1995), supported by stratigraphic data assembled by Bond and others (1984), indicate that this rifting took place between 625 and 570 Ma.

If the Sams Creek formed on oceanic crust during rifting as suggested by Smith and Barnes (1994), it would be younger than the Late Proterozoic/Early Cambrian, Catoctin Formation. This would place it at most as Early Cambrian in age. The unit has not been found to be associated with rocks that may originally have been pelagic sediments, nor are outcrops of the Sams Creek floored by oceanic crust.

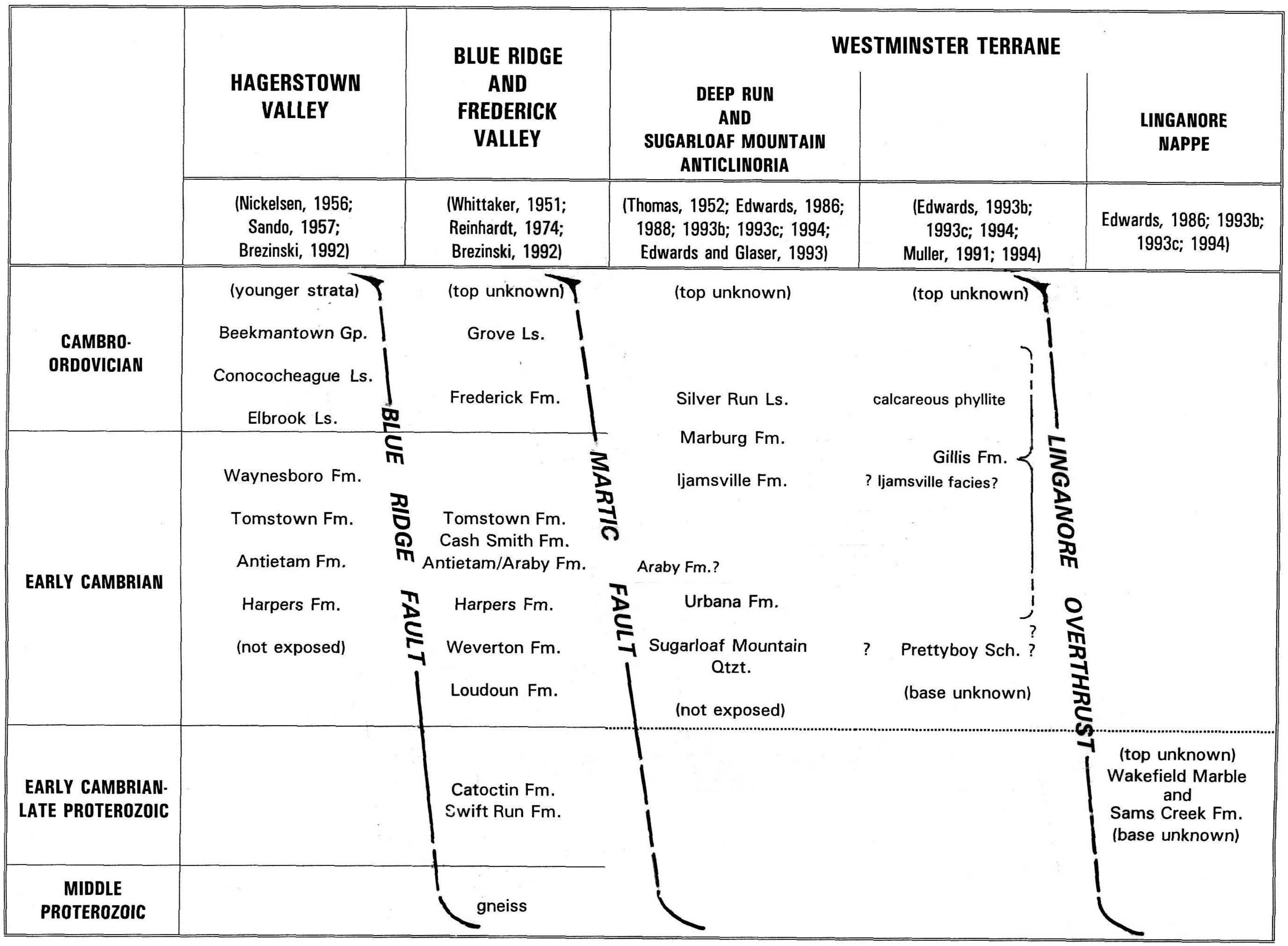


FIGURE 6.– Correlation of formations in the Westminster terrane with Piedmont and Appalachian formations of known age.

WAKEFIELD MARBLE

Jonas (1928) correlated the Wakefield Marble with the Precambrian Cockeysville Marble, but unlike the type Cockeysville in Baltimore County (Williams, 1892; Mathews and Miller, 1905; Knopf and Jonas, 1929b; Crowley, 1976), this marble in Carroll County is associated with metavolcanic rocks. In the Blue Ridge region of Maryland and northern Virginia, lenses of white to light blue-gray crystalline marble crop out beneath volcanic rocks of the Upper Proterozoic Catoctin Formation (Jonas, 1927; Jonas and Stose, 1938a; Furcron, 1939; Stose and Stose, 1946; Nickelsen, 1956; Mack, 1965; Parker, 1968; Espenshade and Clarke, 1976; Wehr, 1985).

Jonas and Stose (1938a) and Stose and Stose (1946) interpreted the Wakefield Marble as Precambrian in age, and overlain by the Sams Creek Formation. However, Fisher (1978) placed the Wakefield in the Middle Ordovician, above the Sams Creek Formation. He reported that the unit in the New Windsor Quadrangle contained structures that resembled stromatolites, as well as what appeared to be pellets and possible shell fragments, but these features were not further identified or dated. The association of the Wakefield with the metavolcanic rocks of the Sams Creek Formation argues for a similar age, which is probably Early Cambrian.

SUGARLOAF MOUNTAIN QUARTZITE

Keyes (1891) and Clarke and Mathews (1906) originally correlated the quartzite on Sugarloaf Mountain with the Lower Cambrian Weverton Quartzite to the west on Catoctin Mountain in Frederick County. However, Jonas and Stose (1938a; 1938b) and Stose and Stose (1946) declined to equate it with the Weverton because the absence of fossils in both units made such a correlation moot. Scotford (1951) and Thomas (1952) both considered the Sugarloaf Mountain Quartzite to be equivalent to the Weverton Quartzite. This interpretation was followed by Cloos and Cooke (1953) and Hopson (1964).

URBANA FORMATION

Jonas and Stose (1938a; 1938b) and Stose and Stose (1946) included the Urbana in their Precambrian (?) volcanic series as a probable pyroclastic facies of the underlying metabasalt, because they believed it contained tuffaceous material and thin layers of metabasalt. Scotford (1951) correlated the unit with the lithologically similar Early Cambrian Harpers Phyllite, because he equated the underlying Sugarloaf Mountain Quartzite with the Weverton Formation of Early Cambrian age and interpreted the structure of Sugarloaf Mountain as an anticline. This stratigraphic relationship was adopted by Cloos and Cooke (1953), Hopson (1964), and subsequently by most workers. However, Fisher (*in* Higgins, 1987) gave the age of the Urbana as ranging from Early to Middle Cambrian.

ARABY FORMATION

The siltstones, shales, and interbedded argillaceous quartzites of the Araby Formation lie east of the thick, white, quartzitic sandstones of the Antietam Formation in the Blue Ridge. In the western Blue Ridge Province of Maryland, the Antietam conformably overlies the Harpers with a gradational contact (Southworth and Brezinski, 1996). In central Virginia, Schwab (1971; 1972) describes the unit as fingering out to the east into the Harpers facies. Reinhardt (1974) interpreted the Araby as a probable distal tongue of the Antietam Formation.

An Early Cambrian age for the Antietam in Maryland was determined by Stose and Stose (1946) from the presence of *Scolithus* tubes and trilobite fragments. The outcrops in the Frederick Valley from which the Stose's specimens were collected were identified by Reinhardt (1974) as Araby Formation. However, it is possible that some of these fossiliferous rocks were not Araby, but instead were dark shales of the overlying Cash Smith Formation which contains specimens of the Early Cambrian *Salterella sp.* and *Olenellus getzi* (Edwards, 1988).

The stratigraphic relationship and relative ages of the Araby and Ijamsville Formations is uncertain as the identification of rocks within the Westminster terrane as Araby is open to question.

IJAMSVILLE FORMATION

The Ijamsville was included in the Glenarm Series of Precambrian (?) age by Jonas and Stose (1938a; 1938b) and by Stose and Stose (1946) because they considered it to be, in part, correlative with the albite-chlorite facies of the Wissahickon

Formation. Fisher (1978), and Fisher and others (1979) also correlated the Ijamsville with the albite-chlorite, or western, facies of the Wissahickon Formation but assigned it an age range from Early Cambrian to Early Ordovician.

In the western part of the Blue Ridge Province and in the Appalachian Province, the Early Cambrian Waynesboro Formation is characterized by the presence of red shale and sandstone (Brezinski, 1992). However, these strata are calcareous, and limestone and dolomite also make up a considerable percentage of the unit.

East of the Blue Ridge, red-colored strata equivalent to the Waynesboro are not present in the Early Paleozoic rocks of the Frederick Valley. Reinhardt (1974) suggested that the Araby Formation may be equivalent to the Waynesboro, and that offshore from the site of Araby deposition the Ijamsville was deposited in the deep marginal basin at the base of the continental shelf. This would give an age of Early Cambrian for the Ijamsville. In the Westminster terrane, no carbonate rocks occur with the red-colored phyllites of the Ijamsville Formation.

MARBURG FORMATION

Jonas and Stose (1938a; 1938b) placed the Marburg in the Precambrian and considered it to be equivalent in part to the Urbana and Ijamsville Formations, as well as to the albite-chlorite facies of the Wissahickon Formation. Edwards (1984; 1986) estimated the Marburg to be possibly as young as Early Ordovician, because he regarded the Silver Run Limestone, possibly of early Ordovician age, to be a member of the Marburg. I now agree that the Silver Run is a separate formation. Age estimates of the unit range from Late Cambrian to earliest Ordovician (see below). The Marburg, which is overlain by the Silver Run, probably ranges in age from Middle to Late Cambrian.

SILVER RUN LIMESTONE

Jonas and Stose (1938a; 1938b) and Stose and Stose (1946) interpreted the Silver Run Limestone to lie stratigraphically beneath their Precambrian (?) western Piedmont volcanic series, and considered the Silver Run and Wakefield Marble to be equivalent because in the area between Union Bridge and New Windsor the two units appeared to grade together. Fisher (1978) placed the Silver Run beneath his Ijamsville Phyllite and estimated its age to be Early Paleozoic (?). He later revised the age of the unit to Late Cambrian (Fisher, *in* Higgins, 1987).

The Silver Run is very similar to lithologies in the Frederick Formation in Maryland (Reinhardt, 1976) and the Conestoga Formation in the Piedmont of southeastern Pennsylvania (Fisher, 1978). In Maryland, the Lower Paleozoic carbonate shelf of the Laurentian continent prograded eastward with time over the non-carbonate silts and muds of the clastic basin to the east (Reinhardt, 1974; 1976; Taylor and others, 1996). The shaly, deep-water slope limestones of the Upper Cambrian Frederick Formation (Taylor and others, 1996) overlap the Araby on the east side of the Frederick Valley Synclinorium (Reinhardt, 1974; 1976). By the Early Ordovician, the carbonate shelf, as represented by the Grove Limestone, was established in the Frederick Valley (Reinhardt, 1974; 1976; Taylor and others, 1996). Tongues of carbonate sediment were transported down the slope and, as the Silver Run Limestone, were prograded upon the silt/ mud protolith of the Ijamsville Formation in the marine basin (Reinhardt, 1974; 1976). Reinhardt's definition of the Ijamsville includes the lithology I have called Marburg.

Fossils recovered from the Frederick Formation indicate that the age of the unit is Late Cambrian (Jonas and Stose, 1936; Stose and Stose, 1946; Rasetti, 1959; 1961; Reinhardt, 1974; Taylor and others, 1996), possibly extending into the earliest Ordovician (Taylor and others, 1996). The Grove Formation has yielded fossils that indicate an age range from Late Cambrian into the Early Ordovician (Taylor and others, 1996).

In Pennsylvania, the Conestoga Formation has been assigned ages that range from Middle Cambrian to Early Ordovician, based on tentative identification of fossils near York in York County and from the eastern Chester Valley near Norristown in Montgomery County (Stose and Jonas, 1939; Stose and Stose, 1944; Gohn, 1978). The Conestoga represents Upper Cambrian to Lower Ordovician slope and basinal carbonate rocks and overlies Lower to Middle Cambrian slope to platform deposits (Gohn, 1978).

No fossils have been found in the Silver Run in Maryland. Examination of rock samples for conodonts by A.G. Harris and J.E. Repetski of the U.S.

Geological Survey (personal communication, 1987) also failed to provide any fossil evidence.

GILLIS FORMATION

The Gillis Formation is an assemblage of undifferentiated phyllitic rocks considered to be the eastern equivalent of the Urbana, Ijamsville, and Marburg Formations. Therefore, the Gillis would encompass the same age range of Early to Late Cambrian as do those units, and may include rocks as young as Early Ordovician.

PRETTYBOY SCHIST

The Prettyboy Schist cannot be correlated with formations in the eastern Piedmont as it is bounded to the east by the Pleasant Grove shear zone. To the west, Muller (1991; 1994) indicated that the Prettyboy Schist was overlain by the Gillis Formation. I have proposed that the Gillis ranges in age from Early to Late Cambrian, and possibly into the Ordovician (Edwards, 1996). This would give the age of the older Prettyboy as probable Early Cambrian.

STRUCTURE

INTRODUCTION

Major structural features that I have recognized in the Westminster terrane are the Sugarloaf Mountain and Deep Run anticlinoria, the Deep Run, Cranberry, Avondale, Winfield, and Hyattstown faults, and the Linganore thrust fault (Figure 7). Normal faults associated with the Mesozoic age Gettysburg and Culpeper basins extend into the Westminster terrane. The Martic fault forms the western border of the terrane and the Pleasant Grove shear zone is the eastern boundary.

