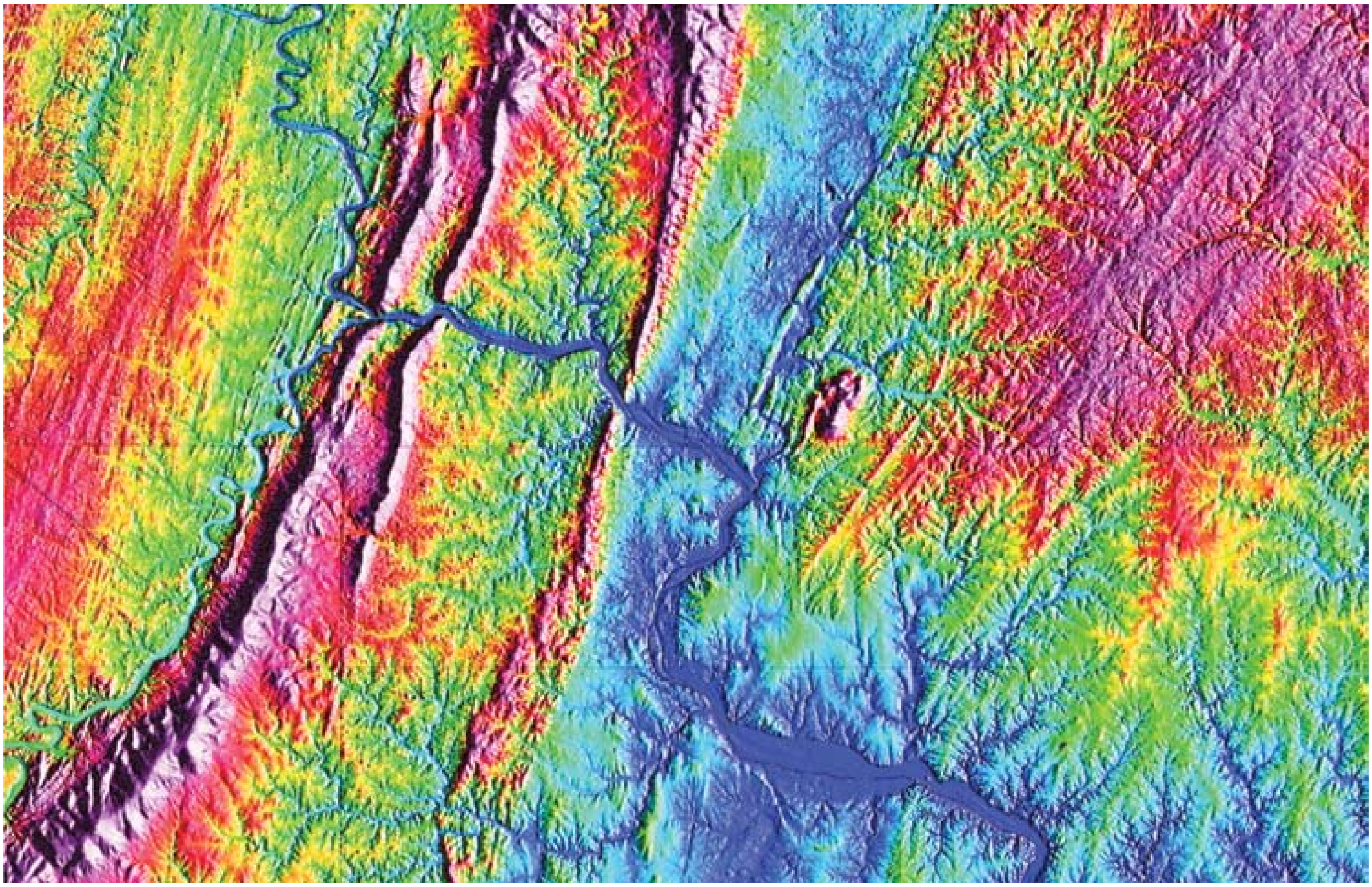
Prepared in cooperation with the Maryland Geological Survey

Geologic Map of the Frederick 30′ × 60′ Quadrangle, Maryland, Virginia, and West Virginia

By Scott Southworth, David K. Brezinski, Avery Ala Drake, Jr., William C. Burton, Randall C. Orndorff, Albert J. Froelich, James E. Reddy, Danielle Denenny, and David L. Daniels



Pamphlet to accompany

Scientific Investigations Map 2889

2007

U.S. Department of the Interior
U.S. Geological Survey

U.S. Department of the Interior
Dirk Kempthorne, Secretary

U.S. Geological Survey
Mark D. Myers, Director

U.S. Geological Survey, Reston, Virginia: 2007

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Cover: Color-shaded-relief image of the Frederick 30´ × 60´ quadrangle showing high topographic elevations in shades of red and low topographic elevations in shades of blue. The hillside is illuminated from the east. The highest elevation is 1,920 ft above sea level on Blue Ridge at the southwestern part of the map area in Loudoun County, Va., and the lowest elevation is 140 ft above sea level along the Potomac River at Great Falls, Montgomery County, Md. The higher elevation regions, such as the ridges of the Blue Ridge province, portions of the Great Valley of the Valley and Ridge province, and Sugarloaf Mountain and parts of the Westminster terrane in the Piedmont province, are in contrast to the lower elevation region of the Culpeper and Gettysburg basins, Frederick Valley, and Potomac River valley within the Piedmont province in the eastern half of the map area. The elevation differences are a function of rock hardness and different erosion histories. Image produced by David L. Daniels, USGS, using a 5-m digital elevation model of USGS.

Suggested citation:

Southworth, Scott, Brezinski, D.K., Drake, A.A., Jr., Burton, W.C., Orndorff, R.C., Froelich, A.J., Reddy, J.E., Denenny, Danielle, and Daniels, D.L., 2007, Geologic map of the Frederick 30´ × 60´ quadrangle, Maryland, Virginia, and West Virginia: U.S. Geological Survey Scientific Investigations Map 2889, scale 1:100,000, 42-p. text.

ISBN 978-1-4113-1165-7

Contents

Figures

Conversion Factors

SI to Inch/Pound

Multiply	By	To obtain
	Length	
centimeter (cm)	0.3937	inch (in.)
millimeter (mm)	0.03937	inch (in.)
meter (m)	3.281	foot (ft)
meter (m)	1.094	yard (yd)
kilometer (km)	0.6215	mile (mi)
kilometer (km)	0.5400	mile, nautical (nmi)
	Area	
square meter (m^2)	0.000247	acre
square kilometer (km^2)	0.3861	square mile (mi^2)

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By Scott Southworth,[1] David K. Brezinski,[2] Avery Ala Drake, Jr.,[3] William C. Burton,[1] Randall C. Orndorff,[1] Albert J. Froelich,[4] James E. Reddy,[1] Danielle Denenny,[1] and David L. Daniels[3]

Introduction

The Frederick 30′ × 60′ quadrangle lies within the Potomac River watershed of the Chesapeake Bay drainage basin. The map area covers parts of Montgomery, Howard, Carroll, Frederick, and Washington Counties in Maryland; Loudoun, Clarke, and Fairfax Counties in Virginia; and Jefferson and Berkeley Counties in West Virginia. Many geologic features (such as faults and folds) are named for geographic features that may or may not be shown on the 1:100,000-scale base map; see figure 2 for additional features. See page 29 for Description of Map Units.

The geology of the Frederick 30′ × 60′ quadrangle, Maryland, Virginia, and West Virginia, was first mapped on the 32 1:24,000-scale 7.5-minute quadrangle base maps between 1989 and 1994. The geologic data were compiled manually at 1:100,000 scale in 1997 and were digitized between 1998 and 1999. The geologic map and database may be used to support activities such as land-use planning, soil mapping, groundwater availability and quality studies, identifying aggregate resources, and conducting engineering and environmental studies. See the index map of 1:24,000-scale geologic maps (fig. 1) for site-specific studies.

The map area covers distinct geologic provinces and sections of the central Appalachian region that are defined by unique bedrock and resulting landforms (fig. 2). From west to east, the provinces include the Great Valley section of the Valley and Ridge province, the Blue Ridge province, and the Piedmont province; in the extreme southeastern corner, a small part of the Coastal Plain province is present. The Piedmont province is divided into several sections; from west to east, they are the Frederick Valley synclinorium, the Culpeper and Gettysburg basins, the Sugarloaf Mountain anticlinorium, the Westminster terrane, and the Potomac terrane. The geology of the Frederick quadrangle is discussed by geologic province and sections; the geologic units within each province are discussed from oldest to youngest. Where applicable, the discussion includes information on tectonic origins.

The Blue Ridge province contains Mesoproterozoic (1 billion years old, or 1 Ga) paragneiss and granitic gneisses that are intruded by a swarm of Neoproterozoic (570 million years old, or 570 Ma) metadiabase and metarhyolite dikes. Unconformably overlying the gneisses are Neoproterozoic metasedimentary rocks and metavolcanic rocks associated with the dikes. The Mesoproterozoic gneisses were deformed and metamorphosed during the Grenville orogeny. Subsequently, the Neoproterozoic metasedimentary and metavolcanic rocks accumulated during a continental rifting event (Rankin, 1976). Clastic metasedimentary rocks of the newly formed continental margin were deposited paraconformably upon the Neoproterozoic rocks.

To the east, Neoproterozoic and early Paleozoic metasedimentary and metavolcanic rocks were deposited on the margin of the rifted continent. These rocks underlie the Sugarloaf Mountain anticlinorium and Westminster and Potomac terranes. As the rifted continental margin stabilized and became a passive margin during the early Paleozoic, carbonate rocks were deposited on the broad continental shelf. Those carbonate rocks are now exposed in the Great Valley section and the Frederick Valley synclinorium.

The early Paleozoic carbonate platform became unstable in response to the Ordovician Taconian orogeny. Deformation associated with this tectonic event is recorded in rocks of the Piedmont province to the east. These rocks, which are now part of the Potomac terrane, were thrust westward onto rocks of the Westminster terrane; next, rocks of the Westminster terrane were thrust onto rocks now exposed in the Sugarloaf Mountain anticlinorium and Frederick Valley synclinorium (Drake and others, 1989; Southworth, 1996).

The early Paleozoic sea eventually closed up and disappeared during the continental collision of tectonic plates during the late Paleozoic Alleghanian orogeny. The Alleghanian orogeny transported all of the rocks within the map area westward along the North Mountain thrust fault, which is exposed immediately northwest of the quadrangle. The Alleghanian orogeny produced numerous thrust faults and folds in the rock and regional-scale folds that help define the geologic provinces (fig. 2). The Massanutten synclinorium underlies the Great Valley section, the Blue Ridge-South Mountain anti-

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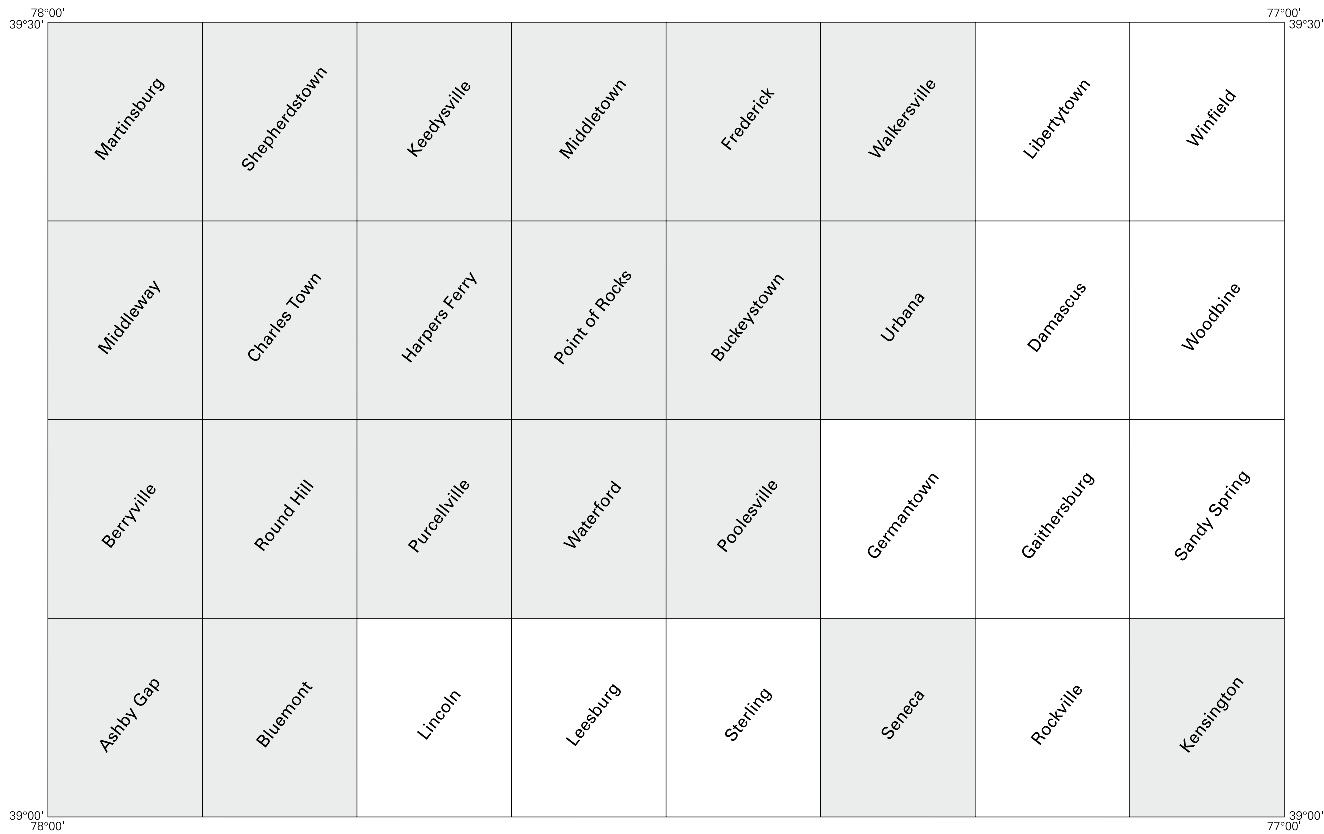

SOURCES OF GEOLOGIC DATA

Ashby Gap	Gathright and Nystrom (1974)	Middleway	Dean and others (1990)
Berryville	Edmundson and Nunan (1973); Dean and others (1990)	Point of Rocks	Burton and others (1995); Brezinski (2004b)
Bluemont	Southworth (1994)	Poolesville	Southworth (1998)
Buckeystown	Southworth and Brezinski (2003)	Purcellville	Southworth (1995)
Charles Town	Dean and others (1990)	Round Hill	McDowell and Milton (1992)
Frederick	Brezinski (2004a)	Seneca	Drake and others (1999)
Harpers Ferry	Southworth and Brezinski (1996b)	Shepherdstown	Dean and others (1987)
Keedysville	Dean and others (1987)	Urbana	Southworth (1999)
Kensington	Drake (1998)	Walkersville	Brezinski and others (2004)
Martinsburg	Dean and others (1987)	Waterford	Burton and others (1995)
Middletown	Brezinski and Fauth (2005)		

Figure 1. Index map of the Frederick 30′ × 60′ quadrangle showing 7.5-minute 1:24,000-scale quadrangle names and a list of published geologic maps of the areas shown in gray.

clinorium underlies the Blue Ridge province, and the Frederick Valley synclinorium and Sugarloaf Mountain anticlinorium underlie the western Piedmont province.