Early descriptions of the geology of the Maryland Piedmont depicted it as a large synclinorium in which the formations in the eastern and western limbs were deemed more or less equivalent. However, the eastern units were more highly deformed and metamorphosed owing to the presence of many deep-seated intrusive igneous bodies (Mathews, 1904; 1905; and Clark and Mathews, 1906). The structure was defined by a broad cleavage fan where the cleavage on the eastern limb dipped to the west, steepened to vertical across the axis which lay along the trend of Dug Hill Ridge and Parrs Ridge, and became east-dipping on the western limb (Keyes, 1891). Other than the Martic overthrust (Jonas, 1924; 1927), the existence of large, transported rock masses or large overthrust faults within the Piedmont was not recognized nor generally accepted before the work of Hopson (1964) and Crowley (1976).

Evidence for a thrust fault in the western Piedmont between Sugarloaf Mountain and the Frederick Valley was reported by Keyes (1891) and Williams (1892). Mathews and Grasty (1909) mentioned the possible presence of unrecognized faults within the western Piedmont, and suggested that the metavolcanics had been faulted over the marble. In Carroll County, Jonas (1928) placed the Martic overthrust between the metavolcanic/marble association and the Wissahickon albite schist, but Jonas and Stose (1938a) moved the Martic westward to the edge of the Frederick Valley, approximately where Keyes (1891) and Williams (1892) had indicated a fault. Cloos (1941) did not recognize any large over-thrusts in the western Piedmont and did not consider them essential to his interpretation of the geology.

However, he did acknowledge that small, local thrusts may be necessary to explain the relationship between the Sugarloaf Mountain anticlinorium and the phyllites to the east (Cloos, 1964). Fisher (1978) mapped no major thrusts in New Windsor area, but placed the metavolcanics and marble conformably upon the phyllites. Fisher and others (1979) continued to adhere to the concept of a major regional Piedmont synclinorium, and indicated no overthrust faults in the western Piedmont. Southworth (1996) interpreted the Martic fault to be more extensive in Maryland than previously recognized.

In the western part of the Westminster terrane, the predominant direction of dip of the foliation is eastward. However, east of a line between Mt. Airy and the Pennsylvania State Line at Maryland Route 30, running parallel to the Frederick-Carroll County line and including the crest of the Deep Run anticlinorium, the foliation becomes overprinted by a prominent spaced cleavage. Adjacent to this line, this cleavage dips steeply to the east, but eastward across the terrane the cleavage changes from vertical to steeply west-dipping. This change from east-dipping foliation to west-dipping cleavage corresponds to where Stose and Stose (1946) show a change in the dip of axial planes of minor folds from east to west across the Piedmont, and also to where Fisher (1978) shows the Marston generation of steep cleavage across the New Windsor Quadrangle. Strike of the steep-dipping spaced cleavage is approximately parallel to the strike of high-angle reverse faults that traverse the area, as well as to the Pleasant Grove shear zone.

SUGARLOAF MOUNTAIN ANTICLINORIUM

Sugarloaf Mountain was identified as an anticlinal structure by Scotford (1951). However, Thomas (1952) named it the Sugarloaf Mountain anticlinorium because the outcrop pattern of the Sugarloaf Mountain Quartzite exhibited subsidiary anticlines and synclines. The fold extends for a distance of 25 miles from western Montgomery County northward through eastern Frederick County (Figure 7). The average width of the structure ranges between 2 and 3 miles, but reaches a maximum of 5 miles across Sugarloaf Mountain itself. The oldest unit exposed is the Sugarloaf Mountain Quartzite, which forms an elongate outcrop area at the apex of the fold. The north-plunging nose of the outcrop of Sugarloaf Mountain Quartzite lies just south of Bennett Creek, but the south-plunging nose is buried by Mesozoic rocks of the Culpeper Basin.

The Urbana Formation surrounds the Sugarloaf Mountain Quartzite and occupies the axis of the structure north of Sugarloaf Mountain to where it passes beneath the Gettysburg Basin. The Ijamsville Formation lies outboard of the Urbana on both the flanks of the anticlinorium. A stratigraphic interpretation of this map pattern has the Sugarloaf Mountain Quartzite overlain by the Urbana, which in turn is overlain by the Ijamsville.

The Sugarloaf Mountain anticlinorium is overturned to the northwest (Tucker, 1983). Foliation in formations on the western flank dips more steeply to the east than in those on the eastern flank, an indication that the formation of the anticlinorium was coeval with the regional deformation.

DEEP RUN ANTICLINORIUM

The Deep Run anticlinorium (Figure 7), misnamed Dug Hill Anticline by Edwards (1993b), lies northeast of Union Mills in Carroll County. It was originally mapped as a syncline by Jonas (1928), but the Urbana Formation is exposed at the core and the southeast flank is successively overlain by a narrow band of Ijamsville and a wide expanse of Marburg. The northwest flank is cut off by the Deep Run fault. The width of the structure ranges up to three miles, and it is exposed for about 6 miles along strike before it passes north into Pennsylvania. At Union Mills the anticlinorium plunges to the southwest and disappears.

The Deep Run anticlinorium appears to be an upright fold. Foliation on the west flank of the fold dips steeply east. The crest is defined by the most northwesterly of three subsidiary isoclinal anticlines outlined by a coarse-grained quartzite layer in the Urbana. The axial planes of these folds are parallel to the spaced cleavage, which here dips steeply to the west.

NORMAL FAULTS

Normal faults in the Westminster terrane almost certainly are due to the Mesozoic tensional deformation that produced the Gettysburg and Culpeper Basins. Post-depositional normal faults south of Keymar and north and east of Mayberry in Carroll County outline the Trevanion sub-basin of the Gettysburg Basin, as well as the Tyrone Basin, a small outlier of the Gettysburg Basin lying within the Westminster terrane one mile east of Mayberry. Northwest of Uniontown, an offset in the unconformity at the base of the Mesozoic rocks (Edwards, 1986) indicates that the Hyattstown fault may have been reactivated by the Mesozoic deformation to produce small, post-depositional displacements. Other small offsets along this unconformity lie between Ladiesburg and the Pennsylvania State line (Edwards, 1986; 1988; Edwards and Glaser, 1993). The locations of these normal faults may have been influenced by the preexisting, late Paleozoic cleavage and faults.

REVERSE FAULTS

Deep Run Fault

The Deep Run fault (Figure 7) is a west-verging, high-angle reverse or thrust fault that extends from the Pennsylvania State line southwest along Deep Run to the valley of Big Pipe Creek at Union Mills, Carroll County. The fault cuts out the northwest flank of the Deep Run anticlinorium and

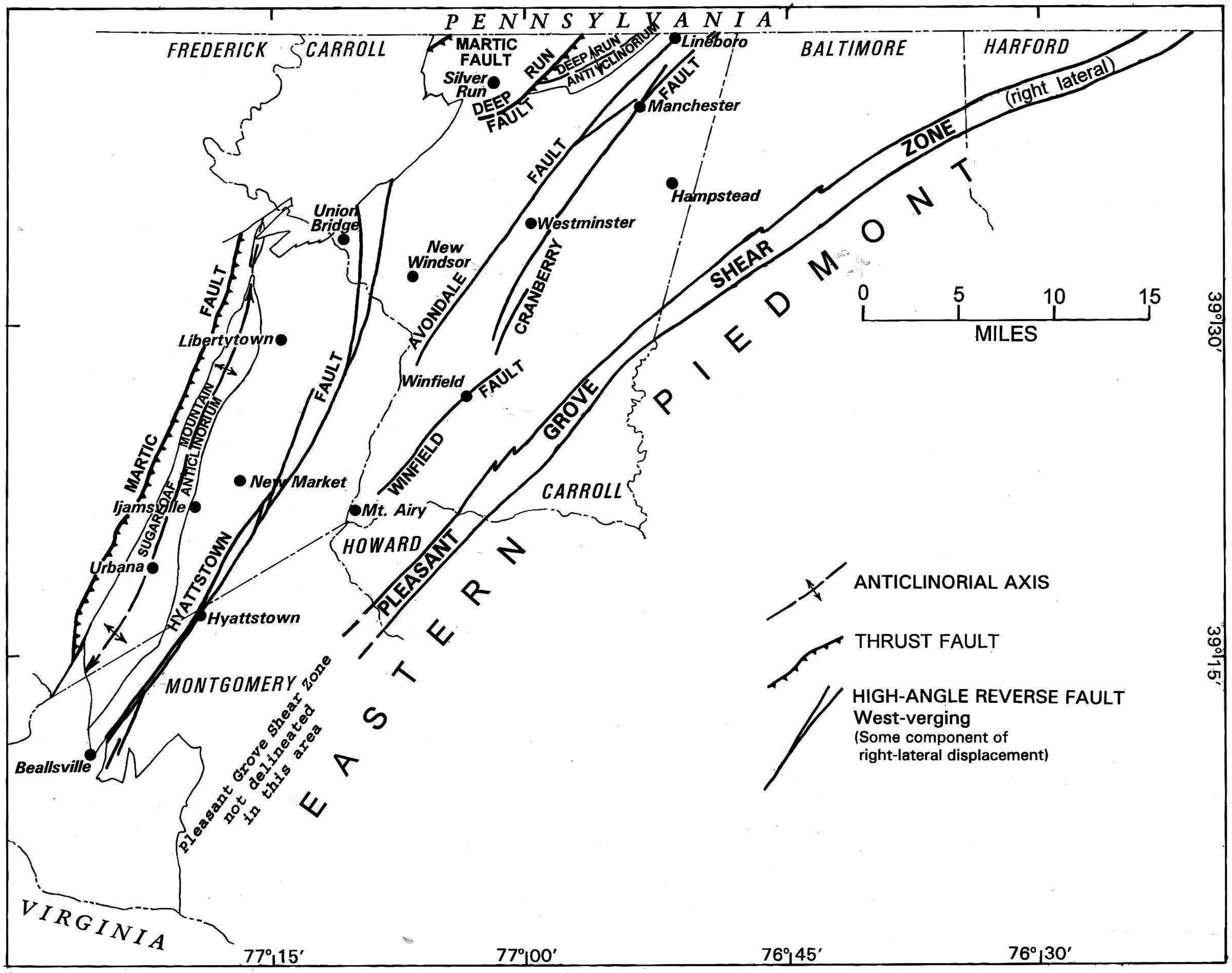


FIGURE 7.– Major pre-Mesozoic structural elements in the Westminster terrane (excluding the Linganore Nappe). (Adapted from Edwards, 1986, 1988, 1993a, 1993b, 1993c, 1993d, 1994, 1996, and unpublished data; Fisher, 1978; Jonas and Stose, 1938a;

places the Urbana Formation on the east in contact with the Marburg Formation on the west. Jonas (1928) mapped the Martic overthrust at this location, but showed Loudoun Schist thrust over the Harpers Formation.

The Deep Run fault strikes approximately 45 degrees to the northeast and dips between 60 and 80 degrees southeast, parallel to foliation in the surrounding rocks. Southwest of Union Mills it passes into the Marburg Formation and cannot be traced farther. Sheared and phyllonitized phyllite is exposed along Geeting Road north of the intersection with Deep Run Road. Movement on the fault appears to have occurred after formation of the Deep Run anticlinorium.

Cranberry Fault System

A series of straight, nearly vertical faults crosses the western Piedmont from the Pennsylvania State line near Lineboro in Carroll County southwest to Beallsville in Montgomery County (Figure 7). These include the Cranberry, Winfield, Avondale, and Hyattstown faults as well as a number of unnamed faults and short fault segments that are parallel to and splay out from the larger, named faults (Edwards, 1993b; 1993c; 1994). In northern Carroll County and western Montgomery County, a pronounced ridge-and-valley topography is associated with these fault zones.

Jonas (1928) mapped northeast striking, nearly vertical normal faults across central Carroll County associated with the belt of metavolcanic rocks and marble. Edwards (1993b; 1993c; 1994) initially interpreted these faults as east-verging, high-angle reverse faults, or backthrusts. However, I now consider them to be west-verging, high-angle reverse faults. Each fault is actually a narrow band, or zone, of closely spaced, parallel or *en echelon* faults. In places, some of the faults show a component of strike slip movement. North of latitude 39°37′30″, the faults strike about N45°E, but to the south the strike changes to N30°E. Dips range from nearly vertical to steeply southeast. Movement postdates the emplacement and folding of the Linganore nappe as well as the regional metamorphism, but is older than Mesozoic, as the faults are covered unconformably by rocks of Mesozoic age in the Gettysburg and Culpeper Basins.

Cranberry Fault: The Cranberry fault (Figure 7) was named for Cranberry Station on Maryland Route 852 (Old Manchester Road) and the Maryland Midland Railroad, about one mile northeast of Westminster. It enters the state from Pennsylvania and extends to the southwest in a nearly straight line from just east of Lineboro to Nicodemus Road south of Westminster. This fault forms the eastern boundary to the outcrop area of Sams Creek Formation in northeast Carroll County. Other than along short fault segments that lie between the Cranberry and Winfield Faults south of Fenby, metavolcanic rocks do not occur farther east in the Westminster terrane.

Winfield Fault: The Winfield fault (Figure 7) is probably an *en echelon* continuation of the Cranberry Fault, offset to the southeast by about 1 mile. The location of this fault is marked chiefly by an alignment of narrow bodies of coarse-grained diabasic metabasalt and chlorite schist.

Avondale Fault: The Avondale fault (Figure 7) lies west of the Cranberry Fault in Carroll County and is parallel to it. It forms the remarkably straight contact between the Sams Creek and Gillis Formations in this area and is the eastern boundary to the largest areas covered by the Sams Creek and Wakefield Formations in Carroll County.