Tens of millions of years after the Alleghanian orogeny, early Mesozoic continental rifting formed the Culpeper and Gettysburg basins, which once were connected to form a large down-faulted basin filled with sediments that eroded from the adjacent Blue Ridge and Piedmont highlands. Continued rifting resulted in igneous intrusions and extrusive volcanic rock at about 200 Ma, and eventually led to the opening of the Atlantic Ocean. Sediments eroded from the Appalachian highlands were deposited by river systems and transgressing seas and now form the Coastal Plain province.

Great Valley Section of the Valley and Ridge Province

Geologic Setting

The Great Valley section of the Valley and Ridge province is a broad valley underlain mostly by carbonate rocks west of the Blue Ridge. The rocks form the Massanutten synclinorium, a broad fold with an overturned east limb. The western boundary of the Great Valley is not within the map area, but is defined by the clastic rocks that underlie Great North Mountain to the southwest in the Winchester,

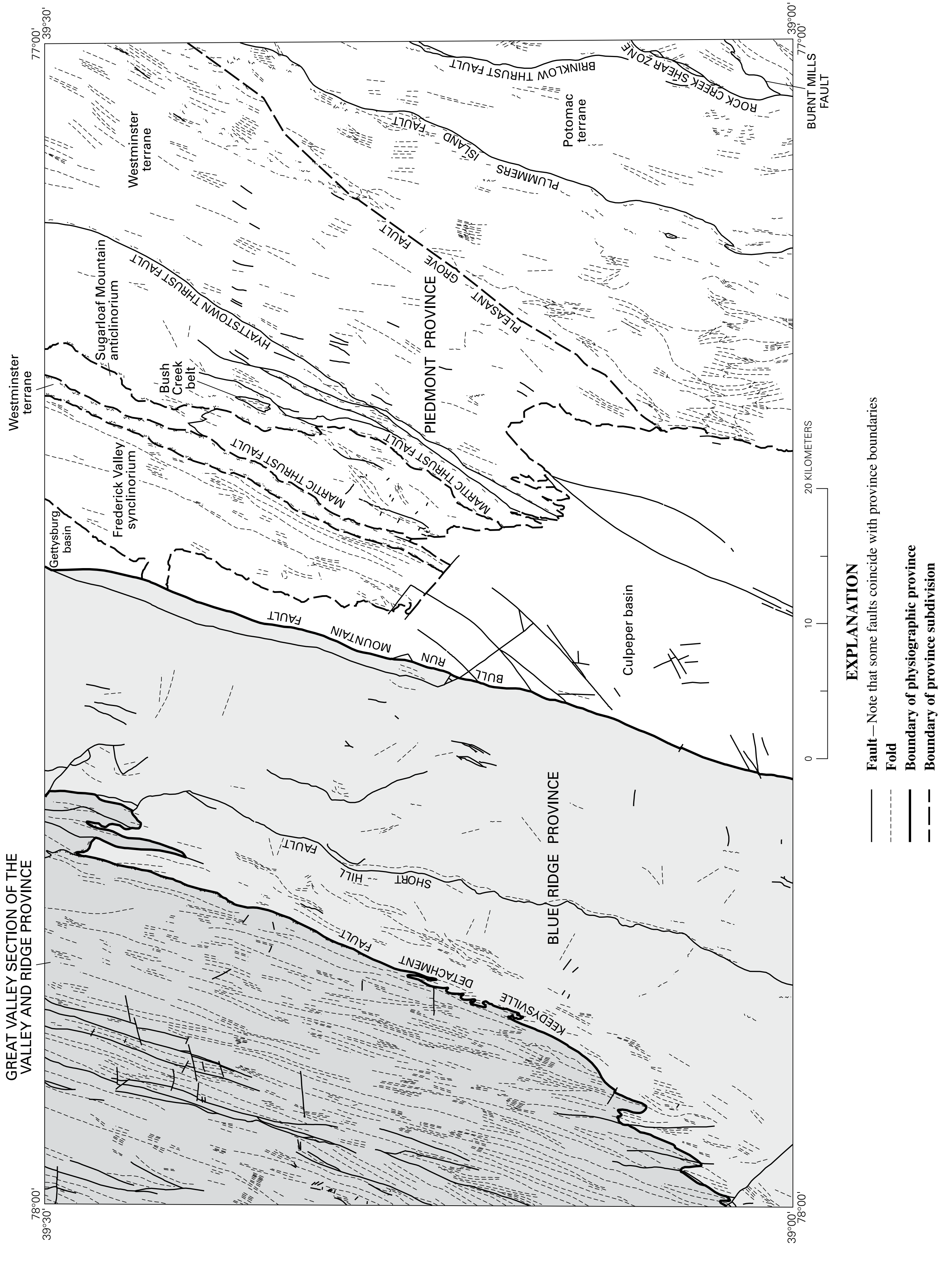

Figure 2. Map of the Frederick 30′ × 60′ quadrangle showing major physiographic provinces and structural features.

Va.-W. Va. 30′ × 60′ quadrangle. There, the Alleghanian North Mountain thrust fault places the Cambrian and Ordovician rocks of the Great Valley onto Silurian and Devonian rocks.

Lower Paleozoic Sedimentary Rocks

Tomstown Formation

The carbonate rocks of the Lower Cambrian Tomstown Formation (_t) (Tomstown Dolomite of Stose (1906)) are subdivided into the Bolivar Heights (_tbh), Fort Duncan (_tf), Benevola (_tb), and Dargan (_td) Members (Brezinski, 1992). The Tomstown rocks offer the first evidence that the eastern part of the rifted continent had evolved into a passive continental margin. The vertical sequence of rocks suggests a change from a shallow, carbonate shelf to a deep shelf and then to a carbonate bank.

The Bolivar Heights Member (_tbh) is a thin-bedded limestone containing wispy dolomitic burrows that increase in abundance upsection, where bioturbation was more prevalent. The base of the member is a 15-m-thick interval of mylonitic marble known as the Keedysville marble bed (Brezinski and others, 1996). The marble bed's lower contact defines a regional thrust fault that detached the carbonate rocks from the underlying sandstone of the Antietam Formation of the Blue Ridge province (Brezinski and others, 1996). The Fort Duncan Member (_tf) is a dark, thick-bedded, burrow-mottled dolostone whose base is probably an erosional surface at the top of the Bolivar Heights Member. The Benevola Member (_tb) is a very thick bedded to massive, sugary dolostone with faint crossbedding. The base is gradational with the underlying bioturbated dolostone of the Fort Duncan Member. This rock is quarried for aggregate because it is pure and massive. The Dargan Member (_td) consists of a lower bioturbated dolostone alternating with intervals of laminated dolostone. In the upper part, bioturbated and oolitic dolostone is interbedded with laminated limestone and silty dolostone.

Waynesboro Formation

The Lower Cambrian Waynesboro Formation (_wa) (Stose, 1906) has been subdivided into the Red Run (_war), Cavetown (_wact), and Chewsville (_wac) Members (Brezinski, 1992). These members have distinctive physiographic expressions that facilitate field mapping; sandstone of the lower Red Run and upper Chewsville Members underlies low hills with the intervening, less resistant carbonate rock of the Cavetown Member underlying a swale between the hills.

The Red Run Member (_war) consists of interbedded sandstone and laminated, ribbony, sandy dolostone. The Cavetown Member (_wact) is typically not well exposed. The lower part consists of a thick-bedded, massive limestone and bioturbated dolostone; the middle part consists of bioturbated dolomitic limestone and dolostone and thin calcareous sandstone and shale; and the upper part consists of thick-bedded, bioturbated dolomite with laminated ribbony dolomite at the very top. The Chewsville Member (_wac) is distinctive with its dark siltstone, sandstone, and shale. The siltstone commonly exhibits ripple marks and mudcracks. The sandstone is crossbedded and contains *Skolithos linearis* burrows. These rocks were deposited in a shallow, subtidal to supratidal environment.

Elbrook Limestone

The Middle and Upper Cambrian Elbrook Limestone (_e) (Stose, 1906) consists of lower, middle, and upper informal members (Brezinski, 1996) that were not differentiated on this map due to poor exposure. The lower part of the formation consists of cyclic intervals of limestone, shale, and shaly dolostone; the middle part of the formation is largely composed of thin-bedded to bioturbated limestone; and the upper part is a thick sequence of medium-bedded algal limestone, dolostone, and dolomitic shale. These rocks were deposited in a shallowing-upward, peritidal environment.

Conococheague Limestone and Big Spring Station Member

The Upper Cambrian and Lower Ordovician Conococheague Limestone (O_c) (Stose, 1910) consists of interbedded limestone, dolostone, and sandstone arranged in cycles. The lower 100 m consists of coarse-grained, calcareous to dolomitic sandstone, fine-grained limestone with intraformational conglomerate, and fine-grained dolostone of the Upper Cambrian Big Spring Station Member (_cb) that forms low ridges. Above the Big Spring Station Member, the Conococheague Limestone includes intraformational conglomerates, algal bioherms, ribbon rock, and oolites, arranged in cycles. Like the underlying rocks of the Elbrook Limestone, these rocks represent shallowing-upward marine deposits of a peritidal environment.

Beekmantown Group.—Consisting of Stonehenge Limestone and Stoufferstown Member, Rockdale Run Formation, and Pinesburg Station Dolomite.

Stonehenge Limestone and Stoufferstown Member

Only the Lower Ordovician lower part of the Stonehenge Limestone is mapped in this quadrangle. The basal part of the Stonehenge Limestone, the Stoufferstown Member (Obss) (Sando, 1958), consists of silty, laminated limestone. The remainder of the Stonehenge Limestone (Obs) (Stose, 1910) consists of thick-bedded, fossiliferous limestone. Algal bioherms, intraformational conglomerates, and bioclastic beds alternate with thin dolostone beds. Unlike the peritidal environments of the underlying Conococheague Limestone, the Stonehenge Limestone was deposited in a subtidal environment.

Rockdale Run Formation

The Lower and Middle Ordovician Rockdale Run Formation (Obrr) (Sando, 1957) consists of cyclically bedded limestone and dolostone. The limestone is thin to medium bedded, fossiliferous, and contains intraformational conglomerates, algal bioherms, bioclastic zones, burrow mottling, and chert nodules. The dolostone is laminated and displays abundant mudcracks. These rocks reflect an alternation between subtidal to peritidal environments similar to that in the Conococheague Limestone (O_c) discussed previously.

Pinesburg Station Dolomite

The Middle Ordovician Pinesburg Station Dolomite (Obps) (Sando, 1957) consists of medium- to thick-bedded dolostone and laminated dolostone that contains chert nodules. Crosshatched joints weather to form a diagnostic “butcher-block” pattern on the surface. Thin intervals of fine-grained limestone occur in the lower part. Near the top of the formation, irregularly bedded, brecciated dolostone that indicates paleokarst is common. These rocks reflect a restricted shallow-marine environment that was at times exposed to air.

St. Paul Group

The Middle Ordovician St. Paul Group (Osnr) consists of thick-bedded, micritic, fenestral limestone having thin-bedded dolomitic limestone and interbedded with laminated dolostone in the lower part. These rocks were unconformably deposited in a tidal flat to lagoonal environment above the Pinesburg Station Dolomite (Obps). The New Market Limestone and Row Park Limestone, which are the only parts of the St. Paul Group that occur in this quadrangle, are not differentiated on the map.

Chambersburg Limestone

The Middle Ordovician Chambersburg Limestone (Oc) (Stose, 1910) consists of argillaceous and nodular limestone that is perhaps the most fossiliferous unit in the Great Valley. The unit represents a change in depositional environment from a passive-continental-margin carbonate platform to an active continental-margin shelf; the transition is possibly associated with the Ordovician Taconian orogeny.

Martinsburg Formation

The Middle and Upper Ordovician Martinsburg Formation (Om) consists of shale, siltstone, and sandstone with argillaceous limestone at the base. Turbidites exhibiting typical Bouma cycles with load clasts are characteristic. The turbidites indicate the foundering of the margin and its evolution into a foreland basin (that is, the margin sank at the same time that sea level was rising), where shallow-water carbonate sedimentation gave way to deepwater clastic sediments.

Structure

The rocks that underlie the Great Valley form the Massanutten synclinorium, a regional fold that resulted from the late Paleozoic Alleghanian orogeny. The core of the synclinorium mostly consists of clastic rocks of the Middle and Upper Ordovician Martinsburg Formation. The Massanutten synclinorium, Blue Ridge-South Mountain anticlinorium, Frederick Valley synclinorium, and Sugarloaf Mountain anticlinorium constitute a fold train that was transported westward above the North Mountain thrust fault during the late Paleozoic. The rocks of the Great Valley are highly folded with tight and upright second-, third-, and fourth-order disharmonic folds that verge up the limbs of the higher order folds (see fig. 2). Axial-planar cleavage is most evident in the shale of the Martinsburg Formation. There are several late-forming thrust faults on the inner limbs of the Massanutten synclinorium that truncate units. High-angle tear faults and normal faults cut the folds.

Metamorphism

The rocks of the eastern part of the Great Valley were subjected to the same deformation and lower-greenschist-facies metamorphic conditions as the rocks of the westernmost Blue Ridge province. Minor amounts of chlorite and sericite are evident in some of the rocks, especially those that exhibit slaty cleavage and (or) mylonitic foliation. Most of the carbonate rocks of the Great Valley are not metamorphosed.