Hyattstown Fault: The Hyattstown fault (Figure 7) extends from the Gettysburg Basin northwest of Uniontown, Carroll County, south through Frederick and Montgomery Counties to the Culpeper Basin south of Beallsville. Interleaved phyllitic metabasalt and sheared marble lie along the fault both north and south of McKinstrys Mill. Some dolomitic layers in the marble show boudinage with the axis of the boudins plunging down dip, which suggests lateral or strike-slip displacement along the fault (Figure 8). In a few places, minor folds in sheared metabasalt suggest some movement was right-lateral. South of Maryland Highway 26, the Hyattstown fault forms the eastern limit of metavolcanic rocks in the southern part of the Westminster terrane, as the Cranberry fault does in the north. The fault trace is marked by narrow, elongate horses of metabasalt and sheared chlorite phyllite of the Sams Creek Formation.

Throughout most of its length the strike of the Hyattstown fault is N30°E, but north of Unionville the trend changes to more north-south, and the fault displacement diminishes. This displacement appears to have been taken up by the Avondale, Winfield, and Cranberry faults which lie northeast of the Hyattstown fault.

OVERTHRUST FAULTS

Martic Fault

The first reference to a great overthrust fault in the western Piedmont that separated crystalline rocks from unmetamorphosed Paleozoic rocks was by Jonas (1924) in a discussion of the geology of western Carroll County, Maryland. However, the name, Martic overthrust, was first used in the western Piedmont of northern Virginia for the contact between crystalline rocks of presumed Precambrian age and the Everona limestone, considered to be equivalent to the Lower Paleozoic Frederick Formation of Maryland (Jonas, 1927). Knopf and Jonas (1929a) formally applied the name, Martic fault, or Martic overthrust, to the boundary between Precambrian crystalline rocks and unmetamorphosed Paleozoic rocks in Lancaster County, Pennsylvania.

As depicted on the Geologic Map of Carroll County (Jonas, 1928), the Martic overthrust west of Westminster placed Precambrian metavolcanic rocks, Cockeysville Marble, and Wissahickon albite-chlorite schist upon Cambrian Harpers Formation and Ordovician Conestoga Limestone. However, north of Westminster on this map the fault was drawn between the Loudoun and Harpers Formations. Later, Jonas and Stose (1938a) positioned the Martic Fault farther to the west as the boundary between the western Piedmont metasedimentary rocks and the non-metamorphosed rocks of the Frederick Valley (Figure 7). This contact had earlier been mentioned by Keyes (1891) and Williams (1892) as the site of a thrust fault. Southworth (1996) also placed the Martic fault at this location, but he also mapped two windows through the overthrust sheet east of the fault trace. One window exposed Urbana Formation and the underlying Sugarloaf Mountain Quartzite of the Sugarloaf Mountain anticlinorium as the footwall. The other, smaller window lay across Bush Creek west of Monrovia and showed Urbana in the footwall. In my mapping in the area, these windows were not recognized as my interpretation of the Sugarloaf Mountain structure is stratigraphic, with the Ijamsville younger than the Urbana and overlying it.

The trace of the Martic fault defines the western limit of the Westminster terrane and places the Ijamsville Formation in contact with the Araby Formation of the Frederick Valley Synclinorium, but in a few places the Ijamsville is in contact with limestone of the Frederick Formation. The attitude of the fault surface parallels the strike and dip of foliation in both the footwall and hanging wall rocks. Deformation appears to have been ductile as the rock units on either side of the fault have not been brecciated.

Linganore Overthrust and Linganore Nappe

West of Westminster on the Geologic Map of Carroll County, Jonas (1928) shows the contact between the metavolcanic rocks and marble with the metasedimentary rocks as an irregular, curvilinear line which she called the Martic overthrust. My mapping has shown that throughout the western part of the Westminster terrane in Carroll and Frederick Counties, contacts between formations in the metasedimentary rocks as well as individual layers terminate against the metavolcanic rocks and marble (Edwards, 1986; 1994; and unpublished data, Walkersville and Urbana Quadrangles). I have interpreted the Sams Creek Formation and Wakefield Marble as not in stratigraphic conformity with the surrounding metasedimentary rock units, but separated from them by the Linganore overthrust (Edwards, 1984; 1986). The hanging block is the Linganore nappe (Edwards, 1986) and consists of the Sams Creek Formation and Wakefield Marble. The footwall is made up of the metasedimentary rock units. Below the sole thrust, the phyllitic rocks have been intensely sheared and in places exhibit s-c structure (Figure 9). Locally, rocks on both sides of the fault have been impregnated with vein quartz.

The following examples illustrate relationships between the metavolcanic rocks and the metasedimentary rocks at specific localities in Carroll and Frederick Counties:

Town Branch area, Walkersville Quadrangle (Figure 10):

About two miles south of Libertytown, Frederick County, an irregularly shaped body of the Sams Creek Formation is surrounded by Ijamsville

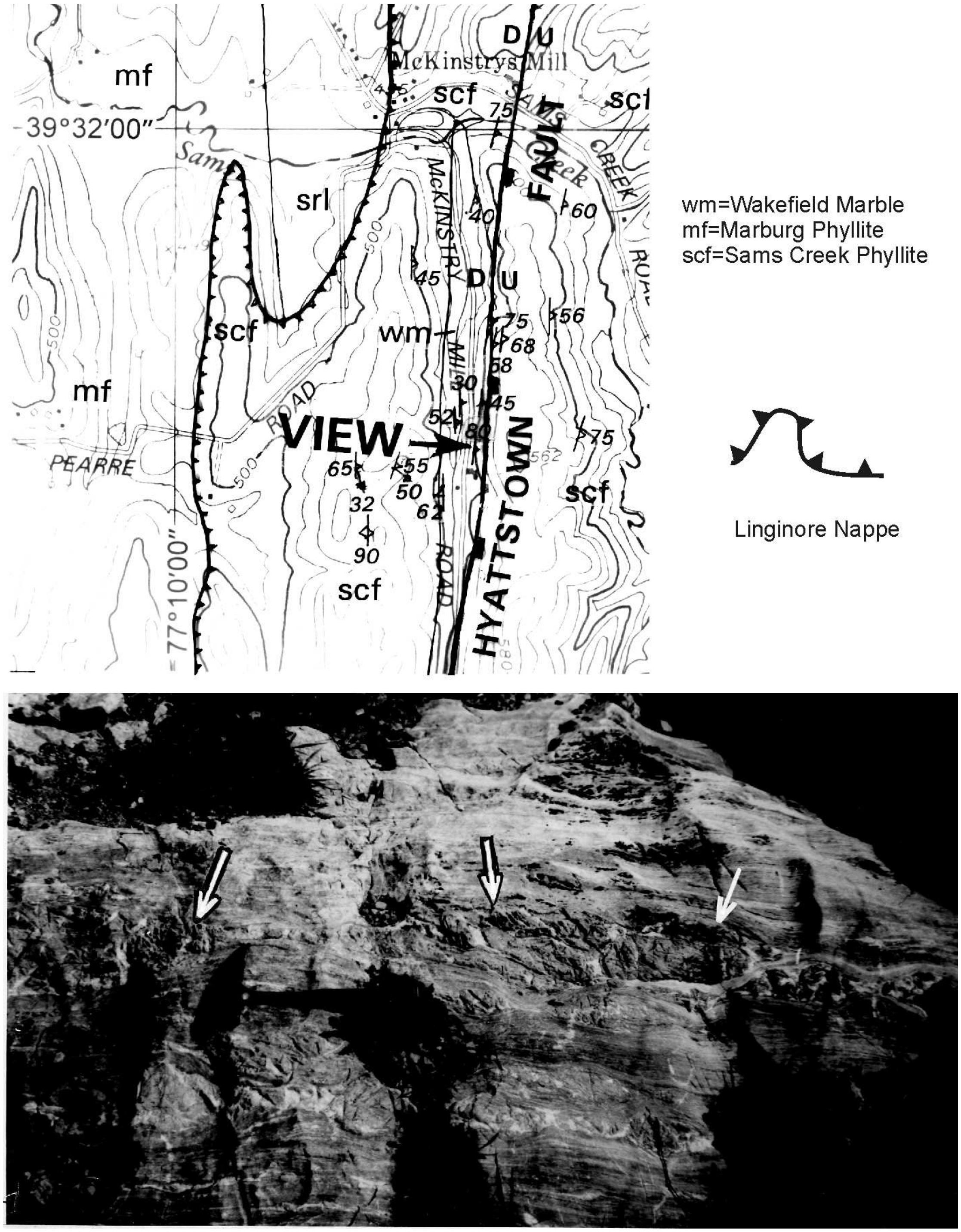


FIGURE 8.– Wakefield Marble outcrop along Hyattstown Fault, view to east. McKinstry Mill Road, Frederick County, 0.7 mile south of McKinstrys Mill, Carroll County (Union Bridge Quadrangle, Edwards, 1986). Arrow points to boudins in layer above pick. Long axes of boudins plunge downdip onto outcrop, indicating lateral extension due to strike-slip movement.

Formation at the confluence of Town Branch with Linganore Creek. A quartzite bed in the Ijamsville forms the north-south trending ridge along Artie Kemp Road south of Maryland Route 26. As this ridge is traced south toward Linganore Creek, the quartzite curves down the east side of the hill, crosses Town Branch, and terminates against the Sams Creek Formation east of the creek. In a large cliff exposure at the contact, the original granular texture of the quartzite has been destroyed by shear and the rock has been impregnated with vein quartz until it has become dense and porcelain-like. On the hill above this outcrop, the adjacent metabasalt is also strongly sheared and brecciated. The metabasalt is interpreted to be in a klippe lying upon the quartzite. This locality has been selected as the type locality of the Linganore overthrust fault and the Linganore nappe.

Horsehead Rock area, Libertytown and Walkersville Quadrangles (Figure 11):

About 1.5 miles south of Libertytown, a thick quartzite layer in the Marburg Formation forms the prominent hill east of Maryland Route 75. At the intersection of the highway and Arlington Road, this quartzite layer passes southward beneath metabasalt of the Sams Creek Formation and reappears 0.4 mile to the south on the west side of the highway, where small outcrops can be seen both north and south of Artie Kemp Road. The metabasalt is interpreted to be in the hanging wall of the Linganore nappe and has overridden the quartzite layer in the Marburg Formation.

New London area, Libertytown and Walkersville Quadrangles (Figure 12):

The large hill west of Maryland Route 75 at New London is also formed by a thick quartzite layer in the Marburg Formation. This quartzite can be traced to the northeast into a deep re-entrant in the contact with the Sams Creek Formation north of Lime Plant Road, before it is terminates against this contact. At the southern end of the hill, the quartzite layer also terminates against the Sams Creek Formation just east of Maryland Route 75. The Sams Creek is interpreted to be the hanging wall of the Linganore nappe which has overridden the previously folded quartzite layer in the Marburg. On the west side of the hill, a small klippe of Sams Creek Formation lies across the contact of the quartzite with phyllite of the Marburg.

Fahrney Branch area, Urbana Quadrangle (Figure 13):

In the triangular area that lies between Maryland Route 80, Prices Distillery Road, and Fahrney Branch, about 2.5 miles east of Urbana, several quartzite layers in the Marburg Formation can be traced to where they terminate at the contact with the Sams Creek Formation. These are interpreted as folded and exposed layers of quartzite in the Marburg Formation which have been subsequently overridden by the Linganore nappe. This relationship is well exposed in the valley wall along the south side of Fahrney Branch just west of where the Potomac Edison Transmission Company power line crosses Prices Distillery Road.

Greenwood Church Road area, New Windsor and Union Bridge Quadrangles (Figure 14):

Just west of the intersection of Greenwood Church Road with Old New Windsor Road, about 1.5 miles south of New Windsor, Carroll County, the contact between the Sams Creek and Marburg Formations makes a tight, U-shaped curve open to the north. A thin, south-southwest striking quartzite bed in the Marburg Formation can be traced directly into the Sams Creek/Marburg contact. This area is interpreted as a post-thrust fold of the Linganore Overthrust in which erosion has exposed the metasedimentary rocks of the footwall beneath the metavolcanics of the hanging wall. A small, elongate outcrop of metabasalt within the Marburg is interpreted as a small downfold of the hanging wall that has been preserved as a remnant klippe.

Mapleville Road area, Libertytown Quadrangle (Figure 15):

On Maryland Route 26, one half mile west of Mapleville Road, a small, north-south trending anticline of Ijamsville Formation surrounded by Marburg is cut off to the north by the Sams Creek Formation. Just south of Maryland Route 26 this band of Ijamsville is overlain by a thin belt of metavolcanic rocks projecting eastward from a small, irregularly shaped body of the Sams Creek. The metasedimentary rocks at this locality are interpreted as footwall rocks exposed in a window through the Linganore nappe, which also contains a small klippe of the nappe rocks.