Blue Ridge Province

Geologic Setting

The Blue Ridge province in the Frederick 30′ × 60′ quadrangle consists of rocks of the Blue Ridge-South Mountain anticlinorium, which is a large west-verging complex fold. The anticlinorium exposes allochthonous rocks above and transported by the North Mountain thrust fault during the late Paleozoic Alleghanian orogeny (Evans, 1988). The core of the anticlinorium consists of Mesoproterozoic paragneiss and granitic gneisses that are intruded by Neoproterozoic granite, a swarm of metadiabase dikes, and several metarhyolite dikes. Deposited unconformably on the basement gneisses are Neoproterozoic metasedimentary rocks (Fauquier Group and Swift Run Formation), which are, in turn, overlain by metavolcanic rocks (Catoctin Formation). A thin unit of phyllite and conglomerate (Loudoun Formation) locally is transitional between the rocks of the Catoctin Formation and the clastic metasedimentary rocks of the overlying Lower Cambrian Chilhowee Group (Weverton, Harpers, and Antietam Formations). This cover-rock sequence of metasedimentary and metavolcanic rocks mostly underlies the three limbs of the Blue Ridge-South Mountain anticlinorium: from east to west, these limbs are represented by Catoctin Mountain, Black Oak Ridge-Short Hill-South Mountain, and Blue Ridge-Elk Ridge. Several outliers of cover rocks in the core of the anticlinorium also were preserved from the erosion of folds and faults.

The boundary between the Blue Ridge province and the Great Valley section to the west is the stratigraphic contact between the ridge-forming metasandstone of the Antietam Formation and the overlying limestone and dolostone of the Lower Cambrian Tomstown Formation. At the northern part of Pleasant Valley in Washington County, Md., the Rohrersville fault (Southworth and Brezinski, 1996a), which separates Cambrian limestone of the Great Valley from older metasedimentary and metavolcanic rocks of the Blue Ridge, acts as the provincial boundary. To the east, the boundary between the Blue Ridge and Piedmont provinces is marked by the lower slope of Catoctin and Furnace Mountains along a Mesozoic normal fault. Exceptions to this boundary placement are found east and south of Furnace Mountain near the Potomac River in Loudoun County, Va., where the unnamed carbonaceous phyllite unit and dolostone of the Tomstown Formation are stratigraphically above Antietam Formation; these rocks are discussed under the Blue Ridge province.

Mesoproterozoic Rocks

The Mesoproterozoic rocks in the core of the Blue Ridge-South Mountain anticlinorium are paragneisses and granitic orthogneisses. The Mesoproterozoic paragneisses are poorly exposed and occur as lenses and layers within granitic gneiss. They are interpreted to be the country rock that existed before intrusion of the granite. The most distinctive unit is garnet-graphite paragneiss (Yp). A well-layered texture, flakes of specular graphite, and large crystals of garnet (almandine) suggest an impure sandstone or graywacke as the protolith (Burton and Southworth, 1996). Amphibolite (Ya), a spotted, locally well-foliated hornblende-orthopyroxene-plagioclase gneiss that contains subordinate sills or dike-like bodies of metanorite, metadiorite, and hornblende-biotite gneiss, is interpreted to be a mafic metavolcanic rock. Quartzite and quartz-sericite tectonite (Yq) have rounded grains of quartz and zircon; seams of black, carbonaceous phyllonite; and pods of garnet-graphite paragneiss. The quartzite is of sedimentary origin and has been locally sheared.

At least four groups of orthogneisses are present in this quadrangle; the groupings are based on isotopic age data (Aleinikoff and others, 2000) as follows: (1) 1,153±6 Ma layered granitic gneiss (Ylg), 1,149±19 Ma hornblende monzonite gneiss (Yhm), 1,144±2 Ma porphyroblastic metagranite (Ypg), and about 1,140 Ma coarse-grained metagranite (Ymc); (2) 1,111±2 Ma biotitic and 1,112±3 Ma leucocratic Marshall Metagranite (Ym); (3) 1,077±4 Ma quartz-plagioclase gneiss (Yqp) and 1,077±4 garnetiferous metagranite (Ygt); and (4) 1,060±2 Ma white leucocratic metagranite (Yg), 1,059±2 Ma pink leucocratic metagranite (Yml), 1,055±4 Ma biotite granite gneiss (Ybg), and 1,055±2 Ma megacrystic metagranite (Ypb). Different groups predominate west (western Blue Ridge) and east (eastern Blue Ridge) of the Short Hill fault. Five types of granitic rock are mapped in the eastern Blue Ridge. These include (from oldest to youngest) coarse-grained metagranite (Ymc), the Marshall Metagranite (Ym) (Jonas, 1928; Espenshade, 1986), garnetiferous metagranite (Ygt), white leucocratic metagranite (Yg), and pink leucocratic metagranite (Yml). In general, most of these rocks are all light colored, medium grained, and distinguished by the presence or absence of garnet and (or) biotite. Only one of these units (Ymc) is coarse grained.

Six types of granitic rock are present in the western Blue Ridge. Massive quartz-hornblende-orthopyroxene-microcline-plagioclase charnockitic granite (Yc) is mapped primarily on the basis of float of fresh black rock having a distinctive orange crust. Charnockitic granite occurs as dike- and plug-like bodies whose age is uncertain (Aleinikoff and others, 2000). Layered granitic gneiss (Ylg), the oldest dated rock in the region, has the variegated texture of a migmatite. The protolith of this layered gneiss is interpreted to be a felsic volcanic rock. Hornblende monzonite gneiss (Yhm) has a characteristic spotted texture with up to 30 percent hornblende. Porphyroblastic metagranite (Ypg) is characterized by ovoid porphyroblasts of microcline as much as 3 centimeters (cm) long and garnet 1 cm in diameter. Garnetiferous metagranite (Ygt) and Marshall Metagranite (Ym) also occur in the western Blue Ridge as dikes and sills, and the garnetiferous metagranite also occurs as a large body near the Potomac River.

Neoproterozoic Rocks

Cobbler Mountain Alkali Feldspar Quartz Syenite of the Robertson River Igneous Suite

The Robertson River Igneous Suite consists of nine types of peralkaline to metaluminous granite and syenite (Tollo and Lowe, 1994). Only one member of this suite, the Cobbler Mountain Alkali Feldspar Quartz Syenite (Zrc), occurs in the Frederick quadrangle where it intrudes Mesoproterozoic rocks of the Blue Ridge province within the southwestern part of the map area. The syenite is a medium-grained massive rock containing distinctive stubby mesoperthite crystals. The rock lacks the Grenvillian foliation seen in the Mesoproterozoic rocks of the region because it was intruded about 300 m.y. later (Tollo and Lowe, 1994).

Metasedimentary Rocks of the Fauquier Group and Swift Run Formation

A sequence of clastic metasedimentary rocks unconformably overlies the Mesoproterozoic gneisses and Neoproterozoic Cobbler Mountain Alkali Feldspar Quartz Syenite. These rocks, the Neoproterozoic Fauquier Group and Swift Run Formation, occupy the same stratigraphic position but are not in contact with each other. Rocks of the Fauquier Group are restricted to the east limb of the Blue Ridge-South Mountain anticlinorium. The boundary between the Fauquier Group rocks and those of the Swift Run Formation are two transverse-normal faults that were active during deposition of both groups of strata (Kline and others, 1991).

The stratigraphic nomenclature of Kasselas (1993) is used here for rocks of the Fauquier Group, which was formerly called the Fauquier Formation by Espenshade (1986). The

Fauquier Group consists of the Swains Mountain Formation and Carter Run Formation. The base of the Swains Mountain Formation contains a local, clast-supported boulder conglomerate (Zfsc) consisting of boulders and cobbles of Mesoproterozoic granite gneiss; the conglomerate is interpreted to be a debris-flow deposit. The remainder of the Swains Mountain consists of gray, coarse- to fine-grained meta-arkose and finer grained metamudstone (Zfsm) overlying the boulder conglomerate. The Swains Mountain is overlain by gray metasiltstone and meta-arkose of the Carter Run Formation (Zfcr). The rocks of the Fauquier Group dramatically increase in thickness to the south beyond the quadrangle boundary, and they do not occur north of the cross fault that dropped them down against the Mesoproterozoic rocks. A small outlier of these rocks near Mountville in Loudoun County, Va., probably also was deposited in a fault-bounded basin.

Rocks of the Swift Run Formation (Stose and Stose, 1946) consist of metasandstone and schist (Zss), phyllite (Zsp), and marble (Zsm). The clastic rocks become finer grained upward in section and crossbedding suggests a fluvial origin, but the marble and some phyllite may be lake or shallow-marine deposits. The three types of rocks are not present in the same stratigraphic positions everywhere due to facies variations.

The massive basal metasandstone and schist unit (Zss) locally contains pebbles and cobbles of quartz, phyllite, and ferruginous sandstone, and grades upward and laterally into quartz-sericite schist. The quartz-sericite schist becomes finer grained as it grades upward into tan, sandy, sericitic phyllite (Zsp). White, pink, and tan, massive to schistose, calcitic and dolomitic marble (Zsm) occurs as local pods. Although the marble pods have been elongated by deformation, they probably originated as local lake or shallow-marine deposits that were not laterally extensive.

Metadiabase and Metarhyolite Dikes

A northeast-trending swarm of tabular dikes intrudes the Mesoproterozoic and some Neoproterozoic rocks. The dikes consist mostly of green metadiabase (Zmd) with some gray metarhyolite (Zrd) (Southworth and others, 2006) and range in thickness from 0.5 to 5 m. Texturally, the metadiabase ranges from fine grained (most common) to coarse grained to porphyritic. The metarhyolite is fine grained to porphyritic with plagioclase phenocrysts in a matrix of microcrystalline quartz and potassium feldspar. Near Middletown, Md., one of these dikes appears to cut metabasalt of the lower part of the Catoctin Formation (Zcm). Zircons from a metarhyolite dike along the Potomac River yielded a U-Pb date of 571.5±5 Ma (Aleinikoff and others, 1995). The dikes were probably feeders to the volcanic flows of the Catoctin Formation.

Metavolcanic and Metasedimentary Rocks of the Catoctin Formation

The Catoctin Formation (Keith, 1894) is characterized mainly by green, aphanitic, massive to schistose, amygdaloidal metabasalt and chlorite schist (Zcm). In several places at or near the base are bodies of white calcitic marble (Zcma) similar to, but more extensive than, the marble (Zsm) within the underlying Swift Run Formation. Local metabasalt breccia contains blocky masses of light-green epidosite. The metabasalt contains interbeds of thin, discontinuous, finely laminated, metasedimentary phyllite (Zcs); dark, variegated, vesicular, tuffaceous phyllite (Zcp); and phyllite and quartz-muscovite schist of metarhyolite composition (Zcr). The rocks of the Catoctin Formation show considerable variation in thickness and proportions of rock types along strike. In Maryland, metabasalt gives way northward to phyllite, and in Pennsylvania metarhyolite is the dominant unit. Metabasalt of the Catoctin Formation in Virginia has a Rb/Sr age of 570±36 Ma (Badger and Sinha, 1988), and metarhyolite of the Catoctin Formation in Pennsylvania has a U-Pb age of 597±18 Ma (Aleinikoff and others, 1995).

Paleozoic Clastic Metasedimentary Rocks of the Chilhowee Group

The Lower Cambrian Chilhowee Group (Safford, 1856) consists of the Loudoun, Weverton, Harpers, and Antietam Formations. The contact between the rocks of the Chilhowee Group and the underlying rocks of the Catoctin Formation is conformable to locally unconformable. Rip-up clasts of phyllite, metabasalt, and red jasper from the Catoctin Formation record a period of erosion before deposition of the Loudoun Formation. Rocks of the Chilhowee Group represent a fluvial to shallow-marine transgressive sequence exhibiting a depositional transition from rift to passive-continental margin, the latter marked by the conformably overlying carbonate rocks.

Loudoun Formation

The Loudoun Formation (Keith, 1894; Stose and Stose, 1946) locally occurs between the Catoctin and Weverton Formations and consists of a thin, discontinuous sequence of predominantly phyllite (_clp) and a minor quartz-pebble conglomerate and pebbly metasandstone (_clc). Rocks of the Catoctin Formation grade into the overlying lower phyllite unit. The phyllite is interpreted to include metamorphosed volcanic tuff, mudstone, and (or) fossil soil (Reed, 1955; Nickelsen, 1956). The discontinuous and lensoid quartz-pebble conglomerate probably represents a local alluvial fan deposit. Cross-stratified beds of quartzite occur locally between the conglomerate and underlying phyllite. The conglomerate also is transitional into the overlying quartzite of the Weverton Formation.

Weverton Formation

The Weverton Formation (Keith, 1894) is divided into three members (in ascending order): the Buzzard Knob Member (_cwb), the Maryland Heights Member (_cwm), and the Owens Creek Member (_cwo) (Brezinski, 1992). The Buzzard

Knob Member is a light, massive, vitreous quartzite interbedded with metagraywacke and metasiltstone. The Maryland Heights Member is a dark, granular quartzite interbedded with dark metasiltstone. The Owens Creek Member is a dark, poorly sorted, crossbedded quartzite and quartz-pebble conglomerate interbedded with dark metasiltstone. The Maryland Heights Member on Catoctin Mountain contains a thick bed of vitreous quartzite that is mapped separately (_cwmq). The Weverton is mapped undivided (_cw) only in the southern part of the quadrangle, west of Bull Run Mountain fault.

Harpers Formation

The Harpers Formation (_ch) (Keith, 1894) is mainly a dark, foliated, quartz-laminated metasiltstone and biotite-chlorite-muscovite-quartz phyllite. Primary sedimentary structures are mostly obscured by recrystallization and cleavage. Rocks of the Harpers Formation on Catoctin Mountain are more strongly foliated and phyllitic than the Harpers' metasiltstone and metashale on Short Hill-South Mountain or on Blue Ridge-Elk Ridge. On Blue Ridge-Elk Ridge, the lower part of the Harpers Formation contains thin beds of pebble conglomerate, which indicate that the lower contact is transitional above the underlying Weverton Formation. The upper part of the Harpers contains thin beds of clean metasandstone (_chs), which contains burrows of the trace fossil *Skolithos linearis*. The metasandstone is transitional into the overlying Antietam Formation (_ca).

Antietam Formation

The Antietam Formation (_ca) (Keith, 1894) consists of a thin-bedded metasandstone and meta-arkose. The unit is exposed only along the Potomac River north of Harpers Ferry, W. Va., and south of Point of Rocks, Md., on Furnace Mountain. The Antietam underlies prominent ridges that are littered with friable float. Locally, the clean metasandstone has worm burrows of the trace fossil *Skolithos linearis*.

Carbonaceous Phyllite

In Loudoun County, Va., south of Point of Rocks, Md., a Lower Cambrian lustrous, gray, laminated, carbonaceous phyllite (_cp) that produces a distinctive dark soil is locally present between rocks of the Antietam Formation and the overlying Tomstown Formation. This unit occupies a stratigraphic position similar to that of the dark shale of the Cash Smith Formation in the Frederick Valley to the north in Maryland. The organic shale and mudstone mark the end of clastic sedimentation prior to the development of an Early Cambrian carbonate shelf.

Tomstown Formation East of Catoctin Mountain

Light-gray dolostone of the Lower Cambrian Tomstown Formation (Stose, 1906) (_t) extends from near the town of Furnace Mountain south of the Potomac River in Loudoun County, Va., north along Catoctin Mountain to west of Frederick, Md. The dolostone is exposed along U.S. Route 15, in a pasture south of the Potomac River, as small outcrops in streams, and is recorded in drill core (Hoy and Schumacher, 1956) to the north in Maryland. This dolostone resembles the Bolivar Heights Member of the Tomstown that is exposed north of Harpers Ferry, W. Va.; however, the Tomstown mapped east of Catoctin Mountain differs from the Tomstown mapped to the west in the Great Valley section of the Valley and Ridge province.

Structure

Mesoproterozoic

Mesoproterozoic foliation in the Blue Ridge province is defined by mineral assemblages typical of granulite-facies metamorphism. At least three episodes of deformation affected the oldest rocks (Burton and others, 1995; Aleinikoff and others, 2000). The northwest-trending foliation (D_1), which locally is parallel to unit contacts, is cut by a weaker foliation with mineral lineations and southeast-plunging sheath folds (D_2). The D_2 features were later deformed into broad, northwest-trending folds (D_3). The D_1 deformation event is younger than the age of crystallization (1,153 Ma) of the oldest granitic gneisses, but is older than the weakly foliated 1,077±4 Ma granite that cuts it. The D_2 deformation occurred after the latest intrusion at 1,055 Ma, and D_3 deformation was still later based on the observation that D_3 features cut D_2 features. Outcrops of ductile folds in gneiss are rare.

The quartz tectonite unit (Yq) that parallels Butchers Branch in the southwestern part of the western Blue Ridge may be a Mesoproterozoic silicified fault rock because it parallels unit contacts and is transected by Paleozoic schistosity and cleavage. Monazite ages from Mesoproterozoic rocks on either side of the Short Hill fault suggest that the gneisses on either side were not in proximity to each other during intrusion, so the fault may have existed at that time.

Neoproterozoic

Two cross faults and one strike-parallel fault southwest of Leesburg, Va., juxtapose the rocks of the Neoproterozoic Fauquier Group and Swift Run Formation against Mesoproterozoic gneiss. These are interpreted to be syndepositional normal faults (Kline and others, 1991). The faults do not appear to cut the rocks of the Neoproterozoic Catoctin Formation, which indicates that they were active prior to extrusion of the Catoctin's metabasalt.

The presence of a metadiabase dike swarm in the basement rocks of the Blue Ridge is strong evidence that a 50 percent extension of the crust occurred during crustal rifting, even though few normal faults have been recognized in the basement gneiss complex. This long period of Neoproterozoic continental extension began with the emplacement of the anorogenic granite of the Robertson River Intrusive Suite at about 722 Ma and continued through the volcanism of the Catoctin Formation at about 565 Ma. The extension ultimately resulted in the opening of the Iapetus Ocean. The dikes and extrusive lava flows of the Catoctin Formation mark the peak of continental rifting activity.

Paleozoic

The rocks of the Blue Ridge province were deformed and metamorphosed during the Paleozoic to produce the Blue Ridge-South Mountain anticlinorium. This event most likely was the result of the late Paleozoic (Permian?) Alleghanian orogeny, although some argon data suggest an earlier Devonian to Mississippian thermal event may have been responsible (Kunk and Burton, 1999). The anticlinorium is a broad, asymmetrical, west-verging, and gently north-plunging fold complex. Gently plunging folds occupy the homoclinal east limb, and more complexly deformed and tightly folded rocks are located on the overturned west limbs. The stratigraphy on the west limb of the anticlinorium is repeated by the Short Hill fault, which is an early Paleozoic (or older?) normal fault that was contractionally reactivated and folded during the formation of the anticlinorium. The formation of the anticlinorium was accompanied by a main fold phase (F_1) and associated axial-planar cleavage (S_1), and a later, minor fold phase (F_2) and associated crenulation cleavage (S_2).

Folds

The Blue Ridge-South Mountain anticlinorium is a large west-verging F_1 fold. The east limb underlies Catoctin Mountain and Furnace Mountain, and the fault-repeated west limbs underlie Blue Ridge-Elk Ridge and the sequence of Black Oak Ridge, Short Hill, and South Mountain. Map-scale F_1 parasitic folds include those on Purcell Knob (which is east of Keys Gap on Blue Ridge), the Hillsboro syncline that underlies Short Hill Mountain and Black Oak Ridge, several synclines of the Swift Run Formation east of Short Hill Mountain, and the Furnace Mountain syncline. These F_1 parasitic folds contain second- and third-order folds.

Later deformation produced open to tight F_2 folds accompanied by axial-planar crenulation cleavage and spaced cleavage, all of which may have been a continuation of the earlier phase of deformation (Nickelsen, 1956; Southworth and others, 2006). F_2 folds superimposed on F_1 folds and S_1 cleavage are exposed on Blue Ridge from Wilson Gap to its terminus north of Rohrersville, Md., and on Catoctin Mountain south of Point of Rocks, Md.

Cleavage

A regional, penetrative, northeast-striking, southeast-dipping S_1 cleavage (South Mountain cleavage of Cloos (1951) and Mitra and Elliott (1980)) overprints Mesoproterozoic foliation and bedding in Neoproterozoic and Cambrian rocks. The S_1 cleavage is axial planar to the Blue Ridge-South Mountain anticlinorium and coeval with its formation. The foliation is slaty to schistose, depending on the host rock.

The S_2 cleavage is discontinuous, is commonly axial planar to F_2 folds, did not involve extensive recrystallization, and formed mostly by pressure solution. S_2 has about the same strike as S_1 but at a slightly steeper dip.

Faults

Paleozoic faults were mapped on the basis of stratigraphic truncation and omission, mylonitic foliation, and localized deformational fabrics. The most regionally extensive faults are also the most enigmatic. The Short Hill fault can be traced about 60 kilometers (km) from a shear zone in Mesoproterozoic rocks in Fauquier Co., Va., south of the Frederick quadrangle, to an area near Rohrersville, Md., where limestone of the Middle and Upper Cambrian Elbrook Formation structurally overlies metabasalt of the Neoproterozoic Catoctin Formation along a flat-lying fault that plunges northward with the Blue Ridge-South Mountain anticlinorium. This fault is interpreted to be an early Paleozoic normal fault that was contractionally reactivated as a thrust fault and then was folded with the anticlinorium (Southworth and Brezinski, 1996a).

The Keedysville marble bed is a mylonite derived from the Bolivar Heights Member of the Tomstown Formation. The mylonite indicates that a regional detachment was present between the carbonate rock sequence and the underlying clastic rocks of the Chilhowee Group before the anticlinorium was folded (Brezinski and others, 1996).

Other intraformational thrust faults, strike-slip faults, and normal faults are either synchronous with or postdate F_1 folding of the anticlinorium. The Mesoproterozoic gneiss contains zones of mylonite and phyllonite that superficially resemble fine-grained, metasedimentary rocks but actually were formed by ductile faulting. The mylonite contains minerals typical of lower-greenschist-facies metamorphism and is probably contemporaneous with the development of coplanar S_1 cleavage. Several shear zones are as much as about 1 km wide and juxtapose different basement gneiss units.

Mesozoic

Several small, brittle normal faults in the Mesoproterozoic rocks may be early Mesozoic (Burton and others, 1995), because they are similar to the family of brittle normal faults that cuts the east limb of the anticlinorium near Point of Rocks, Md. Elsewhere in the Blue Ridge province, the only evidence of Mesozoic structures is the north-trending Early Jurassic diabase dikes.

Metamorphism

Mesoproterozoic

Plutonism, metamorphism, and deformation in the Blue Ridge province spanned about 150 m.y., from about 1,153 to

1,000 Ma (Aleinikoff and others, 2000). Mesoproterozoic deformation and metamorphism ended no earlier than about 1,055 Ma, which is the age of the youngest deformed unit (megacrystic metagranite, Ypb). Granulite-facies mineral assemblages of (1) orthopyroxene and microcline in charnockitic granite and (2) orthopyroxene and brown hornblende in amphibolite show granoblastic texture and triple-junction grain boundaries. Monazite ages (Aleinikoff and others, 2000) indicate that there was no regional thermal event hotter than 720°C that affected the rocks after the Grenville orogeny. The ^{40}Ar/^{39}Ar age of hornblende from a Grenville rock provides a cooling date of 1,000 to 920 Ma (Kunk and others, 1993), which could be designated as the minimum age for regional metamorphism in this area.

Paleozoic

Paleozoic deformation was accompanied by recrystallization under lower-greenschist-facies metamorphic conditions. The formation of S_1 cleavage was accompanied by the growth of fine-grained muscovite, chlorite, biotite, epidote, actinolite, and accessory minerals in the rocks of the Neoproterozoic and Lower Cambrian cover sequence. Biotite is only recognized in cover rocks on the east limb of the Blue Ridge-South Mountain anticlinorium. Some of the cover rocks show multiple generations of white muscovite-sericite, suggesting a complex metamorphic history. Retrograde mineral assemblages of muscovite, biotite, and chlorite replaced feldspar, brown biotite, and garnet in Mesoproterozoic gneisses; Neoproterozoic metadiabase dikes and metabasalt contain actinolite, chlorite, and epidote. The age of metamorphism and deformation is poorly constrained but is usually attributed to the late Paleozoic Alleghanian orogeny (Mitra and Elliott, 1980). The Blue Ridge province rocks were transported westward during the Alleghanian orogeny (Evans, 1988), but the metamorphism and deformation that they exhibit may be older.

Piedmont Province

Geologic Setting

The Piedmont, which means “foot of the mountain,” is the province east of the lower slope of Catoctin Mountain in the Blue Ridge province. In the eastern part of the province, crystalline rocks of the Potomac terrane were thrust onto metamorphic rocks of the Westminster terrane along the Pleasant Grove fault. The metasedimentary and metavolcanic rocks of the Westminster terrane were thrust westward along the Martic fault onto metasedimentary rocks now exposed in the Sugarloaf Mountain anticlinorium and Frederick Valley synclinorium. Except for some valleys underlain by carbonate rocks, the Piedmont is a dissected plateau. Rocks of the Sugarloaf Mountain anticlinorium and Frederick Valley synclinorium are correlative with rocks of the Blue Ridge anticlinorium and the Massanutten synclinorium (Great Valley), respectively, and they also have similar landforms. Mesozoic sedimentary rocks of the Culpeper and Gettysburg basins unconformably overlie the older rocks. The sedimentary rocks were intruded by diabase dikes and sills.

Culpeper and Gettysburg Basins

In the Frederick 30′ × 60′ quadrangle, Triassic and Jurassic sedimentary and volcanic rocks were formerly assigned to the Culpeper Group (Lee, 1979, 1980), which was in turn divided informally into a lower part and an upper part. The former lower part was revised as the Chatham Group, and the former upper part was revised as the Meriden Group by Weems and Olsen (1997). In this quadrangle, the Chatham Group includes the mainly Upper Triassic sequence of continental sedimentary rocks and some basalt; the Meriden Group includes the Lower Jurassic series of basalt flows and intercalated sedimentary rocks (Midland Formation, Hickory Grove Basalt, Turkey Run Formation, and Sander Basalt) (Lee and Froelich, 1989). Both the Chatham and Meriden Groups belong to the Newark Supergroup (Froelich and Olsen, 1984).

Chatham Group.—Consisting of Manassas Sandstone, Bull Run Formation, Catharpin Creek Formation, and Mount Zion Church Basalt.

Manassas Sandstone

The Upper Triassic Manassas Sandstone (Lee, 1977, 1979) is divided into the Reston Member (Lee, 1977) (^cmr), the Tuscarora Creek Member (Lee, 1977) (^cmt), and the Poolesville Member (Lee and Froelich, 1989) (^cmp). The rocks assigned here to the Tuscarora Creek Member and the Poolesville Member in the Culpeper basin have been called the New Oxford Formation by workers in Maryland and Pennsylvania (Cleaves and others, 1968; Berg and others, 1980). These rocks were deposited by braided streams that flowed across a lowland.

The Reston Member (^cmr) is the basal conglomerate that is faulted against and unconformably overlies older metasedimentary rocks of the Potomac and Westminster terranes. The conglomerate is composed of cobbles, pebbles, and boulders of micaceous quartzite, phyllite, metagraywacke, and schist in an arkosic matrix of sand, clay, muscovite, and feldspar. The deposits are lensoid and discontinuous, which indicates that they are probably channel deposits of a river system.

The Tuscarora Creek Member (^cmt) is a basal conglomerate that unconformably overlies carbonate rocks of the Upper Cambrian Frederick Formation (and rocks of the Urbana Formation at one locality). Although the Tuscarora Creek is laterally equivalent to the Reston Member, the clasts are from different source rocks. The Tuscarora Creek contains limestone and dolostone clasts derived from the Frederick and possibly the Grove Formations. The conglomerate locally is lensoidal and discontinuous as it represents debris-flow channels incised into an alluvial fan. In the subsurface along the western margin of the basin, the conglomerate is probably the base of the stratigraphically higher conglomerate in the Leesburg Member of the Bull Run Formation.

The Poolesville Member (^cmp) is an arkosic, muscovite-rich sandstone interbedded with siltstone containing sparse quartz pebbles that fines upward. The base of the unit is transitional with the underlying Reston and Tuscarora Creek Members. The Poolesville Member also grades up into the overlying Balls Bluff Member of the Bull Run Formation; therefore, the contact between the two units is gradational and approximately located.

Bull Run Formation

Rocks previously assigned to the Upper Triassic Balls Bluff Siltstone by Lee (1977, 1979) are now assigned to the Bull Run Formation, which consists of the Leesburg Member, the Balls Bluff Member, and the Groveton Member by Weems and Olsen (1997). The three members are laterally equivalent, but are characterized by different lithologies that represent variable depositional environments. As the climate changed from wet to dry, alluvial fans formed and extended from the highlands west of the border fault onto playas with lakes and intermittent streams. The resulting deposits are conglomerates interbedded with sandstone and siltstone at every scale.