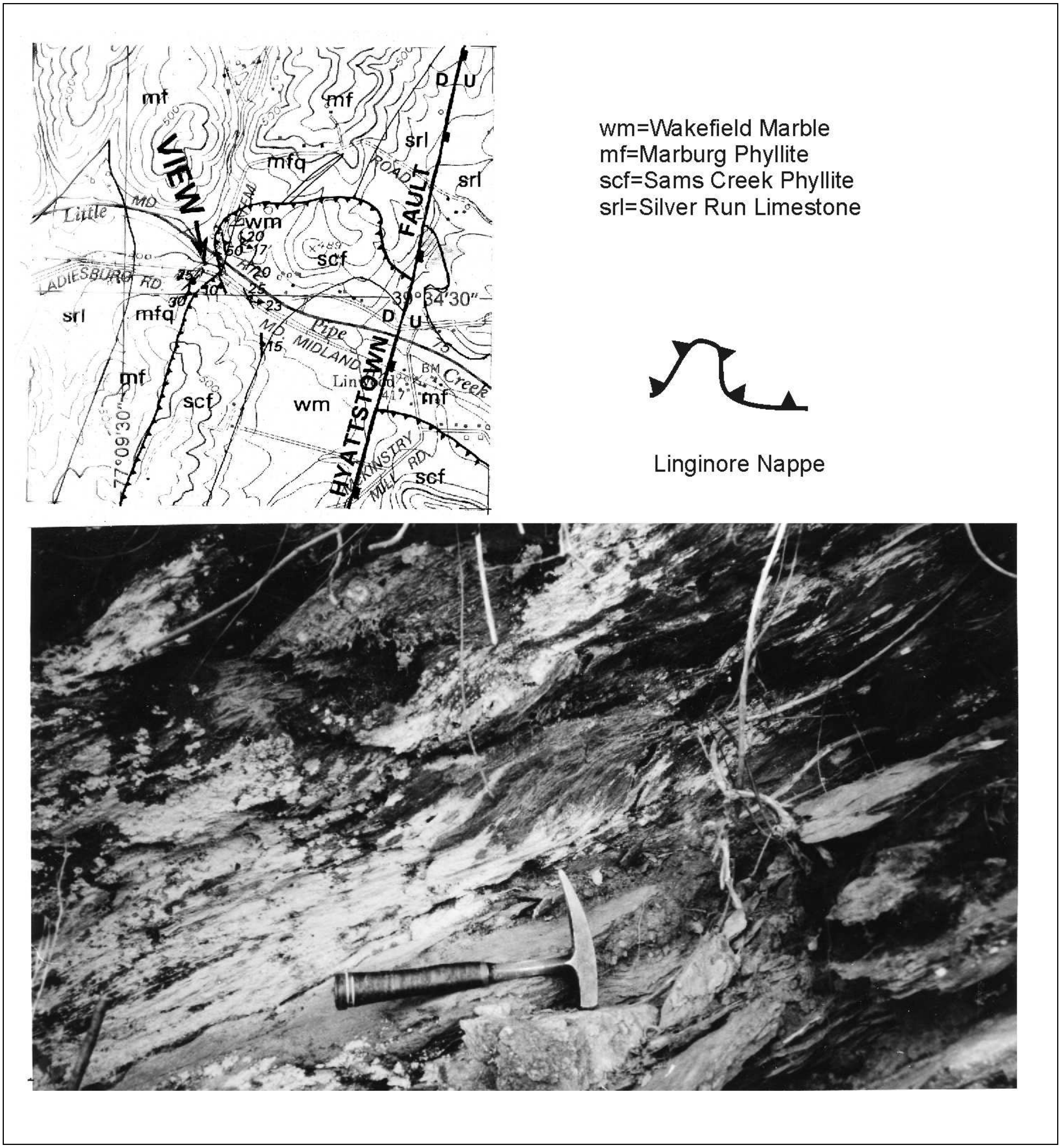


Figure 9– Phyllite in Marburg Formation exhibiting s-c structure due to overriding by Linganore nappe; view to southeast. Outcrop along Maryland Midland Railway 0.05 mile east of Ladiesburg Road and 0.6 mile west of Linwood, Carroll County (Union Bridge Quadrangle, Edwards, 1986). Sole of nappe as projected from outcrop of Sams Creek Formation to the east is about 50 feet above this outcrop.

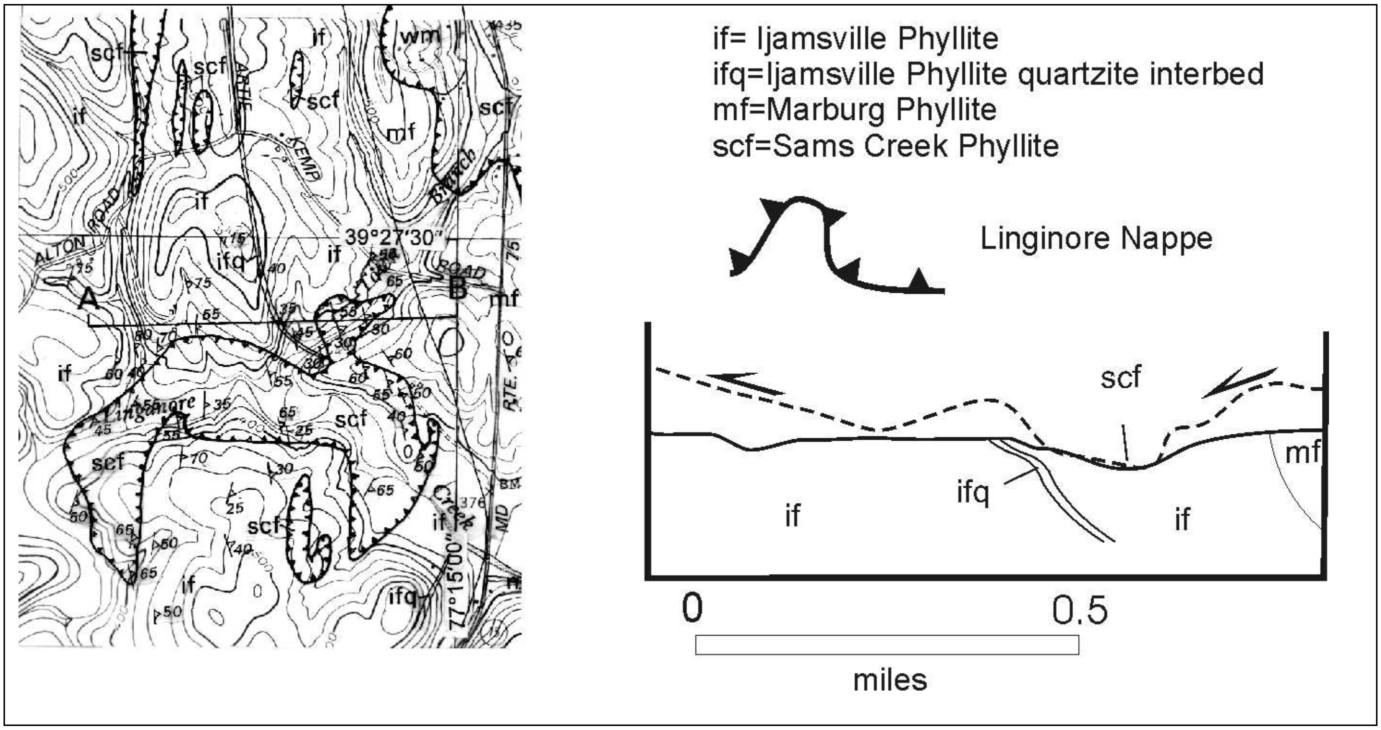


FIGURE 10.– Detailed geology of the Linganore nappe in the Town Branch area, Frederick County, Walkersville Quadrangle, (Edwards, unpublished data).

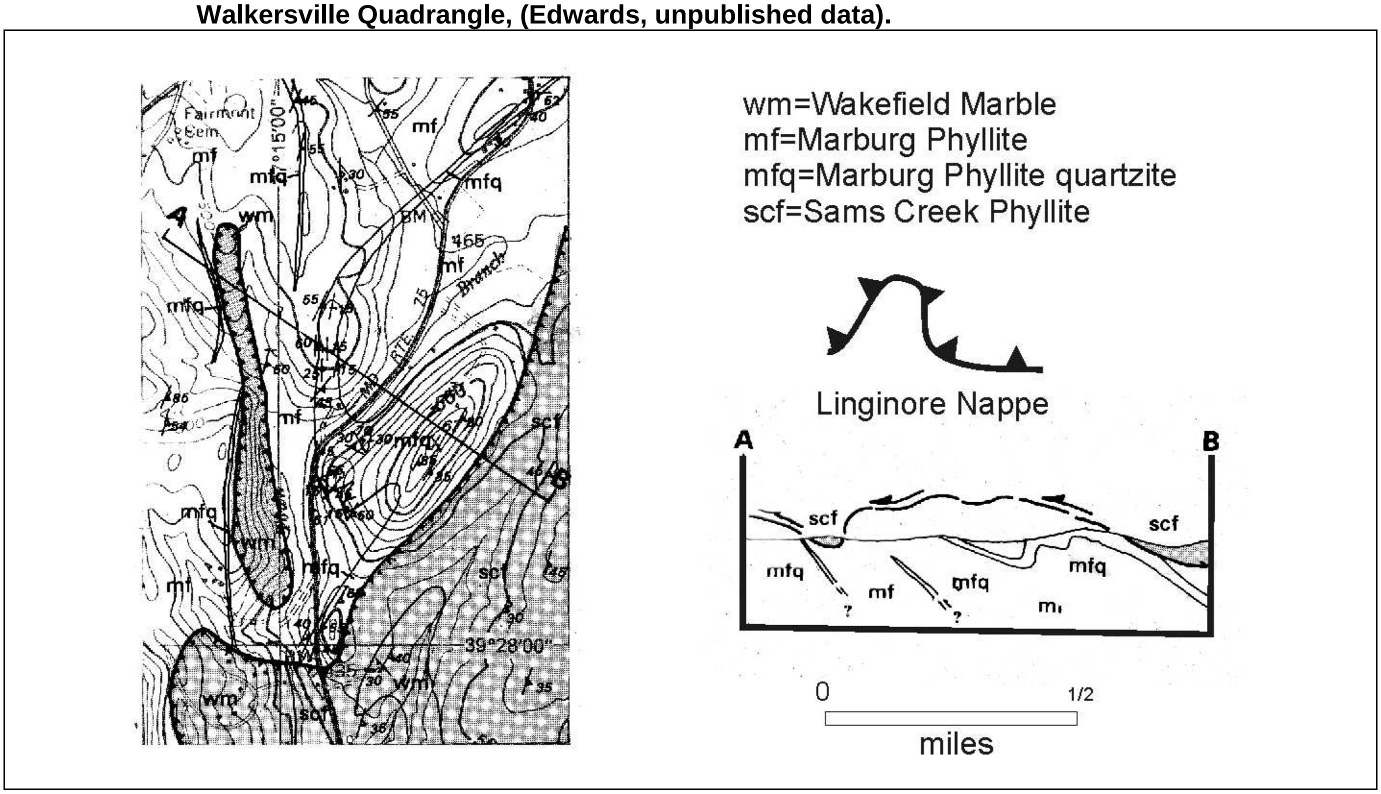


FIGURE 11.– Detailed geology of the Linganore nappe in the Horsehead Rock area south of Libertyown, Frederick County, (Libertytown Quadrangle, Edwards, 1994; and Walkersville Quadrangle, Edwards, unpub. data).

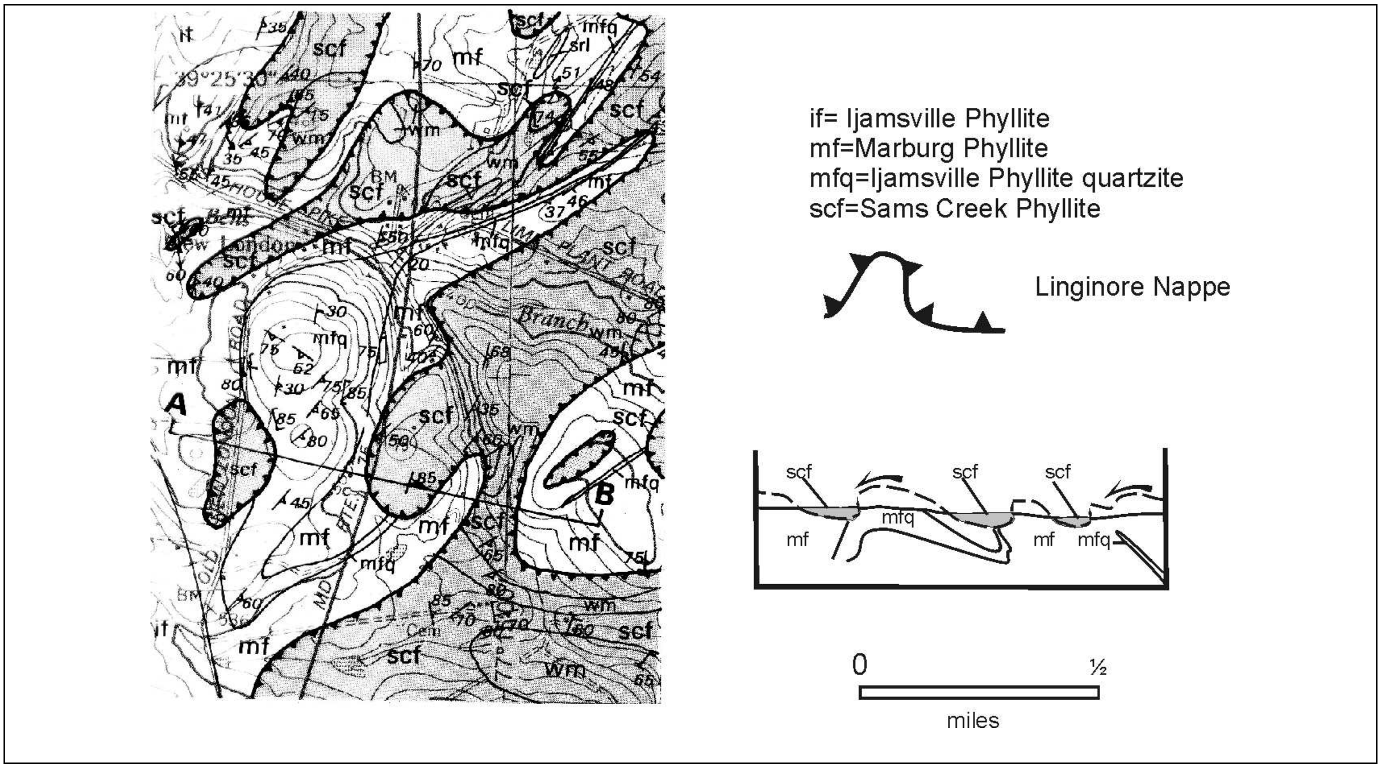


FIGURE 12.– Detailed geology of the Linganore nappe in the New London area, Frederick County; Libertytown Quadrangle, (Edwards, 1994; and Walkersville Quadrangle, Edwards, unpub. data).