The Leesburg Member (^cbl) is a conspicuous carbonate conglomerate composed of subangular to subrounded boulders, cobbles, and pebbles of limestone and dolostone in a sandy siltstone matrix. The source of the carbonate rock clasts includes the limestone and dolostone of the Tomstown, Frederick, and Grove Formations. The conglomerate intertongues with the sandstone and siltstone of the Balls Bluff Member and forms a complex map pattern. The sandstone and siltstone then pinch out to the west. This unit is similar to the conglomerate of the Tuscarora Creek Member (^cmt) of the Manassas Sandstone and is probably stratigraphically continuous with it in the subsurface.

The Balls Bluff Member (^cbb) is mainly feldspathic, silty sandstone interbedded with clayey and sandy siltstone in cyclic sequences as much as 3 m thick. The unit is gradational with the underlying Poolesville Member of the Manassas Sandstone, intertongues laterally with rocks of the Groveton Member and Leesburg Member of the Bull Run Formation, and is overlain unconformably by rocks of the Upper Triassic and Lower Jurassic Catharpin Creek Formation (J^cc).

The Groveton Member (^cbg) is mostly a thin-bedded to laminated, silty and sandy lacustrine shale interbedded with clayey and sandy siltstone in cyclic sequences 3 to 9 m thick. The unit is gradational with the underlying Balls Bluff Member and is considered to be a lateral equivalent. The rocks are also conformably overlain by rocks of the Catharpin Creek Formation. The shale is poorly exposed but can be traced by shale chips in soil.

Catharpin Creek Formation

The Upper Triassic and Lower Jurassic Catharpin Creek Formation (J^cc) consists of cyclic sequences of interbedded sandstone, siltstone, and conglomerate as much as 30 m thick. The contact with the underlying Upper Triassic Bull Run Formation is gradational and intertonguing, but the contact with the overlying Lower Jurassic Mount Zion Church Basalt (Jcm) is a sharp disconformity. When this unit was deposited, the climate had once again become wetter; therefore, mainly fluvial to lacustrine deposits accumulated.

The Goose Creek Member (J^ccg) of the Catharpin Creek Formation is a lenticular body of conglomerate composed of subrounded pebbles and cobbles of quartzite, metabasalt, metasiltstone, gneiss, limestone, and vein quartz, all derived from rocks of the Blue Ridge province. The conglomerate is interbedded with pebbly arkosic sandstone and its matrix is locally rich in calcite. Like the conglomeratic rocks of the Tuscarora Creek Member (^cmt) of the Manassas Sandstone and the Leesburg Member (^cbl) of the Bull Run Formation, the Goose Creek Member probably represents a debris-flow channel incised into an alluvial fan; the distinction between the Goose Creek Member and the other two units is the source and composition of its clasts. The resistant clasts exposed at the surface of this unit remain as a lag gravel deposit.

Mount Zion Church Basalt

The Lower Jurassic Mount Zion Church Basalt (Jcm) is a high-titanium, quartz-normative tholeiitic basalt. Vesicles and amygdules at the tops indicate one or two flows. The basalt underlies a low ridge but is poorly exposed.

Meriden Group.—Consisting of Midland Formation, Hickory Grove Basalt, Turkey Run Formation, and Sander Basalt.

Midland Formation

The Lower Jurassic Midland Formation (Jmm) consists of cyclic sequences of interbedded siltstone, sandstone, and shale. Lenticular deposits of variegated cobble and pebble conglomerate and conglomeratic arkosic sandstone (Jmmc) are mapped separately. The conglomeratic strata represent alluvial fans that prograded eastward into lakes situated on playas. Shale and siltstone contain the remains of the abundant and diverse fish that lived in the lakes.

Hickory Grove Basalt

The Lower Jurassic Hickory Grove Basalt (Jmh) consists of two or three flows of high-titanium, high-iron, quartz-normative tholeiitic basalt with vesicles and amygdules locally at the tops of flows. Locally, the flows are separated by sandstone and siltstone (Jmhs) that, in places, are disconformable with both the underlying and overlying strata.

Turkey Run Formation

The Lower Jurassic Turkey Run Formation (Jmt) consists of cyclic sequences of interbedded sandstone, siltstone, conglomerate, and shale. The conglomerate (Jmtc) is composed of subrounded boulders, cobbles, and pebbles of metabasalt, quartzite, marble, quartz, and basalt. Like the Midland Formation, these deposits represent alluvial fans that prograded into lakes on a playa that were later covered with basaltic lava flows.

Sander Basalt

The Lower Jurassic Sander Basalt (Jms) is the uppermost unit of basalt flows and sedimentary rocks and is the youngest bedrock in the map area. The stratigraphically lower flows of the Sander are high-titanium, high-iron, quartz-normative basalts. Poorly exposed sandstone and siltstone (Jmss) separates the lower flows from the stratigraphically higher flows of low-titanium, quartz-normative basalt. The Sander Basalt has distinctive curved columnar joints.

Thermally Metamorphosed Rocks

The Upper Triassic and Lower Jurassic strata (J^tm) of the Newark Supergroup were thermally metamorphosed by diabase intrusions (Jd, Jdc, Jdh, Jdg). Zoned contact aureoles in the country rock may be seen adjacent to the diabase. The largest contact aureoles are found adjacent to the diabase sills along the Dulles Greenway (Virginia State Route 267) at Belmont Ridge in Loudoun County, Va., and near Boyds, Md. Thin aureoles may be seen adjacent to narrow diabase dikes. Siltstone and shale are altered to cordierite-spotted hornfels in the inner aureole; epidote-chlorite hornfels characterizes the outer aureole. Sandstone is metamorphosed to tourmaline granofels and (or) quartzite; carbonate conglomerate is metamorphosed to marble.

Diabase Dikes and Sills

Early Jurassic diabase from three varieties of magma is mapped in the Culpeper and Gettysburg basins (Froelich and Gottfried, 1988). Both the olivine-normative diabase and the low-titanium, quartz-normative tholeiitic diabase occurs as dikes (Jd). High-titanium, quartz-normative tholeiitic diabase (Jdh) occurs as both narrow dikes and thick, differentiated sills that contain cumulates (mapped separately as unit Jdc) in the lower parts and late-stage differentiates in the higher parts. The differentiates include granophyre (mapped separately as unit Jdg), ferrogabbro, diorite, syenite, and aplite. The thin sills and thicker sheets of diabase are irregular in shape. The dikes are linear, discontinuous, and were emplaced en echelon along dilated fractures. The diabase dike exposed along the Maryland side of the Potomac River, between Sandy Hook and Weverton, has an $^{40}Ar/^{39}Ar$ age of 200 Ma (Kunk and others, 1992).

Frederick Valley Synclinorium

Araby Formation

The Lower and Middle Cambrian Araby Formation (_ar) (Reinhardt, 1974, 1977) consists of burrow-mottled sandy metasiltstone whose bedding is obscured by structural foliations. The metasiltstone is interpreted as a deepwater-slope facies of a starved clastic basin (Reinhardt, 1974). The Araby Formation is conformably overlain by limestone and limestone breccia of the Rocky Springs Station Member of the Frederick Formation. In the northeastern part of the Frederick Valley, within the map area, metashale beds thicken near the top of the unit.

Cash Smith Formation

The Middle and Upper Cambrian Cash Smith Formation (Edwards, 1988) (_cs) is a dark shale and slate that grades up into thin-bedded, calcareous shale with limestone nodules. The Cash Smith is transitional between the metasiltstone of the underlying Araby Formation and the shale of the overlying Rocky Springs Station Member (_frs) of the Frederick Formation. Although the Cash Smith is similar to the dark shale beds within the mostly carbonate Rocky Springs Station Member, neither unit can be continuously mapped across the synclinorium.

Frederick Formation

The Upper Cambrian Frederick Formation (Frederick Limestone of Keyes, 1890; Stose and Stose, 1946; Reinhardt, 1974, 1977) is a thick interval of limestone and dolostone that contains thin intervals of shale and sandstone. The Frederick Limestone was renamed Frederick Formation by Southworth and Brezinski (2003), and the three members of Reinhardt (1974, 1977) are shown on the map; in ascending order, they are the Rocky Springs Station, Adamstown, and Lime Kiln Members. The Rocky Springs Station Member (_fr) is characterized by intervals of polymictic breccia that may be traced locally. This lower member was deposited by offshelf submarine slides that accumulated at the toe of a paleoslope (Reinhardt, 1974). An interval of grayish-black shale (_frs) that is similar to the shale of the Cash Smith Formation (which locally underlies the unit to the north) is interbedded with the limestone.

The Adamstown Member (_fa) consists of thinly bedded limestone and thin intervals of shale that were probably deposited in an oceanic basin (Reinhardt, 1974). The Lime Kiln Member (_fl) consists of thinly bedded limestone interbedded with algal limestone at the top of the formation. This upper member appears to record aggradation from ocean-basin deposition to shallow-shelf deposition (Reinhardt, 1974).

Grove Formation

The Upper Cambrian and Lower Ordovician Grove Formation (Stose and Jonas, 1935; Jonas and Stose; 1938b;

Reinhardt, 1974) is an interval of carbonate rock in the center of the Frederick Valley. The Grove consists of two informal members. The lower member (O_gl) consists of crossbedded, sandy limestone; sandy dolomitic limestone; and sandy dolostone that, as a package, is distinct from the underlying and overlying strata. These rocks were probably deposited on the shelf edge as a sand wave complex.

Above the basal limestone and dolostone member are limestone and dolostone of the upper member (O_gu). The strata are arranged in cycles consisting of thrombolitic and stromatolitic limestone and laminated dolostone that were deposited in a peritidal environment.

Sugarloaf Mountain Anticlinorium and Bush Creek Belt

Sugarloaf Mountain Quartzite

The Lower Cambrian Sugarloaf Mountain Quartzite (Jonas and Stose, 1938b) is a medium-bedded to massive quartzite cemented by silica and sericite. Crossbeds, graded beds, and sparse ripple marks show that these are continental-margin deposits laid down in shallow water. Poorly exposed laminated metasiltstone is interbedded with the quartzite. The Sugarloaf Mountain Quartzite is subdivided into informal lower (_sql), middle (_sqm), and upper (_squ) members. The upper member is well exposed at the summit of Sugarloaf Mountain, the middle member forms the prominent ridge north of the summit (which may be traversed by following the Northern Peaks trail), but the lower member is poorly exposed (Southworth and Brezinski, 2003).

Urbana Formation

The Lower Cambrian(?) Urbana Formation (Urbana Phyllite of Jonas and Stose, 1938b; Edwards, 1986) conformably overlies the Sugarloaf Mountain Quartzite and is structurally overlain by rocks of the Ijamsville Formation along the Martic fault. The Urbana Formation (_u) consists of quartzite, calcareous metasandstone, metagraywacke, and metasiltstone, all of which cannot be differentiated because of poor exposure and the interbedding of all the rock types; however, there are mappable bodies of marble (_um) and quartzite (_uq). Most of the rock units in the Urbana Formation are discontinuous lenses that are sandy, calcareous, friable, or deeply weathered and thus are poorly exposed. The quartzite, metasandstone, and metasiltstone are crossbedded and ripple-marked, which indicates that they were deposited in shallow water. Schistose to massive, sandy, chlorite-rich marble (_um) is interbedded with metasiltstone and metasandstone. Massive quartzite (_uq) interbedded with vuggy calcareous metasandstone mapped within broad belts of metasiltstone are probably local channel deposits and not a continuous stratigraphic horizon.

Metasiltstone, calcareous metasandstone, marble, and quartzite crop out along Bush Creek. These rocks are lithologically and structurally identical to rocks of the Urbana Formation mapped to the west, and they are surrounded by Ijamsville Phyllite. The rocks along Bush Creek are interpreted to be the Urbana Formation exposed beneath the Martic thrust sheet in a tectonic window (Southworth, 1999).

Westminster Terrane

Prettyboy Schist

The Neoproterozoic(?) and Lower Cambrian(?) Prettyboy Schist (Crowley, 1976) (_Zp) is quartz-muscovite-chlorite-albite schist and muscovite-quartz-albite schist containing characteristic white, euhedral albite porphyroblasts and oxidized cubes of pyrite. The Prettyboy Schist may be a coarser, distal-facies equivalent of the rocks of the Marburg Formation (Drake, 1994; Howard, 1994). However, the Prettyboy rocks exhibit a higher metamorphic grade, thus making the gradational contact between the two units a metamorphic isograd (Fisher, 1978). The Prettyboy Schist crops out in two areas interpreted to be antiforms within the northeastern part of the Westminster terrane in the northeastern corner of the quadrangle. Massive to schistose metabasalt (_Zpb) forms a lensoidal body within the schist of the northernmost antiform. Granular quartzite (_Zpq), as much as 1 m thick, is interbedded with the schist (_Zp) in sequences as thick as 30 m.

Marburg Formation

The Neoproterozoic(?) and Lower Cambrian(?) Marburg Formation (Drake, 1994) (Marburg Schist of Jonas and Stose, 1938b) consists of phyllitic metasiltstone (_Zmbs) and small bodies of metagraywacke (_Zmbg), metabasalt (_Zmbb), and quartzite (_Zmbq). Quartz-sericite-chlorite metasiltstone contains local chloritoid and albite porphyroblasts, and chlorite-albite metasiltstone contains ribbons and laminae of quartz 0.25 cm thick. Both of these varieties of the Marburg are impregnated with vein quartz and are highly folded. Thin layers and lenses of muscovite-chlorite-paragonite-hematite phyllite that are lithologically similar to rocks of the Ijamsville Phyllite are locally seen within the fine-grained rocks but are too small to map. The quartz laminae in the metasiltstone may be the result of both sedimentary (turbidite) and metamorphic processes.

Metagraywacke (_Zmbg) consists of a dark, quartz-rich granular graywacke locally interbedded with the phyllite and metasiltstone (_Zmbs). The small metabasalt body south of Barnesville, Md. (_Zmbb), is interpreted to be an epiclastic deposit. The quartzite (_Zmbq) is medium to coarse grained with a high chlorite content.

The contact between the rocks of the Marburg Formation and the Sams Creek Formation is the Hyattstown thrust fault, but rocks of the Marburg Formation may stratigraphically underlie rocks of the Sams Creek Formation in the northern part of the map near Sams Creek, Md. North of Winfield, Md., the Marburg Formation is interpreted to structurally overlie the Prettyboy Schist. The Marburg Formation contains a minor amount of hematitic phyllite that resembles rocks of the Ijamsville Phyllite, although the rock units never come into contact. The Marburg Formation contains some fine-grained albite schist that is similar to the coarse-grained albite schist of the Prettyboy Schist. Because of these two lithologic similarities, the Marburg Formation may be a transitional facies between the Ijamsville Phyllite and Prettyboy Schist; otherwise, the Marburg rocks are unique to this region. The rocks mapped here as Marburg Formation were previously assigned to the Wissahickon Formation by Fisher (1978) and to the Gillis Group by Edwards (1986, 1994).