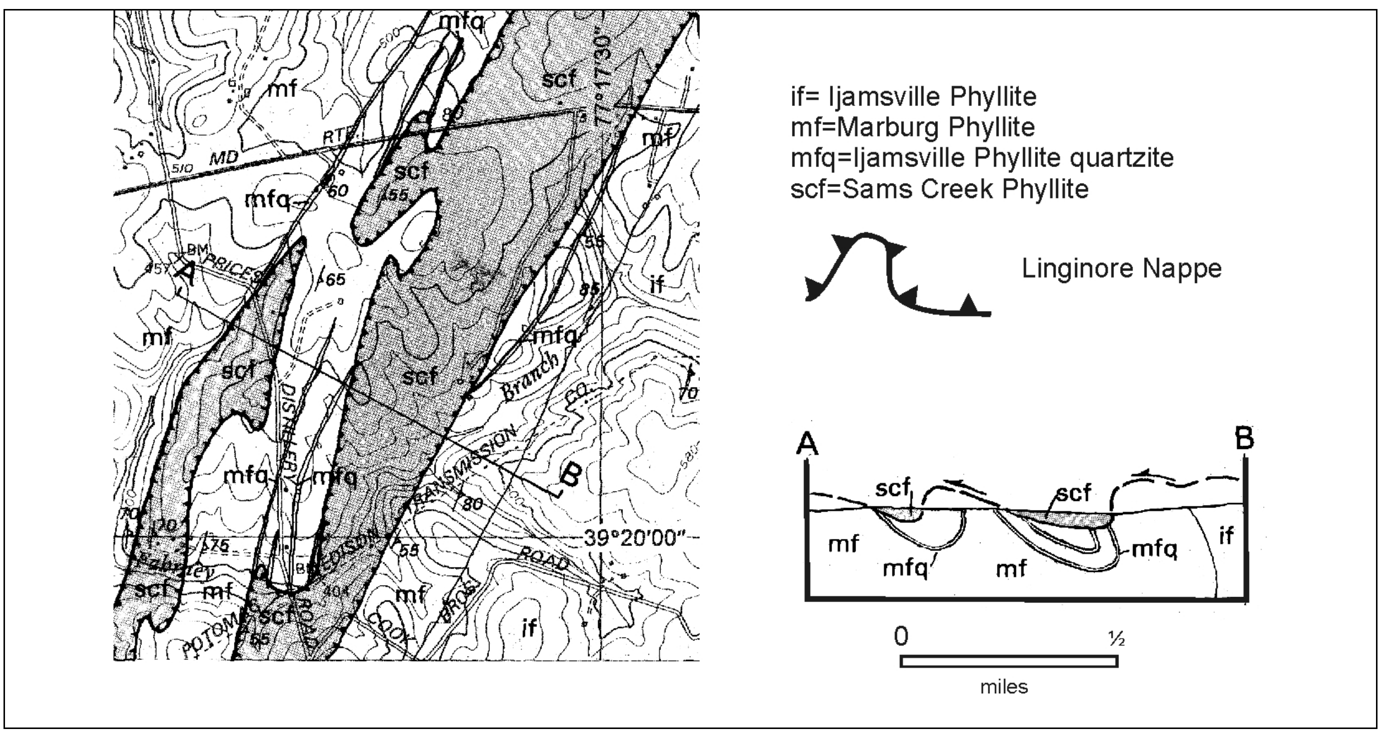


Figure 13.– Detailed geology of the Linganore nappe in the Farhney Branch area, south of Maryland Route 80, Frederick County; Urbana Quadrangle, (Edwards, unpub. data).

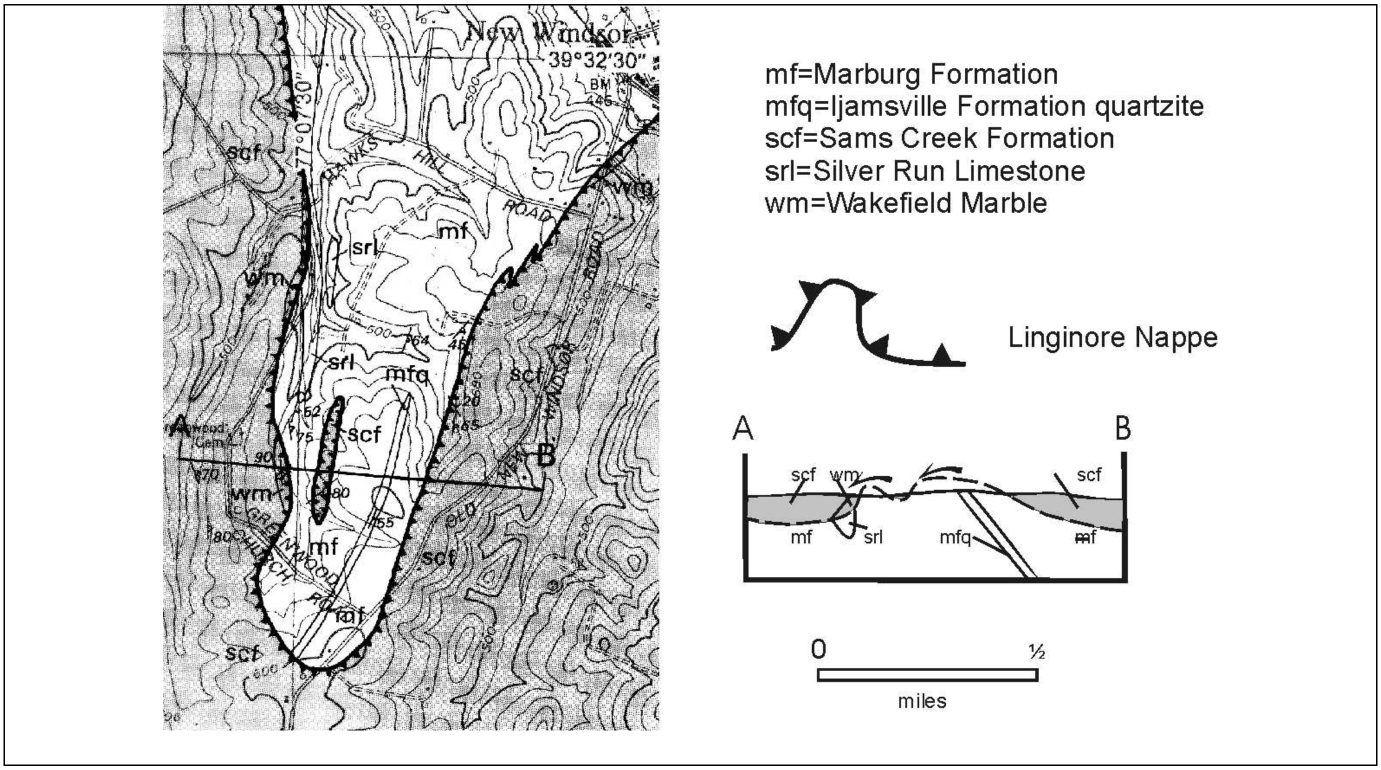


Figure 14.– Detailed geology of the Linganore nappe in the Greenwood Church Road area, Carroll County, Union Bridge Quadrangle, (Edwards, 1986; and adapted from New Windsor Quadrangle, Fisher, 1978).

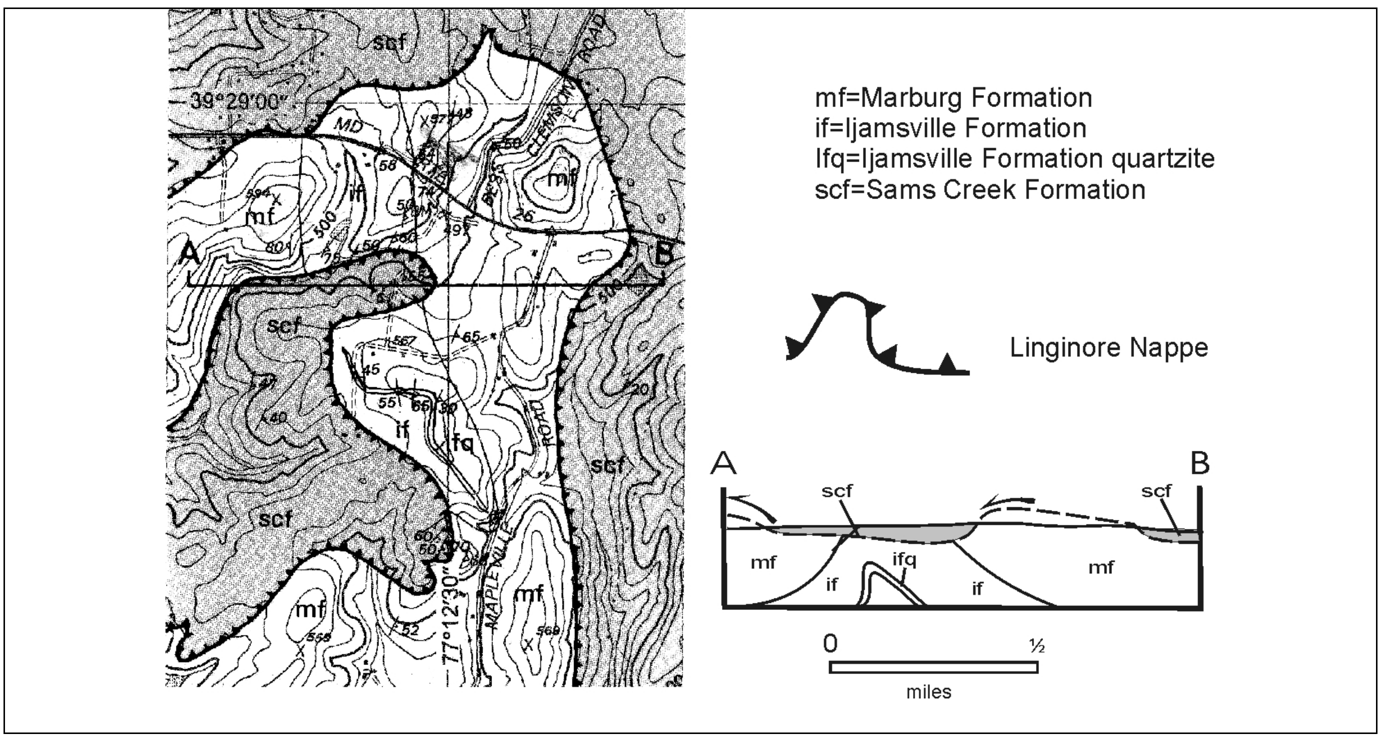


Figure 15.– Detailed geology of the Linganore nappe in the Mapleville Road area, Carroll County; Libertytown Quadrangle, (Edwards, 1994).

McKinstrys Mill area, Union Bridge Quadrangle (Figure 16):

South of McKinstrys Mill on the Carroll/ Frederick County line, the Silver Run Limestone and Marburg Formation strike directly into the Sams Creek Formation at Pearre Road. The metabasalt is interpreted as the hanging wall of the Linganore nappe which overlies the contact between the Silver Run and Marburg Formations. North of McKinstrys Mill, in the area bounded by McKinstrys Mill Road, Marble Quarry Road, and Priestland Road, a small klippe of Wakefield Marble lies across the contact between the Marburg and the Silver Run Limestone.

Ladiesburg Road area, Union Bridge Quadrangle (Figure 17):

Just east of the horseshoe bend in Ladiesburg Road 0.75 mile east of Union Bridge in Carroll County, Wakefield Marble is exposed below the brick house on the small knoll. Dark blue-gray, thinly laminated Silver Run Limestone surrounds this exposure. The hill west of the small stream is underlain by the Marburg Formation. This outcrop of Wakefield Marble is interpreted as a small klippe of the Linganore nappe lying on Silver Run Limestone.

The field relations shown at the above localities are the basis for my interpretation that the Sams Creek Formation and Wakefield Marble have been thrust upon the metasedimentary rocks and constitute the Linganore nappe, a major structural feature in the western Piedmont (Figure 4). The youngest rock unit to have been overridden by the nappe is the Silver Run Limestone of probable Cambro-Ordovician age. Therefore, the most likely time of emplacement for the nappe was after the Middle Ordovician, possibly during the Late Ordovician Taconic Orogeny. Metamorphism of the nappe rocks and the underlying metasedimentary rocks appears to have occurred after emplacement of the nappe, probably also during the Taconic Orogeny, as both sequences have been metamorphosed to lower greenschist facies.

The Gillis Formation was envisioned by Edwards (1986) as the off-shelf, eastern equivalent of the continental margin Urbana, Ijamsville, and Marburg Formations, and lay conformably upon the Sams Creek and Wakefield Formations as part of the Linganore nappe. However, as stratigraphic evidence of such a conformable contact is lacking, this contact is now considered to be the Linganore overthrust, with the Sams Creek and Wakefield Formations thrust over the Gillis.

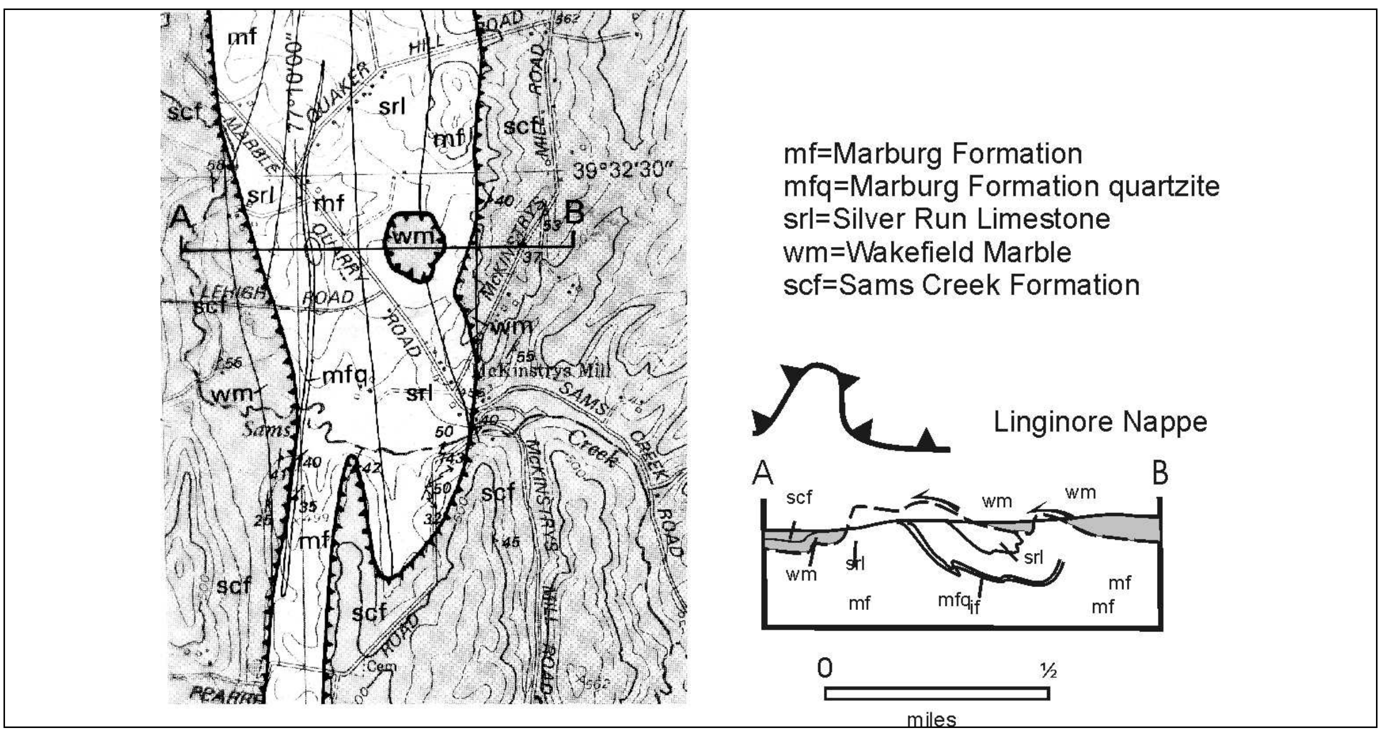


FIGURE 16.– Detailed geology of the Linganore nappe in the McKinstrys Mill Area, Carroll and Frederick Counties; Union Bridge Quadrangle, (Edwards, 1986).

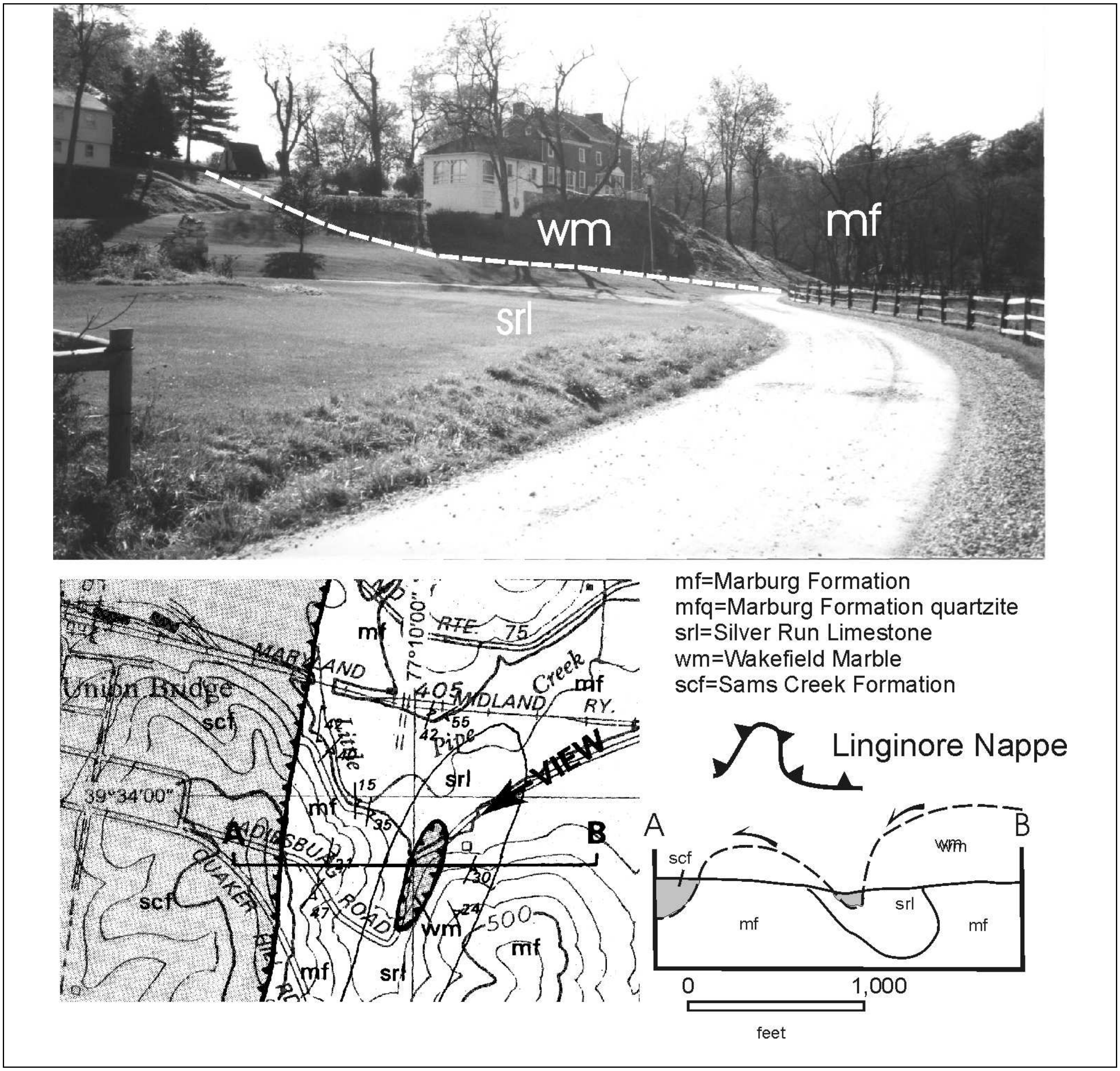


Figure 17.– Ladiesburg Road area, Carroll County, view to southwest. Ladiesburg Road, 0.75 mile west of the intersection with Maryland Route 75 at Linwood, and 0.75 mile east of the intersection with Maryland Route 75 in the center of Union Bridge (Union Bridge Quadrangle, Edwards, 1986). A small klippe of Wakefield Marble exposed below the house on the small knoll is completely surrounded by Silver Run Limestone. Hill in background beyond stream valley is Marburg Formation.

srl: Silver Run Limestone
mf: Marburg Formation

LINGANORE NAPPE (shaded)
scf: Sams Creek Formation
wm: Wakefield Marble

PLEASANT GROVE SHEAR ZONE

The Pleasant Grove shear zone (Figures 4 and 7) is a belt of fine-grained rocks, between 0.5 and 2 miles in width, that crosses the Maryland Piedmont from the Pennsylvania State line west of Cardiff in Harford County at least as far as western Howard County. Rocks within this belt are primarily phyllite, fine-grained graywacke, and quartzite and are distinct from the coarser grained rocks of the Liberty Complex to the east and of the Prettyboy Schist to the west (Muller, 1985). They have not been mapped farther to the south across Montgomery County (P.D. Muller, written communication, 1997). Although the Pleasant Grove shear zone has little to no topographic or physiographic expression, it displays a prominent pattern on aeromagnetic maps of the Piedmont (Fisher and others, 1979).

Crowley (1976) gave the name, Pleasant Grove Formation, to this lithology for exposures near Pleasant Grove Church in west-central Baltimore County. Previously these rocks had been included in the Peters Creek Schist (Knopf and Jonas, 1923) or Peters Creek Formation (Knopf and Jonas, 1929b), and were considered to lie above schists of the Wissahickon Formation along the axis of the central Piedmont syncline. Indications of retrograde metamorphism in the Peters Creek Formation led Knopf and Jonas (1929b) to speculate on the presence of a fault within the unit, although no further evidence was cited.

The Pleasant Grove lithology, as described by Muller (1994), consists primarily of lustrous, medium gray to green-gray, fine-grained chlorite-quartz-muscovite schist or phyllite with lesser amounts of thinly laminated metagraywacke and micaceous quartzite. The phyllite displays a distinctive phacoidal parting, referred to informally as 'oyster-shell structure,' which is due to an anastomosing phyllonitic foliation produced by intense ductile shearing. Thin stringers and pods of milky quartz are locally abundant and represent the sheared-out limbs and hinges of minor isoclinal folds.

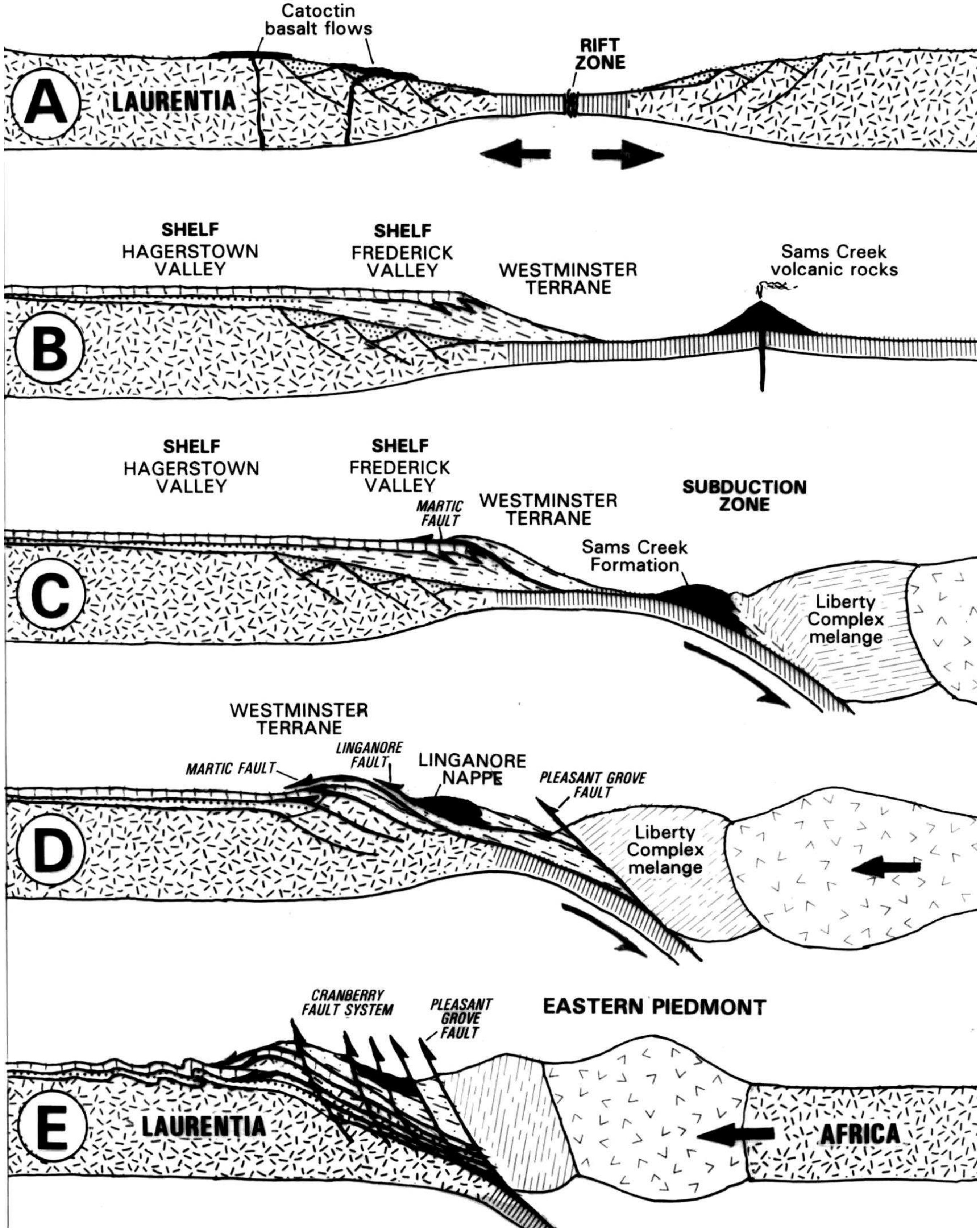
On the basis of the above structural features, Muller and Edwards (1985) identified the lithology as a tectonic unit and called it the Pleasant Grove Zone. This feature probably formed initially as a thrust fault during Taconic deformation (Muller and others, 1989; Muller, 1991), but was later modified by extensive Late Paleozoic Alleghanian right-lateral strike-slip ductile deformation (Krol and others, 1990; Krol and Muller, 1995) with at least 90 to 95 miles displacement (Valentino and others, 1994). It is now more correctly referred to as the Pleasant Grove shear zone (P.D. Muller, 1997, personal communication).

The Pleasant Grove shear zone is the geologic and structural boundary between the Eastern Piedmont accreted terranes of easterly derived, allochthonous, subduction zone melange and the Westminster terrane composed of Laurentian continental-margin, drift facies metasedimentary and metavolcanic rocks (Rankin and others, 1990). Along strike to the southwest in Virginia, the Mountain Run fault (Pavlides, 1986; 1994; Southworth, 1996) occupies this position. Jonas (1927) originally considered the Mountain Run fault to be an extension of the Martic overthrust, but it is more likely an extension of the Pleasant Grove shear zone (Southworth, 1996). To the northeast, in the Piedmont of southeastern Pennsylvania and adjacent New Jersey, the Pleasant Grove Shear Zone extends into the Huntington Valley Shear Zone (Valentino and others, 1994).

TECTONIC MODEL

Following the Late Proterozoic to Early Cambrian rifting event which split the Grenvillian continental craton, the continental fragments drifted apart and an ocean basin formed between them (Rankin 1975: Bond and others, 1984; Badger and Sinha, 1988; Aleinikoff and others, 1995). Basalt flows of the Catoctin Formation were extruded along the initial rift and rift stage sediments were deposited in down-faulted basins along the continental margin. The ocean basin continued to expand as basalt was extruded along the central rift zone and added to the crust (Figure 18, A).