Ijamsville Phyllite

The Neoproterozoic(?) and Lower Cambrian(?) Ijamsville Phyllite (Jonas and Stose, 1938b) consists of eight mappable varieties: phyllite (_Zip), metabasalt (_Zib), quartzite (_Ziq), marble (_Zim), metalimestone (_Zil), phyllitic conglomerate (_Zic), conglomeratic metagraywacke (_Zicm), and chloritic phyllite (_Zicp). The Ijamsville is mapped in four distinct belts as follows: (1) from the type locality at Ijamsville, Md., south to Beallsville, Md., (2) in a klippe of the Martic fault west of Sugarloaf Mountain, (3) between the klippe and rocks of the Sams Creek Formation near Chestnut Grove, and (4) above the Martic fault east of Sugarloaf Mountain.

The muscovite-chlorite-paragonite-chloritoid phyllite variety (_Zip) often has composite foliations and abundant quartz veins that are folded and transposed to form phyllonites with dull-green clots and patches of retrograde chlorite. The least deformed fine-grained rocks are slates that were quarried for roofing material as early as 1880 (Dale and others, 1914). Bedding in the slate is locally expressed as thin bands of opaque minerals on cleavage surfaces. The dark color of the phyllite and slate results from abundant minute hematite crystals.

Metabasalt (_Zib) contains nodules of epidosite and sparsely crops out as flattened pillows north of Beallsville, Md. Locally, centimeter-thick metabasalt is interlayered with phyllite. Yellowish-gray, massive, fine- to medium-grained quartzite (_Ziq) is interbedded with phyllite, but the bodies are discontinuous and probably represent channel deposits.

Thin-bedded metalimestone (_Zil) containing black carbonaceous phyllite is surrounded by phyllite near the mouth of the Monocacy River. The thin, argillaceous metalimestone may be olistoliths (large clasts) deposited in deepwater mud. The metalimestone resembles the Silver Run Limestone of Jonas and Stose (1938b) and Fisher (1978) (Southworth, 1998). Three pods of sandy limestone (_Zim), 10 cm to 3 m long, are found within conglomeratic phyllite (_Zip) west of the type locality at Ijamsville. The marble is also interpreted to be olistoliths deposited by debris flows in deepwater mud.

An unusual outcrop of phyllitic conglomerate (_Zic) north of Bush Creek and west of Monrovia, Md., is composed of fist-sized, flat chips of muscovite-chlorite phyllite supported by a dark matrix rich in detrital heavy minerals that include zircon, ilmenite, and magnetite. The protolith of this rock is interpreted to be a submarine debris flow.

Chloritic phyllite and metasiltstone (_Zicp) are interbedded with conglomeratic metagraywacke (_Zicm) near Chestnut Grove, Md. The conglomeratic metagraywacke has distinctive subrounded pebbles of white quartz and tan lithic clasts in a green, chloritic siltstone matrix. Large boulders of the distinctive rock litter the uplands, but exposure is poor. The detrital material in the conglomeratic metagraywacke was derived from greenschist-facies metasedimentary rocks with abundant vein quartz, but the source is unknown.

The chloritic phyllite unit (_Zicp) is interlayered with the hematitic phyllite at the type locality of the formation. Northward from the type locality, the phyllite is conglomeratic, contains phyllite and marble clasts and marble lenses, and is interbedded with quartzite of the Sams Creek Formation. Near Linganore Creek, phyllite interbedded with 0.5-m-thick quartzite transitions northward into thick-bedded quartzite that is interbedded with thin layers of phyllite and rip-up clasts of phyllite.

Sams Creek Formation

The Neoproterozoic(?) and Lower Cambrian(?) Sams Creek Formation (Jonas and Stose, 1938b) contains 11 mappable varieties: metabasalt (_Zsb), felsic schist (_Zsf), marble (_Zsm), tuffaceous phyllite (_Zstp), muscovitic phyllite (_Zsmp), hematitic phyllite (_Zshp), metalimestone (_Zsl), quartzite interbedded with phyllite (_Zsqp), quartzite (_Zsq), metasiltstone (_Zss), and calcareous metasandstone (_Zsc). Metabasalt (_Zsb) is mostly massive, aphanitic to porphyritic, and contains calcite-filled amygdules and epidosite nodules. In several places, the metabasalt is a hyaloclastite breccia composed of fragmented metabasalt, a conglomerate of elongated metabasalt clasts, and epiclastic deposits of weathered metabasalt. The metabasalt is interpreted to be metamorphosed basalt flows that were intercalated with beds of quartzite, metasiltstone, phyllite, and marble. The flows are chemically identical to tholeiitic basalt of the Catoctin Formation of the Blue Ridge-South Mountain anticlinorium to the west (Southworth, 1999). Felsic metavolcanic and metavolcaniclastic schist (_Zsf) is interlayered with metabasalt in one place, just west of Fountain Mills.

Massive to thin-bedded, calcitic and dolomitic marble (_Zsm) occurs as linear pods in three different types of Sams Creek phyllite as well as in metabasalt and quartzite in different stratigraphic positions. These marble pods are interpreted to be olistoliths. Several bodies that are as long as 1 km and as wide as 0.5 km are within a “calico” phyllite-clast conglomerate.

Tuffaceous phyllite (_Zstp) is a metavolcaniclastic phyllite that was formerly called the Libertytown Metarhyolite (Jonas and Stose, 1938b). Muscovitic phyllite (_Zsmp) is extensive in the eastern belt of the Sams Creek Formation, adjacent to the thrust sheet of rocks of the Marburg Formation. Hematitic phyllite (_Zshp) closely resembles rocks of the

Ijamsville Phyllite but is interlayered with tuffaceous phyllite that is not recognized in Ijamsville Phyllite to the south. Metalimestone (_Zsl) is identical to metalimestone of the Ijamsville Phyllite and occurs mostly within phyllite (muscovitic, tuffaceous, or hematitic varieties), but one body is adjacent to metabasalt (_Zsb) and another body is above marble (_Zsm).

The quartzite interbedded with phyllite (_Zsqp) is mostly medium-grained quartzite interbedded with phyllite, phyllite-clast conglomerate, and tuffaceous phyllite. The unit is mapped near Lake Linganore, southeast of McKaig, Md. The quartzite, which is similar to that of the Weverton Formation and the Sugarloaf Mountain Quartzite, is interbedded with rocks that can be traced to the type locality of the Ijamsville Phyllite. The variegated phyllite-clast conglomerate and tuffaceous phyllite are associated with marble and metavolcanic rocks of the Sams Creek elsewhere.

Medium-grained quartzite of the Sams Creek Formation (_Zsq) is locally crossbedded and calcareous and probably represents channel deposits within all the other units of the formation. Metasiltstone (_Zss) locally interbedded with quartzite and calcareous metasandstone resembles rocks of the Urbana Formation (Jonas and Stose, 1938a), but the Sams Creek rocks contain metabasalt and the Urbana rocks do not. Friable, coarse-grained, calcareous metasandstone (_Zsc) with large, high-angle crossbeds appears to be overlain by metabasalt (_Zsb) south of Monrovia, Md.

Wakefield Marble

The Neoproterozoic(?) and Lower Cambrian(?) Wakefield Marble (Jonas and Stose, 1938b) (_Zw) is a dolomitic to calcitic marble that can be traced continuously from the northern edge of the map area northward to the type locality in Wakefield Valley in the adjacent New Windsor 7.5-minute quadrangle, where it stratigraphically overlies metabasalt of the Sams Creek Formation (Fisher, 1978). The Wakefield Marble is interpreted to represent shallow-water deposits on submerged islands of basalt (Fisher, 1978). Because the Wakefield is identical to large clasts of marble within both the Sams Creek Formation and Ijamsville Formation, the significance of its stratigraphic position is uncertain.

Potomac Terrane

Metagabbro, Ultramafic Rocks, the Soldiers Delight Ultramafite, and Metatuff

Dark-green and black, fine- to medium-grained metagabbro containing layers of metapyroxenite (_Zg), as well as serpentinite, soapstone, chlorite-tremolite-epidote schist, talc-chlorite schist, and talc-calcite-actinolite schist (mapped together as _Zu), constitute blocks of mafic and ultramafic rock that were emplaced during deposition of turbidites of the Mather Gorge Formation. The Soldiers Delight Ultramafite (_Zsd) (Drake, 1994) is serpentinite that has been sheared and altered to talc schist and soapstone between the Brinklow and Henryton thrust faults. The ultramafite constitutes a fault block that separates the Sykesville Formation (_s) to its west from the Loch Raven Schist (_Zl). Chemical data suggest that the rock originally was pyroxenite that formed beneath the ocean floor (Drake, 1994).

Metasedimentary Rocks

The Mather Gorge Formation (Drake and Froelich, 1997) mostly consists of quartz-rich schist (_Zms), metagraywacke (_Zmg), migmatite (_Zmm), phyllonite (_Zmp), and metatuff (_Zmt). The metagraywacke and schist are interpreted to be deepwater turbidites deposited in a large submarine fan under fairly high-energy conditions (Drake, 1989). In the eastern part of the unit, some of these metasedimentary rocks were later partially melted to form migmatites and sheared to form phyllonites.

The schist unit (_Zms) includes a quartz-muscovite-chlorite-plagioclase-epidote-magnetite-hematite mineral assemblage. Locally, the unit is a muscovitic gneiss containing interbedded metagraywacke and some small blocks of calc-silicate rock.

The well-bedded metagraywacke unit (_Zmg) also contains semipelitic schist, quartzose schist, and some calc-silicate rock interbeds. Metagraywacke beds range from 3 cm to as much as 3 m thick but average about 15 cm. Metagraywacke beds are graded and have sole marks and slump features that are preserved even though the original rocks were subjected to sillimanite-grade metamorphism (Hopson, 1964). In the eastern part of the map unit's areal extent, some of the schist and metagraywacke was partially melted to form stromatic and, less commonly, phlebitic migmatite (_Zmm) (Mehnert, 1971) consisting of a quartz-plagioclase leucosome and a quartz-rich schist paleosome. In the extreme eastern part of the map unit's areal extent, the schist and metagraywacke were locally sheared in broad fault zones. The resulting rock is a lustrous, fine-grained chlorite-sericite phyllonite (_Zmp) containing knots and pods of white vein quartz.

Metatuff (_Zmt) consists of hornblende-plagioclase-quartz-muscovite, felsic, schistose metamorphosed tuff. It is interpreted to be part of a sparse sequence of interlayered mafic and felsic metavolcanic rocks near Great Falls, Va.

The Northwest Branch Formation (_Zn) (Drake, 1998) consists of well-bedded meta-arenite and lesser quartzite and calc-silicate rock. Beds range from 1.3 cm to 1.2 m in thickness and are interbedded with schist similar to that in the overlying Loch Raven Schist.

The Loch Raven Schist (_Zl) (Crowley, 1976) is a thin-bedded, lustrous, quartz-muscovite-biotite-plagioclase schist that, in places, contains garnet, staurolite, and (or) chlorite. The schist is interbedded with semipelitic schist and meta-arenite (_Zlm) and is similar to the underlying Northwest Branch Formation into which it grades.

The Oella Formation (_Zo) (Crowley, 1976) is quartz-plagioclase-biotite-muscovite meta-arenite interbedded with quartz-muscovite-plagioclase schist similar to the underlying

Loch Raven Schist into which it grades. The meta-arenite beds range from 1 cm to about 1 m in thickness.

The Laurel Formation (_l) (Hopson, 1964) is a sedimentary mélange consisting of a quartzofeldspathic matrix that contains quartz grains and fragments of meta-arenite and muscovite-biotite schist, and large porphyroblasts of muscovite. The upper part of the formation (_lu) contains more than 50 percent olistoliths of meta-arenite and muscovite-biotite schist that are locally as long as 5 to 10 m.

The Sykesville Formation (_s) (Hopson, 1964) is also a sedimentary mélange consisting of a quartzofeldspathic matrix that contains distinctive round, eye-shaped quartz lumps and blocks of phyllonite (_Zmp), migmatite (_Zmm), and metagraywacke (_Zmg) of the Mather Gorge Formation; as well as mafic and ultramafic rocks (_Zu), metafelsite, and plagiogranite. The upper part of the formation locally contains 50 percent or more of phyllonite and schist lenses interpreted to be olistoliths derived from the Mather Gorge Formation (Drake, 1989; Muller, 1994).

Cambrian, Ordovician, and Devonian Intrusive Rocks

Intrusive rocks include Ordovician quartz bodies; the Ordovician(?) Bear Island Granodiorite; the Early Ordovician Georgetown Intrusive Suite and Dalecarlia Intrusive Suite; the Middle Ordovician Kensington Tonalite; the Late Ordovician Norbeck Intrusive Suite; and the Late Devonian Guilford Granite and pegmatites.

The Ordovician(?) Bear Island Granodiorite (Cloos and Cooke, 1953) (Ob) is a leucocratic muscovite-biotite granodiorite and related pegmatite composed of quartz, albite, and microcline. The granodiorite and pegmatite form small- to medium-size sheets, sills, and dikes in migmatite and phyllonite of the Mather Gorge Formation. These bodies extend a distance of 18 km from Bear Island northeast to the Plummers Island fault.

The Early Ordovician Dalecarlia Intrusive Suite (Drake and Fleming, 1994) consists of biotite monzogranite and granodiorite (Odm), leucocratic muscovite-biotite monzogranite (Odl), and muscovitic trondhjemite (Odt) that intrudes rocks of the Sykesville Formation, Georgetown Intrusive Suite, and Norbeck Intrusive Suite. Biotite monzogranite and lesser granodiorite contain lenses, zones, and irregular pods of leucocratic muscovite-biotite monzogranite. The biotite monzogranite has a U-Pb single crystal sensitive high-resolution ion microprobe (SHRIMP) age of 478±6 Ma (Aleinikoff and others, 2002). South of Olney, Md., muscovitic trondhjemite encloses a very small body of leucocratic monzongranite; these two Dalecarlia units are in turn enclosed by biotite-hornblende tonalite of the Norbeck Intrusive Suite (described below).