During the Early Cambrian, a mantle plume penetrated the oceanic crust to the east of the Laurentian continent (Smith and Barnes, 1994) and basalt flows built up a volcanic island complex consisting of the Sams Creek Formation (Fisher, 1978; Smith and Barnes, 1994). These volcanic rocks were surrounded and capped by carbonate reefs now represented by the Wakefield Formation (Fisher, 1978; Smith and Barnes, 1994). To the west, the eastern edge of Laurentia stabilized into a passive continental margin and a depositional wedge of sediments accumulated (Wehr and Glover, 1985; Simpson and Eriksson, 1989). By the end of the Early Cambrian a continental shelf had developed, surmounted by a wide carbonate bank (Rodgers,



Catoctin basalt flows
RIFT ZONE
A
LAURENTIA
SHELF
HAGERSTOWN VALLEY
SHELF
FREDERICK VALLEY
WESTMINSTER TERRANE
Sams Creek volcanic rocks
B
SHELF
HAGERSTOWN VALLEY
SHELF
FREDERICK VALLEY
MARTIC FAULT
WESTMINSTER TERRANE
SUBDUCTION ZONE
Sams Creek Formation
Liberty Complex melange
C
WESTMINSTER TERRANE
LINGANORE FAULT
MARTIC FAULT
LINGANORE NAPPE
PLEASANT GROVE FAULT
Liberty Complex melange
D
CRANBERRY FAULT SYSTEM
PLEASANT GROVE FAULT
EASTERN PIEDMONT
E
LAURENTIA
AFRICA

← *Previous page*

FIGURE 18. –Tectonic Model for Evolution of the western Piedmont. (Not to scale. See text for detailed description.)

A: Late Proterozoic/Early Cambrian rifting phase. Grenvillian continent splits into Laurentia and an unidentified eastern counterpart as an ocean basin expands between them.

B: Early Cambrian drift phase. A mantle plume penetrates oceanic crust east of Laurentia and builds an island of Sams Creek volcanic rocks. A wedge of continental shelf sediments accumulates along the stable passive margin of Laurentia.

C: Middle to Late Ordovician plate convergence. Thrusts transport slope and basinal sedimentary rocks onto shelf and shelf deposits onto continent.

D: Late Ordovician Taconic Orogeny. Subduction zone accretionary melange is thrust onto continental margin deposits. Sams Creek volcanic rocks are thrust onto rocks of Westminster terrane. All rocks folded.

E: Late Permian/Early Triassic Alleghanian Orogeny. Final closure of ocean basin as Africa is sutured onto Laurentia. Taconic thrusts reactivated and high-angle reverse faults cut across earlier structures.

1970; Simpson and Eriksson, 1989). In the marginal basin offslope from this prograding shelf, deep-water deposits of the Westminster terrane included Early Cambrian Urbana and Ijamsville Formations, Middle Cambrian Marburg Formation, and deep-water Silver Run Limestone (Figure 18, B).

Plate convergence which ultimately resulted in the Late Ordovician Taconic Orogeny probably began in late Middle Ordovician time (Wehr and Glover, 1985), and oceanic crust east of the Laurentian continent was consumed in an east-dipping subduction zone (Muller and others, 1989; Gates and others, 1991). The basinal deposits of the Westminster terrane were thrust along the Martic fault over the slope and shelf deposits farther west (Rodgers, 1970; Southworth, 1996) (Figure 18, C).

At the culmination of the Taconic Orogeny, tectonic melange of the Liberty Complex (Muller and others, 1989) was thrust onto the Laurentian continental margin deposits along a fault which was parent to the Pleasant Grove shear zone (Muller and Edwards, 1985; Muller and others, 1989; Gates and others, 1991). The Sams Creek volcanic island complex was detached from its oceanic crust substrate east of the Westminster Terrane and thrust westward upon the deformed continental margin sedimentary rocks as the Linganore nappe. Continued tectonism and deformation folded both the allochthonous and autochthonous rocks and metamorphosed them to greenschist facies (Figure 18, D).

Continental collision during the Late Permian/ Early Triassic Alleghanian Orogeny produced west-verging, high-angle reverse faults which cut across all rock units in the Westminster terrane. Westward thrusting along the Martic fault was also reactivated by Alleghanian deformation (Southworth, 1996) (Figure 18, E).

At the culmination of the Alleghanian Orogeny and the final closure of the ocean basin as Africa collided with Laurentia, and subsequent to the westward-directed deformation in the Maryland Piedmont depicted in Figure 18 and described above, blocks of continental crust were moved laterally southwestward into the eastern Piedmont of Maryland along dextral strike slip faults (Glover and Gates, 1987; Gates and others, 1991; Valentino and others, 1994). These crustal blocks of mid-Proterozoic gneissic basement with cover of metamorphosed sedimentary rocks now constitute the Baltimore terrane (Horton and others, 1989). The Pleasant Grove shear zone was also reactivated during Alleghanian deformation as a dextral strike-slip fault (Krol and Muller, 1995).

SUMMARY AND CONCLUSIONS

Bedrock units of the Westminster terrane in the western Piedmont of Maryland occur in two separate, greenschist facies metamorphic series, one sedimentary in origin and autochthonous, the other volcanic in origin and interpreted to be allochthonous.

The stratigraphic succession of the metasedimentary rock units is based on the recognition by earlier workers that Sugarloaf Mountain in southeastern Frederick County is an anticlinorium. At the core of the fold, the Sugarloaf Mountain Quartzite, long interpreted as equivalent to the Lower Cambrian Weverton Formation in the Blue Ridge Province to the west, is the oldest formation exposed. Surrounding the Sugarloaf Mountain Quartzite are the successively younger Urbana and Ijamsville Formations. In Carroll County, the Urbana Formation at the core of the Deep Run anticlinorium is overlain by the Ijamsville and Marburg Formations. The Silver Run Limestone, a deepwater limestone probably equivalent to the Upper Cambrian to Lower Ordovician carbonates of the Frederick Limestone in Maryland and the Conestoga Limestone in Pennsylvania, overlies the Marburg. The Gillis Formation is an undifferentiated phyllite unit in the eastern part of the Westminster terrane that includes lithologies present in all of the western metasedimentary formations from the Urbana up through the Marburg.

The metavolcanic rocks of the Sams Creek Formation, and the associated Wakefield Marble, occur in what is interpreted as a large, refolded thrust sheet named the Linganore nappe. This has been emplaced over the metasedimentary sequence along the Linganore overthrust fault.

All rock units in the Westminster terrane, both those of Linganore Nappe and those in the underlying metasedimentary rock assemblage, have been cut by near vertical, high-angle reverse faults of the Cranberry fault system.

ACKNOWLEDGEMENTS

I would like to thank Emery T. Cleaves, Director of the Maryland Geological Survey, and Kenneth N. Weaver, former Director, for their patience and support over the many years that I have worked in the Maryland Piedmont, collecting data that have been incorporated in this project. Peter D. Muller, of the State University of New York, College at Oneonta (formerly with the Maryland Geological Survey), first suggested that I consider the metavolcanic rocks and marble in the western Piedmont to be in thrust fault contact with the metasedimentary phyllites. I also benefitted from many discussions on Piedmont geology with David K. Brezinski, James P. Reger, James R. Brooks, William P. Crowley (deceased), and Juergen Reinhardt (deceased), colleagues and former colleagues at the Survey, and also with George W. Fisher of the Johns Hopkins University, Allan M. Thompson of the University of Delaware, Robert C. Smith of the Pennsylvania Geological Survey, and Scott Southworth of the United States Geological Survey. I am indebted to each of the above for their contributed ideas and suggestions. I am particularly indebted to James P. Reger for his perseverance in getting this report published following my retirement. Dr. Thomas Anderson (University of Pittsburgh) provided valuable insight during review of the final product (2012).

REFERENCES

Aleinikoff, J.N., Zartman, R.E., Walter, M., Rankin, D.W., Lyttle, P.T., and Burton, W.C., 1995, U-Pb ages of metarhyolites of the Catoctin and Mount Rogers Formations, central and southern Appalachians: evidence for two pulses of Iapetan rifting: American Journal of Science, v. 295, p. 428-454.

Badger, R.L., and Sinha, A.K., 1988, Age and Sr isotopic signature of the Catoctin volcanic province: implications for subcrustal mantle evolution: Geology, v. 16, p. 692-695.

Bond, G.C., Nickerson, P.A., and Kominz, M.A., 1984, Breakup of a supercontinent between 625 Ma and 555 Ma: new evidence and implications for continental histories: Earth and Planetary Science Letters, v. 70, p. 325-345.

Brezinski, D.W., 1992, Lithostratigraphy of the western Blue Ridge cover rocks in Maryland: Maryland Geological Survey, Report of Investigations, No. 55, 69 p.

Clark, W.B., 1897, Outline of present knowledge of the physical features of Maryland, embracing an account of the physiography, geology, and mineral resources: Maryland Geological Survey, Volume 1, pt. 3, p. 139-228.

Clark, W.B., and Mathews, E.B., 1906, The physical features of Maryland: Maryland Geological Survey, Volume 6, pt. 1, p. 27-260.

Cleaves, E.T., Edwards, J., Jr., and Glaser, J.D., 1968, Geologic map of Maryland: Maryland Geological Survey, scale 1:250,000.

Cloos, E., 1941, Structure and fabric of critical areas between Mine Ridge and Potomac River, *in* Cloos, E., and Hietanen, A, 1941, Geology of the "Martic Overthrust" and the Glenarm Series in Pennsylvania and Maryland: Geological Society of America Special Paper 35, Part 1, p. 3-96.

_____, 1964, Structural geology of Howard and Montgomery Counties, *in* The geology of Howard and Montgomery Counties: Baltimore, Maryland Geological Survey, p.216-261.

Cloos, E., and Broedel, C.H., 1940, Geologic map of Howard County: Maryland Geological Survey, scale 1:62,500.

Cloos, E., and Cooke, C.W., 1953, Geologic map of Montgomery County and the District of Columbia: Maryland Department of Geology, Mines, and Water Resources, scale 1:62,500.

Crowley, W.P., 1976, The geology of the crystalline rocks near Baltimore and its bearing on the evolution of the eastern Maryland Piedmont: Maryland Geological Survey, Report of Investigations No. 27. 40 p.

_____, 1977, Geologic map of the Reisterstown Quadrangle, Maryland: Maryland Geological Survey, scale 1:24,000.

Edwards, J., Jr., 1984, The Linganore fault: key to age of Sams Creek Formation in the Piedmont of Maryland (abs.): Geological Society of America Abstracts with Programs, Southeastern and North Central Sections, v. 16, no. 3, p. 135.

____, 1986, Geologic map of the Union Bridge Quadrangle, Carroll and Frederick Counties, Maryland: Maryland Geological Survey, scale 1:24,000.

_____, 1988, Geologic map of the Woodsboro Quadrangle, Carroll and Frederick Counties, Maryland: Maryland Geological Survey, scale 1:24,000.

_____, 1993a, Geologic map of Howard County: Maryland Geological Survey, scale 1:62,500.

_____, 1993b, Geologic map of the Manchester Quadrangle, Carroll County, Maryland: Maryland Geological Survey, open-file map, scale 1:24,000.

_____, 1993c, Geologic map of the Westminster Quadrangle, Carroll County, Maryland: Maryland Geological Survey, open-file map, scale 1:24,000.

_____, 1994, Geologic map of the Libertytown Quadrangle, Carroll and Frederick Counties, Maryland: Maryland Geological Survey, open-file map, scale 1:24,000.

_____, 1996, Geologic map of the Winfield Quadrangle, Carroll and Frederick Counties, Maryland: Maryland Geological Survey, open-file map, scale 1:24,000.

Edwards, J., Jr., and Glaser, J.D., 1993, Geologic map of the Littlestown Quadrangle, Carroll County, Maryland: Maryland Geological Survey, open-file map, scale 1:24,000.

Espenshade, G.H., and Clarke, J.W., 1976, Geology of the Blue Ridge anticlinorium in northern Virginia: Geological Society of America Northeast-Southeast Sections Joint Meeting, Field Trip Guidebook No. 5, 26 p.

Fisher, G.W., 1970, The metamorphosed sedimentary rocks along the Potomac River near Washington, D.C., *in* Fisher, G.W., Pettyjohn, F.J., Reed, J. C., Jr., and Weaver, K.N., Studies in Appalachian geology: Central and Southern: New York, Wiley Interscience Publishers, p. 299-315.

_____, 1978, Geologic map of the New Windsor quadrangle, Carroll County, Maryland: U.S. Geological Survey, Miscellaneous Investigations Map I-1037, scale 1:24,000.

Fisher, G.W., Higgins, M.W., and Zietz, I., 1979, Geological interpretations of aeromagnetic maps of the crystalline rocks in the Appalachians, northern Virginia to New Jersey: Maryland Geological Survey, Report of Investigations 32, 43 p.

Froelich, A.J., 1975, Bedrock map of Montgomery County, Maryland: U.S. Geological Survey, Miscellaneous Investigations Series, Map I-920-D, Scale 1:62,500.

Furcron, A.S., 1939, Geology and mineral resources of the Warrenton Quadrangle, Virginia: Virginia Geological Survey, Bulletin 54, 94 p.

Gates, A.E., Muller, P.D., and Valentino, D.W., 1991, Terranes and tectonics of the Maryland and southeast Pennsylvania Piedmont, in Schultz, A., and Compton-Gooding, E., Geologic evolution of the eastern United States, Field trip guidebook, NE-SE Geological Society of America: Virginia Museum of Natural History, Guidebook 2, p. 1-27.

Glover, L., III, and Gates, A.E., 1987, Alleghanian orogeny in the central and southern Appalachians (abs.) :Geological Society of America, Abstracts with Programs, v. 19, no. 2, p. 86.

Gohn, G.S., 1978, Revised ages of Cambrian and Ordovician formations of the Conestoga Valley near York and Lancaster, southeastern Pennsylvania, *in* Sohl, N.F., and Wright, W.B., Changes in stratigraphic nomenclature by the U.S. Geological Survey, 1977: U.S. Geological Survey, Bulletin 1457-A, p. A94-A97.

Higgins, M.W. (coordinator), 1987, Correlation of stratigraphic units in North America - Piedmont/ Blue Ridge correlation chart: American Association of Petroleum Geologists Correlation Chart Series CSD 150.

_____, 1990, The crystalline rocks of Cecil County, *in* Higgins, M.W., and Conant, L.B., The geology of Cecil County, Maryland: Maryland Geological Survey, Bulletin 37, p. 3-116.

Higgins, M.W., and Fisher, G.W., 1971, A further revision of the stratigraphic nomenclature of the Wissahickon Formation in Maryland: Geological Society of America Bulletin, v. 82, p. 769-774.