The Early Ordovician Georgetown Intrusive Suite (Fleming and others, 1994) consists of biotite-hornblende tonalite (Ogh), quartz gabbro (Ogg), and metapyroxenite (Ogp) that intrude rocks of the Sykesville Formation in Washington, D.C., to the south. In this quadrangle, they are found within the Sykesville Formation in southern Rockville, Md. Biotite-hornblende tonalite has a strong relict-igneous-flow foliation in places. The tonalite contains many ultramafic and mafic xenoliths and (or) autoliths, as well as xenoliths of metasedimentary rocks; mafic minerals, therefore, typically make up 50 percent of the tonalite. Radiometric dating methods have yielded a concordant conventional U-Pb age of 466±3 Ma and a single-crystal U-Pb age of 472±4 Ma (Aleinikoff and others, 2002). Quartz gabbro (Ogg) also contains lesser diorite and even lesser quartz norite. At many places, the unit contains thin cumulate layers of metapyroxenite and augite-hornblende rock. Metapyroxenite (Ogp) is mostly altered to dark-grayish-green serpentinite. Small pods and a swarm of metapyroxenite xenoliths occur within or along the borders of the larger tonalite and quartz-gabbro plutons.

The Middle Ordovician Kensington Tonalite (Cloos and Cooke, 1953; Fleming and others, 1994) (Ok) intruded rocks in the eastern belt of the Sykesville Formation near the Rock Creek shear zone and the Brinklow thrust fault. In and near these fault zones, the unit is intensely foliated to mylonitic muscovite-biotite granodiorite that contains augen and coarse porphyroblasts of microcline. The rock has a single-crystal U-Pb age of 463±8 Ma (Aleinikoff and others, 2002).

Veins, lenses, and irregular bodies of massive, foliated, and jointed vein quartz of several different ages have intruded rocks in the eastern Piedmont. Map-scale quartz bodies (Oq) intruded schist and phyllonite of the Mather Gorge Formation, mélange of the Sykesville Formation, schist of the Oella Formation, tonalite of the Norbeck Intrusive Suite, and the Kensington Tonalite. Loose boulders of quartz commonly litter the upland as the silica is very resistant to physicochemical weathering. One of the largest bodies of quartz is Annapolis Rock, a prominent hill located immediately northeast of the Patuxent River, east of Damascus, Md.

The Late Ordovician Norbeck Intrusive Suite (Drake, 1998) consists of biotite-hornblende tonalite (Ont), quartz gabbro (Ong), ultramafic rocks (Onu), and trondhjemite (Ontr). Most of these bodies intrude rocks of the Sykesville Formation. Biotite-hornblende tonalite contains many xenoliths and (or) autoliths of more mafic rock and locally has a strong relict-igneous-flow foliation. This rock has a concordant conventional U-Pb age of 467±4 Ma and a single-crystal SHRIMP age of 449±7 Ma (Aleinikoff and others, 2002). Quartz gabbro forms small bodies within biotite-hornblende tonalite. Ultramafic rocks include small bodies of serpentinite and soapstone. Trondhjemite is very siliceous and consists largely of plagioclase and quartz.

The Late Devonian Guilford Granite (Dg) (Cloos and Broedal, 1940) is a nonfoliated, homogeneous monzogranite that forms thin bodies that crosscut bedding and schistosity in the Northwest Branch Formation just north of the Burnt Mills fault. The Guilford Granite has a U-Pb age of 362±3 Ma (Aleinikoff and others, 2002).

Late Devonian pegmatite (Dp) is composed of coarse grains of muscovite, microperthitic microcline, albite, and quartz. The rock is nonfoliated and crosscuts schistosity and foliation in the Sykesville and Laurel Formations east of the Rock Creek shear zone.

Structure

The Piedmont province is subdivided into the western, central, and eastern parts, each of which is bounded by regional faults. The central and western parts of the Piedmont share a similar structural history, but the rocks of the eastern Piedmont are more complex and polydeformed. Therefore, the geologic structure of each region is presented with little attempt to correlate the events. As discussed in the section on metamorphism (below), ongoing argon geochronological studies (Kunk and others, 2005) and metamorphic fabric studies (Robert P. Wintsch, Indiana University, 2001, oral and written commun.) will attempt to unravel this complex history.

Western Piedmont

The Culpeper and Gettysburg basins are half grabens bounded on the west by the east-dipping, normal Bull Run Mountain fault. The strata on the east side of the basins unconformably overlie pre-Mesozoic rocks of the Piedmont province but some contacts are normal faults. The strata within the basins mostly dip gently west with the greatest thicknesses found in the western part of the basins. The basins deepened and the strata thickened during slip movement along the normal faults (Smoot, 1991). The minimal displacement on the Bull Run Mountain fault is equal to the greatest thickness of the basins' strata, or about 10 km, as determined by our cross sections. The west-dipping strata, the conglomerates on the western margin, and the fact that all units are truncated by the Bull Run Mountain fault all show that the faulting was active throughout Triassic and Jurassic time. Both the broad folds near the western margin of the basins and the transverse folds formed because displacement along the Bull Run Mountain fault varied along strike. Strike-parallel folds formed as a result of drag along the Bull Run Mountain fault. The northern margin of the Culpeper basin terminates along many normal faults that are both parallel to and transverse to the regional strike.

The rocks that underlie the Frederick Valley have been folded into a doubly plunging synclinorium that is overturned to the west. The east limb of the synclinorium contains a series of northeast- and southwest-plunging anticlines and synclines of the Araby Formation, Cash Smith Formation, and Rocky Springs Station Member of the Frederick Formation. These folds display axial-plane cleavage. The upper member of the Frederick Formation and the lower member of the Grove Formation define second-order folds in the core of the synclinorium, but cleavage is not as pervasive as that on the overturned east limb.

Central Piedmont

The central Piedmont includes the Westminster terrane, the Sugarloaf Mountain anticlinorium, and the Bush Creek belt.

Thrust Sheets and Faults

The rocks of the Westminster terrane are lithotectonic units in a stack of imbricate thrust sheets, the base of which is floored by the Martic fault (Southworth, 1996). The thrust sheets are defined by deformation fabrics in distinct rock types, domains of different fold orientations, and the truncation of rock units. The major faults are the Martic, the Barnesville-Monrovia, and the Hyattstown thrust faults (from west to east and structurally lowest to highest). The faults were probably active during all the orogenies of the Paleozoic Era. Shear-band cleavage and steep folds locally suggest some dextral strike-slip motion along some of the faults (Southworth, 1996). The Martic thrust fault cuts upsection westward, placing the Ijamsville Phyllite on rocks of the Urbana, Araby, and Frederick Formations; the fault is folded with the footwall rocks. The Barnesville-Monrovia thrust fault places rocks of the Sams Creek Formation on rocks of the Ijamsville Phyllite. The Hyattstown thrust fault places rocks of the Marburg Formation on rocks of the Sams Creek Formation. In addition to the named thrust faults discussed above, there are early thrust faults that are now folded, late thrust faults that cut existing faults, reactivated thrust faults, and numerous small intraformational faults of limited displacement in the Westminster terrane.

Foliations

The Martic thrust sheet is composed completely of the Ijamsville Phyllite. The Ijamsville displays a composite foliation that consists of a transposition foliation that is overprinted with phyllonitic foliation and several generations of cleavage. Vein quartz that impregnates the rock has been sheared, transposed, and folded into steep isoclines. These steep F_1 folds were deformed by westward-verging, inclined F_2 folds that plunge steeply to gently in all directions. These F_2 folds exhibit an attendant northeast-dipping, axial-planar, pressure-solution crenulation cleavage.

In the Barnesville-Monrovia thrust sheet, foliated metabasalt of the Sams Creek Formation is structurally aligned parallel to the fault. Sheath folds of metabasalt plunge moderately south to southeast in a zone of high strain near Monrovia, Md. The map pattern just north of Monrovia yields a cross section of the tubular folds.

The dominant foliation in rocks of the Marburg Formation above the Hyattstown fault is transposition foliation. Transposed beds are folded by west-verging, inclined to recumbent folds. Crenulation cleavage that is axial planar to F_2 folds plunges steeply and gently northeast and southwest. All rocks of the Marburg Formation are sheared.

The primary foliation in the Prettyboy Schist is a schistosity that displays transposition. In the northern antiform this foliation is shallow dipping and folded upright with crenulation cleavage. Along the Pleasant Grove fault, the schistosity of the Prettyboy Schist is steep, and pervasive to spaced shear-band cleavage transects the early foliation to form a tectonite.

Folds

Folds are recognized in both outcrop and map patterns (Jonas, 1937). Fisher (1978) described three fold phases that are nearly coaxial: early Wakefield Valley folds (isoclinal folds of bedding with axial-plane schistosity), a Marston fold phase (steep north-northeast-trending folds with axial-planar cleavage), and late kinks of the Jasontown fold phase. The Wakefield Valley and Marston folds enter the northern part of the map and are defined by the contacts of the Prettyboy Schist, Marburg Formation, Sams Creek Formation, and Wakefield Marble. To the south, deformation has obscured evidence of these folds. Some outcrops in the north-central part of the Sams Creek Formation between the Hyattstown and Martic faults show refolded folds. Here, the early schistosity is vertical, trends east to west, and is folded with northeast-striking cleavage that is axial planar to steep F_2 antiforms that plunge in all directions. Similar high strain between the Barnesville-Monrovia fault and the Hyattstown fault has produced tubular sheath folds of metabasalt and phyllite of the Sams Creek Formation.

Sugarloaf Mountain Anticlinorium and Bush Creek Belt

The Sugarloaf Mountain Quartzite and the stratigraphically overlying Urbana Formation were folded to create the doubly plunging Sugarloaf Mountain anticlinorium, which is overturned to the northwest (Scotford, 1951; Thomas, 1952). The north-plunging nose of the anticlinorium is an anticline-syncline-anticline triplet of Sugarloaf Mountain Quartzite. To the south, the structure ends as a plunging anticline. An intraformational thrust fault places part of the main body of the anticlinorium onto its west limb. The numerous small, normal faults that cut the folded quartzite beds are related to Mesozoic extension associated with the formation of the Culpeper basin.

The Sugarloaf Mountain Quartzite and Urbana Formation display a cleavage that is axial planar to the single fold that constitutes the anticlinorium. Metasiltstone of the Urbana Formation is characterized by bedding, one cleavage, and a conspicuous bedding and cleavage intersection lineation. This lineation plunges northward away from Sugarloaf Mountain. Bedding-cleavage intersection lineations in the Urbana Formation, which is mapped in a window of the Martic thrust fault in the Bush Creek belt, plunge gently southward.

Eastern Piedmont

Thrust Sheets and Faults

Metasedimentary and metavolcanic rocks of the Potomac terrane constitute a stack of thrust sheets (Drake, 1989). The thrust sheet of rocks represented by the Mather Gorge Formation was placed over previously undeformed sediments of the Sykesville Formation by the Plummers Island fault. The rocks of the Mather Gorge Formation were polydeformed and polymetamorphosed prior to emplacement (Drake, 1989; Muller, 1994). Olistoliths (clasts) of the Mather Gorge Formation (migmatite, schist, folded metagraywacke, and phyllonite) within the Sykesville Formation demonstrate that deformation and metamorphism of the Mather Gorge Formation predated the sedimentation and deposition of the Sykesville Formation (Drake, 1989; Muller, 1994). From the Plummers Island fault west to Bear Island, ductile fault fabrics in the Mather Gorge Formation are restricted to phyllonite, which is interpreted to be derived from the shearing of schist, metagraywacke, and migmatite of the Mather Gorge Formation (Drake, 1989) as the rocks were transported westward above the rocks of the Sykesville Formation. Along the Potomac River just south of the map area, exposures of strongly sheared rocks in both the Mather Gorge and Sykesville Formations across the steep west-dipping Plummers Island fault suggest that the fault was reactivated, possibly as a back thrust (Fisher, 1970). Argon geochronology suggests that the Plummers Island fault was reactivated in the Carboniferous (Kunk and others, 1998, 2005).

The Loch Raven thrust sheet consists of the Northwest Branch Formation, Loch Raven Schist, and Oella Formation (Drake, 1989). The Laurel Formation is a sedimentary mélange that contains locally abundant olistoliths of previously deformed rocks. The Loch Raven thrust sheet was emplaced along the Burnt Mills fault during deposition of the Laurel Formation. The Loch Raven thrust sheet and Laurel Formation were next overthrust by rocks of the Sykesville Formation along the Brinklow thrust fault (Fleming and Drake, 1998). Both hanging wall and footwall rocks are marked by mylonitic foliation (Drake, 1994). Rocks of the Loch Raven thrust sheet and Sykesville Formation are locally separated by the Rock Creek shear zone (Fleming and others, 1994). The Rock Creek shear zone is characterized by phyllonitized and mylonitized rocks that cover an area as much as 3 km wide. The rocks contain kinematic indicators of thrust faulting, as well as dextral and sinistral strike-slip motion (Fleming and others, 1994; Fleming and Drake, 1998). To the south of the map area, near the National Zoo in Washington, D.C., are some discrete younger thrust faults of the Rock Creek shear zone that have placed crystalline rocks against Quaternary and Tertiary sediments (Fleming and Drake, 1998). The Rock Creek shear zone locally reactivated segments of the Brinklow thrust fault and localized emplacement of the Kensington Tonalite (Fleming and Drake, 1998; Drake, 1998).

Rocks of the Potomac terrane were transported westward onto rocks of the Westminster terrane along the Pleasant Grove fault. The Pleasant Grove fault is a ductile shear zone as much as 1 to 2 km wide that initially formed as a thrust fault during deformation associated with the Ordovician Taconian orogeny (Drake, 1989). K-Ar geochronology suggests that deformation-induced recrystallization was associated with shear-band foliation having dextral strike-slip movement in the late Paleozoic (Pennsylvanian to Permian, 311.4±3.2 Ma) Alleghanian orogeny (Krol and others, 1999). An $^{40}Ar/^{39}Ar$ date on white mica in the shear zone also indicates a 364 to 348 Ma episode of deformation, possibly related to the Acadian orogeny (Krol and others, 1999). Rocks within and on either side of this fault zone have phyllonitic foliation and a spaced shear-band cleavage having dextral shear sense. $^{40}Ar/^{39}Ar$ data near the Potomac River define a Late Devonian deformation zone about 12 km wide that transects the Pleasant Grove fault (Kunk and others, 2005). There is no isotopic evidence of pre-Devonian or significant post-Devonian movement along the Pleasant Grove fault (Kunk and others, 2005).