Hopson, C.A., 1964, The crystalline rocks of Howard and Montgomery Counties, *in* The geology of Howard and Montgomery Counties: Baltimore, Maryland Geological Survey, p. 27-215.

Horton, J.W., Jr., Drake, A.A., Jr., and Rankin, D.W., 1989, Tectonostratigraphic terranes and their Paleozoic boundaries in the central and southern Appalachians, *in* Dallmeyer, R.D., ed., Terranes in the Circum-Atlantic Paleozoic orogens: Geological Society of America Special Paper 230, p. 213-245.

Jonas, A.I., 1924, Pre-Cambrian rocks of the western Piedmont of Maryland: Geological Society of America Bulletin, v. 35, p. 355-364.

_____, 1927, Geologic reconnaissance in the Piedmont of Virginia: Geological Society of America Bulletin, v. 38, p. 837-846.

_____, 1928, Map of Carroll County showing the geological Formations: Maryland Geological Survey, scale 1:62,500.

Jonas, A.I., and Knopf, E.B., 1925, Map of Baltimore County and Baltimore City showing the geological formations: Maryland Geological Survey, scale 1:62,500.

Jonas, A.I., and Stose, G.W., 1936, Age reclassification of the Frederick Limestone: Geological Society of America Bulletin, v. 47, p. 1658-1671.

_____, 1938a, Geologic map of Frederick County: Maryland Geological Survey, scale 1:62,500.

_____, 1938b, New formation names used on the geologic map of Frederick County, Maryland: Washington Academy of Sciences, v. 28. no. 8, p. 345-348.

Keyes, C.R., 1891, A geological section across the Piedmont Plateau in Maryland: Geological Society of America Bulletin, v. 2, p. 319-322.

Knopf, E.B., and Jonas, A.I., 1923, Stratigraphy of the crystalline schists of Pennsylvania and Maryland: American Journal of Science, 5th series, v. 5, p. 40-62.

_____, 1929a, Geology of the McCalls Ferry - Quarryville district, Pennsylvania: U.S. Geological Survey, Bulletin 799, 156 p.

_____, 1929b, The geology of the crystalline rocks of Baltimore County, in Baltimore County: Baltimore, Maryland Geological Survey, p. 97-199.

Krol, M.A., and Muller, P.D., 1995, Microstructural evidence for dextral shearing within the Pleasant Grove Zone, Maryland: Northeastern Geology and Environmental Sciences, v. 17, no. 2, p. 151-161.

Krol, M.A., Onasch, C.M., and Muller, P.D., 1990, Kinematic analysis of the Pleasant Grove shear zone, eastern Maryland Piedmont (abs.): Geological Society of America Abstracts with Programs, Northeastern Section, v. 22, no. 2, p. 28-29.

Mack, T., 1965, Characteristics of the Everona Formation in Virginia: Virginia Division of Mineral Resources, Information Circular 10, 16 p.

Mathews, E.B., 1898, An account of the character and distribution of Maryland building stones, together with a history of the quarrying industry, *in* Merrill, G.P., and Mathews, E.B., The building and decorative stones of Maryland: Maryland Geological Survey, Volume 2, Pt. 2, p. 125-241.

_____, 1904, The structure of the Piedmont plateau as shown in Maryland: American Journal of Science, v. 17, Feb. 1904, p. 141-159.

_____, 1905, Correlation of Maryland and Pennsylvania Piedmont Formations: Geological Society of America Bulletin, v. 16, p. 329-246.

_____, 1933, Map of Maryland showing the geological formations: Maryland Geological Survey, scale 1:380,160.

Mathews, E.B., and Grasty, J.S., 1909, The limestones of Maryland: Maryland Geological Survey, Volume 8, Pt. 3, p. 225-477.

Mathews, E.B., and Miller, W.J., 1905, Cockeysville Marble: Geological Society of America Bulletin, v. 16, p. 347-366.

Muller, P.D., 1985, Geologic map of the Hereford Quadrangle, Maryland: Maryland Geological Survey, scale 1:24,000.

_____, 1991, Geologic map of the Hampstead Quadrangle, Maryland: Maryland Geological Survey, scale 1:24,000.

_____, 1994, Geologic map of the Finksburg Quadrangle, Carroll and Baltimore Counties, Maryland: Maryland Geological Survey, open-file map, scale 1:24,000.

Muller, P.D., Candela, P.A., and Wylie, A.G., 1989, Liberty Complex: Polygenetic melange in the central Maryland Piedmont, *in* Horton, J.W., and Rast, N., 1989, Melanges and olistrostromes of the U.S. Appalachians: Geological Society of America Special Paper 228, p. 113-134.

Muller, P.D., and Chapin, D.A., 1984, Tectonic evolution of the Baltimore Gneiss anticlines, Maryland, *in* Bartholomew, M.J., The Grenville event in the Appalachians and related topics: Geological Society of America Special Paper 194, p. 127-148.

Muller, P. D., and Edwards, J. Jr., 1985, Tectono-stratigraphic relationships in the central Piedmont of Maryland (abs.): Geological Society of America Abstracts with Programs, Northeast Section, v. 17, no. 1, p. 55.

Nickelsen, R.P., 1956, Geology of the Blue Ridge near Harpers Ferry, West Virginia: Geological Society of America Bulletin, v. 67, p. 239-270.

Odom, A.L., and Fullagar, P.D., 1984, Rb-Sr whole-rock and inherited zircon ages of the Crossnore Complex, southern Appalachians, and their implications regarding the time of opening of the Iapetus Ocean: Geological Society of America Special Paper 194, p. 255-261.

Parker, P.E., 1968, Geologic investigations of the Lincoln and Bluemount quadrangles, Virginia: Virginia Division of Mineral Resources, Report of Investigations 14, 23 p.

Pavlides, L., 1986, The Mountain Run fault zone of Virginia, *in* Jacobsen, M.L., and Rodriguez, T.R., compilers, National earthquake hazards reduction program, summaries of technical reports volume XXIII: U.S. Geological Survey, Open-File Report 87-63, p. 93-94.

_____, 1994, Continental margin deposits and the Mountain Run fault zone of Virginia – stratigraphy and tectonics, *in* Drake, A.A., Jr., and Pavlides, L., Stratigraphic Notes, 1993: U.S. Geological Survey, Bulletin 2076, Chapter B, p. B1-B9.

Rankin, D.W., 1975, The continental margin of Eastern North America in the Southern Appalachians; the opening and closing of the proto-Atlantic Ocean: American Journal of Science, Tectonics and Mountain Ranges, v. 275-A, p. 298-336.

Rankin, D.W., Drake, A.A., and Ratcliffe, N.M., 1990, Geologic map of the U.S. Appalachians showing the Laurentian margin and the Taconic orogen, plate 2, *in* Hatcher, R.D., Jr., Thomas, W.A., and Viele, G.W., eds., The Appalachian-Ouachita orogen in the United States: Geological Society of America, The Geology of North America, Boulder, v. F-2, scale 1:2,000,000.

Rasetti, F.R.D., 1959, Trempealeauan trilobites from the Conococheague, Frederick, and Grove Limestones of the central Appalachians: Journal of Paleontology, v.33, p. 375-398.

______, 1961, Dresbachian and Franconian trilobites of the Conococheague and Frederick Limestones of the central Appalachians: Journal of Paleontology, v. 35, p. 104-124.

Reinhardt, J., 1974, Stratigraphy, sedimentology, and Cambro-Ordovician paleogeography of the Frederick Valley, Maryland: Maryland Geological Survey, Report of Investigations 23, 74 p.

Reinhardt, J., and Hardie, L.A., 1976, Selected examples of carbonate sedimentation, lower Paleozoic of Maryland: Maryland Geological Survey, Guidebook No.5, 53 p.

Rodgers, J., 1970, The tectonics of the Appalachians: New York, Wiley Interscience, 271 p.

Sando, W.J., 1957, Beekmantown Group (Lower Ordovician) of Maryland: Geological Society of America Memoir 68, 161 p.

Schwab, F.L., 1970, Origin of the Antietam Formation (Late Precambrian?-Lower Cambrian), central Virginia: Journal of Sedimentary Petrology, v. 40, no. 1, p. 354-366.

_____, 1971, Harpers Formation, central Virginia: a sedimentary model: Journal of Sedimentary Petrology, v.41, p. 139-149.

_____, 1972, The Chilhowee Group and the Late Precambrian-Early Paleozoic sedimentary frame-work in the central and southern Appalachians, *in* Lessing, P., Hayhurst, R.I., Barlow, J.A., and Woodfork, L.D., Appalachian structures: origin, evolution, and possible potential for new exploration frontiers: West Virginia University and West Virginia Geological and Economic Survey seminar, p. 59-86.

_____, 1986, Latest Precambrian-earliest Paleozoic sedimentation, Appalachian Blue Ridge and adjacent areas: review and speculation, *in* McDowell, R.C., and Glover, L., III, eds., The Lowry Volume: Studies in Appalachian geology: Virginia Polytechnic Institute and State University Department of Geological Sciences, Memoir 3, p. 115-137.

Scotford, D.M., 1951, Structure of the Sugarloaf Mountain area, Maryland, as a key to Piedmont stratigraphy: Geological Society of America Bulletin, v.62, p. 45-76.

Simpson, E.L., and Eriksson, K.A., 1989, Sedimentology of the Unicoi Formation in southern and central Virginia: Evidence for Late Proterozoic to Early Cambrian rift-passive margin transition: Geological Society of America Bulletin, v. 101, p. 42-54.

Smith, R.C. II, and Barnes, J.H., 1994, Geochemistry and geology of metabasalt in southeastern Pennsylvania and adjacent Maryland: *in* Faill, R.T., and Sevon, W.D., eds., Various aspects of Piedmont geology in Lancaster and Chester Counties, Pennsylvania: Guidebook, 59th Annual Field Conference of Pennsylvania Geologists, p. 45-71.

Southwick, D.L., 1969, Crystalline rocks of Harford County, *in* The geology of Harford County, Maryland: Baltimore, Maryland Geological Survey, p. 1-76.

Southwick, D.L., and Fisher, G.W., 1967, Revision of stratigraphic nomenclature of the Glenarm Series in Maryland: Maryland Geological Survey, Report of Investigations No. 6, 19 p.

Southwick, D.L., and Owens, J.P., 1968, Geologic map of Harford County: Maryland Geological Survey, County Geologic Map CGM-1, Scale 1:62,500.

Southworth, S., 1996, The Martic Fault in Maryland and its tectonic setting in the central Appalachians, *in*, Brezinski, D.K., and Reger, J.P., Studies in Maryland Geology: Maryland Geological Survey, Special Publication No. 3, p. 205-221.

Southworth, S., and Brezinski, D.K., 1996, Geologic map of the Harpers Ferry Quadrangle, Virginia, Maryland, and West Virginia: U.S.

Geological Survey Bulletin 2123, 33 p. and map: Plate 1, scale 1:24,000.

Stose, G.W., and Jonas, A.I., 1939 (reprinted 1973), Geology and mineral resources of York County, Pennsylvania: Pennsylvania Geological Survey, 4th series, Bulletin C-67, 199 p.

Stose, A.J., and Stose, G.W., 1944, Geology of the Hanover-York district Pennsylvania: U.S. Geological Survey, Professional Paper 204, 84 p.

______, 1946, Geology of Carroll and Frederick Counties, *in* The physical features of Carroll County and Frederick County: Baltimore, Maryland Department of Geology, Mines, and Water Resources, p. 11-131.

Taylor, J.F., Repetski, J.E., and Roebuck, C.A., 1996, Stratigraphic significance of trilobite and conodont faunas from the Cambrian-Ordovician shelfbreak facies in the Frederick Valley, Maryland: Maryland Geological Survey, Special Publication No. 3, p. 141-164.

Thomas, B.K., 1952, Structural Geology and stratigraphy of Sugarloaf Anticlinorium and adjacent Piedmont area, Maryland: Unpublished Ph.D. Dissertation, The Johns Hopkins University, 95 p.

Tucker, M.S., 1983, A geological interpretation of magnetic anomalies in the Sugarloaf mountain area, Maryland: Unpublished M.S. Thesis, University of Pittsburgh, 57 p.

Tyson, P.T., 1860, First report of Philip T. Tyson, State Agricultural Chemist, to the House of Delegates of Maryland, June 1860: Annapolis, Maryland Senate Document E, Maryland House Document C, 145 p., plus maps.

_____, 1862, Second report of Philip T. Tyson, State Agricultural Chemist, to the House of Delegates of Maryland, January, 1862: Annapolis, Maryland Senate Document (F), 72 p.

Valentino, D.W., Gates, A.E., and Glover, L., III, 1994, Late Paleozoic transcurrent assembly of the central Appalachian Piedmont: Tectonics, v. 13, no. 1, p. 110-126.

Wehr, F., 1985, Stratigraphy of the Lynchburg Group and Swift Run Formation, Late Proterozoic (730-570 Ma) central Virginia: Southeastern Geology, v. 25, no.4, p. 225-239.

Wehr, F., and Glover, L., III, 1985, Stratigraphy and tectonics of the Virginia-North Carolina Blue Ridge: evolution of a late Proterozoic-early Paleozoic hinge zone: Geological Society of America Bulletin, v. 96, p. 285-295.

Whittaker, J.C., 1955, Geology of Catoctin Mountain: Geological Society of America Bulletin, v. 66, p. 435-462.

Williams, G.H., 1891, The petrography and structure of the Piedmont Plateau in Maryland: Geological Society of America Bulletin, v. 2, p. 301-322.

_____, 1892, Guide to Baltimore with an account of the geology of its environs: American Institute of Mining Engineers, guidebook (prepared by a local committee), J. Murphy and Company, Baltimore, 139 p.

Williams, G.H., and Clark, W.B., 1893, Geology (chapter 3), *in* Maryland: Its resources, industries, and institutions: Baltimore, Board of World's Fair Managers of Maryland, pp. 55-88.

Ziegler, A.M., and McKerrow, W.S., 1975, Silurian marine red beds: American Journal of Science, v. 275, p. 31-56.