Foliations

Rocks of the Mather Gorge Formation contain several foliations (Drake, 1989). The first schistosity forms a fan along the Potomac River; it dips gently eastward near Seneca, Md., is near vertical at Great Falls, and dips westward near the Maryland border with Washington, D.C. This schistosity has been folded, faulted, and overprinted by several younger foliations. Rocks of the Northwest Branch Formation, Loch Raven Schist, and Oella Formation have a primary schistosity that has been overprinted by a spaced cleavage at many places. Rocks of the Sykesville and Laurel Formations have a crude foliation, defined commonly by aligned clasts, that is overprinted by schistosity in some spots. Rocks of the Georgetown, Norbeck, and Dalecarlia Intrusive Suites have a primary flow foliation that is overprinted by a secondary metamorphic foliation. Rocks of the Guilford Granite are not foliated, but rocks of the Bear Island Granodiorite are locally sheared. Sheared leucocratic granitoid (Bear Island Granodiorite?) near and along the Plummers Island thrust fault at the Potomac River suggests post-Early Ordovician deformation along this fault. Shear strain in all these rocks has resulted in transposition, phyllonitic, and mylonitic foliation (Fleming and Drake, 1998). Rocks of the Mather Gorge Formation along the Pleasant Grove fault have a shear-band cleavage with dextral kinematics of undetermined displacement. Similar movement indicators are only locally found along the Plummers Island fault.

Lineations

The first schistosity in rocks of the Mather Gorge Formation, Northwest Branch Formation, Loch Raven Schist, and Oella Formation is marked by intersecting beds and forms a prominent intersection lineation. Later schistosities in these rocks have intersected the first schistosity, which formed additional intersection lineations. Higher grade rocks have mineral lineations that plunge down the dip of the schistosity.

Rocks of the Sykesville and Laurel Formations are also lineated. Small olistoliths in these rocks are elongated down the dip of the foliation. Profile views of the olistoliths show that they are shaped like pancakes that were flattened, not stretched. Minerals on foliation surfaces are also aligned, which indicates that the rocks have been stretched. Many of the rocks of the Georgetown, Dalecarlia, and Norbeck Intrusive Suites have a downdip mineral lineation that formed in a stretching regime.

Folds

Rocks of the Mather Gorge Formation were folded at least three times (Drake, 1989). The map patterns of the metagraywacke and schist units of the Mather Gorge Formation near the Potomac River illustrate the early west-trending Captain Hickory fold phase. These isoclinal folds were refolded by the northerly trending, upright Potomac folds and northwest-trending Reston folds. The local outcrop pattern of the Plummers Island and Burnt Mills faults, as well as the interpreted tectonic windows, indicate that these faults have been folded. The reclined folded thrust may have occurred during the Potomac fold phase, whereas open folds may be related to later strike-slip transpression.

Metamorphism

The rocks of the Piedmont province were metamorphosed at different times and grades, and they have been subsequently juxtaposed and transported westward during Paleozoic orogenies. In general, the rocks are of the highest grade of metamorphism (sillimanite) in the east and of the lowest grade (chlorite-sericite) in the west. However, the grades of metamorphism do not follow a simple Barrovian sequence as has been described along discrete sections of the Potomac River near Great Falls (Fisher, 1970; Drake, 1989). Recent analysis of $^{40}Ar/^{39}Ar$ dates on hornblende and muscovite from locations across the Maryland Piedmont demonstrate that the rocks experienced a complex polymetamorphic history (Krol and others, 1999; Kunk and others, 2004, 2005). In short, the core of the Potomac terrane at Great Falls records Ordovician cooling ages. To the east of Great Falls, the rocks were structurally deformed and then retrograded in the Early Devonian and Late Pennsylvanian. West of Great Falls, the rocks of the Potomac terrane contain Late Devonian foliations. West of the Potomac terrane and beneath the Pleasant Grove fault, rocks of the Westminster terrane contain Early Silurian foliations, and there is no evidence of Devonian or later deformation.

Sugarloaf Mountain Anticlinorium and Frederick Valley Synclinorium

The Sugarloaf Mountain Quartzite and rocks of the Urbana Formation are at chlorite grade resulting from a single, greenschist-facies metamorphic event. The matrix of the quartzites is rich in sericite and contains sparse chlorite. Cleavage in metasiltstone and marble of the Urbana Formation are marked by aligned sericite crystals and chlorite porphyroblasts that give the rocks a green hue.

Chlorite-grade rocks of the Araby, Cash Smith, Frederick, and Grove Formations locally contain sparse, tiny crystals of sericite and chlorite porphyroblasts that are crudely aligned in the cleavage plane. Cleavage and chlorite crystals are most evident in clay-rich rocks of the overturned east limb of the synclinorium.

Westminster Terrane

Rocks of the Westminster terrane had a complex metamorphic history under greenschist-facies conditions (Kunk and others, 2004). Phyllites of the Ijamsville Phyllite, Marburg Formation, and Sams Creek Formation contain varying proportions of muscovite, chlorite, paragonite, quartz, magnetite, and calcite, all resulting from the first metamorphic event. Metabasalt of the Sams Creek Formation contains varying proportions of actinolite, epidote, and stilpnomelane. Quartzose rocks in all the formations contain sericite and chlorite. Phyllitic rock in fault zones was retrogressively metamorphosed and sheared into phyllonitic diaphthorites (Knopf, 1931). Rocks described by Knopf (1931) as “sick-looking” are characterized by chlorite in multiple shades of green, white quartz, and abundant leucoxene. Phyllites of the Ijamsville Phyllite, Sams Creek Formation, and Marburg Formation locally experienced a later prograde metamorphic event that caused chloritoid and albite to overgrow the earlier foliation. The contacts between the phyllite of the Sams Creek Formation, rocks of the Marburg Formation, and the Prettyboy Schist in the northeastern part of the map area may be isograds as suggested by Fisher (1978). Static chloritoid in phyllite of the Marburg Formation increases in size and abundance to the southeast and is rotated by pressure-solution cleavage. Albite porphyroblasts also increase in size and abundance to the east, from rocks of the Marburg Formation into the Prettyboy Schist. Locally, albite encloses crinkles of the Wakefield and Marston fold phases; thus, the peak of metamorphism postdates the major folding events.

Potomac Terrane

Rocks of the Mather Gorge Formation are polymetamorphic. They experienced a prograde metamorphic event characterized by mineral assemblages ranging from a chlorite zone in the west to a sillimanite zone in the east (Fisher, 1970; Drake, 1989). In the sillimanite zone the rocks are migmatites. This Barrovian metamorphism occurred before the intrusion of the Ordovician(?) Bear Island Granodiorite and maybe before the Middle Ordovician Taconian orogeny (Becker and others, 1993). The high-grade rocks to the east were locally sheared and retrogressively metamorphosed to chlorite-sericite phyllonites. This retrograde metamorphic event was followed by a secondary prograde event that crystallized the chloritoid, muscovite, and biotite in the shimmer aggregate that had formed during the retrograde event. The $^{40}Ar/^{39}Ar$ white mica dates suggest that rocks of the Mather Gorge Formation immediately above the Pleasant Grove fault record thermal evidence of the Taconian (Ordovician), Acadian (Devonian), and Alleghanian (Pennsylvanian to Permian) orogenies (Krol and others, 1999).

The Sykesville Formation was metamorphosed at biotite±garnet±staurolite grade, but its olistoliths were metamorphosed (some at partial melt conditions) and deformed prior to deposition. Foliations containing biotite and garnet are seen in the Loch Raven Schist and Laurel Formation east of the Rock Creek shear zone, which indicates that these rocks experienced two prograde events. Static porphyroblastic staurolite and coarse muscovite have overgrown this foliation as well as the mylonitic and phyllonitic foliations in the shear zone (Fleming and Drake, 1998). Staurolite occurs along fractures in olistoliths of ultramafic and mafic rocks. Rocks of the Middle to Early Ordovician Georgetown, Dalecarlia, and Norbeck Intrusive Suites, and the Ordovician(?) Bear Island Granodiorite have been metamorphosed, but the Late Devonian Guilford Granite has not been metamorphosed.

Coastal Plain Province

The Lower Cretaceous Potomac Formation (Kps) consists of unconsolidated gravel, sand, silt, and clay that unconformably overlies rocks of the Laurel Formation (_l) in the extreme southeastern corner of the map area, near Silver Spring, Md. This is the only remnant in this quadrangle of a fluvial and deltaic deposit that once may have extended as far west as the Blue Ridge province.

Fossils

Some of the sedimentary rocks in the quadrangle contain a variety of fossils that become more abundant and diverse as the rocks get younger. The Cambrian Harpers and Antietam Formations contain burrow traces called *Skolithos linearis*. The Cambrian Antietam Formation also contains *Olenellus* (Walcott, 1896), the oldest trilobite fossil in the central Appalachian region. Other Cambrian rocks (Tomstown, Frederick, and Waynesboro Formations; and Elbrook and Conococheague Limestones) contain parts of trilobites, algal colonies (stromatolites), and conodont microfossils. Ordovician rocks (Grove Formation, Conococheague Limestone, Stonehenge Limestone, Rockdale Run Formation, Pinesburg Station Dolomite, St. Paul Group, and Chambersburg Limestone) contain fewer trilobites and conodonts, but do have more snails, brachiopods, echinoderms, bryozoans, and cephalopods. When the carbonate deposition was replaced by clastic sedimentation of the Martinsburg Formation, mainly snails, clams, and trilobites survived because they could filter out the clay and silt.

Upper Triassic and Lower Jurassic rocks of the Culpeper Group yield phytosaur teeth; coelacanth fish; footprints of crocodiles, lizards, and carniverous dinosaurs; plant impressions, pollen, and spores; insect parts; conchostracans; ostracodes; and fish scales. These fossils occur in the Manassas Sandstone, Bull Run Formation (Balls Bluff Member), Midland Formation, Catharpin Creek Formation, and Turkey Run Formation (Weems, 1987, 1993).

Surficial Materials

Alluvium

Well to poorly sorted Holocene alluvium (Qa) composed of stratified mixtures of unconsolidated clay, silt, sand, gravel, and cobbles underlies flood plains of nearly all rivers and tributaries. The channel of the tributary commonly is incised into bedrock with alluvium exposed along the banks. The thickness of the alluvium is highly variable and is a function of bedrock, topography, and land-use practices. Locally, thick deposits of alluvium resulted from erosion due to agricultural practices of the 19th century; mill dams also caused a buildup of eroded sediment in places. Recent suburban development has introduced large quantities of sediment into tributaries and into the Chesapeake Bay.

Alluvial Terrace Deposits

The map area includes locally preserved remnants of high-level Pleistocene and older(?) terraces (QTt) and low-level Pleistocene and Holocene terraces (Qt) of the ancestral Potomac, Shenandoah, and Monocacy Rivers. These conspicuous terraces consist of rounded sandstone and quartzite cobbles and boulders that contain the trace fossil *Skolithos linearis*, and rounded to angular chert pebbles, cobbles, and boulders whose sources are Early Cambrian and younger rocks of the Valley and Ridge province. The deposits are isolated remnants of former, more extensive terraces. The remnants of older deposits may only be a veneer of coarse clasts; younger, more well-preserved deposits may be several meters thick. Some of the highest deposits—such as Mount Sterling in Loudoun County, Va.; east of Lucketts, Va.; and south of Dickerson, Md.—are the result of the topographic inversion of an ancient channel. The oldest deposits at Sterling, Va., are several meters thick and are deeply oxidized and leached.

Colluvium

Fine and coarse colluvium cover the hill slopes across the quadrangle. The colluvium was derived from the escarpment of the east limb of the Blue Ridge-South Mountain anticlinorium. The deposits occur as lensoid aprons that cover the bedrock of the western margin of the Culpeper basin.

Fine colluvium (Qcf) consists of subangular clasts of quartzite, phyllite, metabasalt, epidosite, and vein quartz. Coarse colluvium (Qcc) consists of cobbles and boulders of predominantly quartzite. Gravity, debris-flow, and freeze-thaw processes acting on the landscape resulted in coarse colluvium concentrations in hillslope depressions on Blue Ridge-Elk Ridge, Short Hill-South Mountain, Catoctin Mountain, and Sugarloaf Mountain. Only the largest boulder streams, boulder fields, and rock slides are portrayed on this map because a thin veneer of colluvium covers virtually all of the mountain slopes. The surface of the deposits consists completely of clasts with no visible matrix supporting them because the finer grained material has washed away, but matrix-supported clasts may occur at depth.

Residuum and Lag Gravel

The limestone of the eastern Great Valley section (Hack, 1965) and the Frederick Valley section (Southworth and Brezinski, 2003), gneiss of the Blue Ridge province, and schist of the Piedmont province uplands (Froelich, 1975) have a thick regolith developed on their surfaces. This regolith consists partly of a residuum of in situ weathered bedrock (saprolite). Some of the regolith is more than 30 m thick, which accounts for the flat topography (note the contours on the base map of the quadrangle) and the lack of outcrop.

Pebbles and cobbles of angular to euhedral white quartz from possible in situ weathering of the underlying carbonate bedrock superficially resemble terrace deposits (Qt or QTt); however, these deposits are lag concentrates from residual material (Qr). Presumably, the vein quartz originally filled fractures and cavities in the carbonate rock in the western and central Piedmont.

Another distinctive residuum, Pleistocene and Holocene lag gravel (Ql), formed from the in situ weathering of conglomeratic rocks of the Goose Creek Member (J^ccg) of the Catharpin Creek Formation in the western part of the Culpeper basin, south of Leesburg, Va. Natural surface accumulations of rounded quartz pebbles and cobbles superficially resemble terrace deposits. Excavations near the Loudoun County Landfill reveal a thick regolith of saprolitized cobbles and boulders around pinnacles of bedrock.

Summary of Geologic History and Tectonics

The rocks of the Frederick 30′ × 60′ quadrangle reflect several Wilson cycles (Wilson, 1966) of opening and closing ocean basins. Rocks of the Blue Ridge province record evidence of a billion-year-old mountain range that resulted from the Grenville orogeny. This continent, called Laurentia, rifted about 500 m.y. later to create an ocean known as Iapetus. Rocks of the central and western Piedmont province (west of the Pleasant Grove fault) as well as rocks of the Great Valley section of the Valley and Ridge province were deposited in various depths and environments within the Iapetus Ocean. For example, slate, phyllite, and quartzite of the Westminster terrane of the central Piedmont were deposited in deep water on the continental rise, whereas carbonate rocks of the Great Valley were deposited in shallow water on a continental shelf platform. Carbonate rocks of the Frederick Valley in the western Piedmont reflect the continental slope that marks the transition between the two settings.

Rocks of the Potomac terrane in the eastern Piedmont are interpreted to be deepwater deposits containing debris of the oceanic crust (Drake, 1989). Parts of this terrane show evidence of deformation and metamorphism not seen elsewhere (Drake, 1989). The earliest thrust sheets were emplaced during sedimentation in a deep oceanic trench. One thrust sheet contains the older Mather Gorge Formation overlying the younger Sykesville Formation; the other thrust sheet contains the older Loch Raven Schist overlying the younger Laurel Formation (Fleming and others, 1992, 1994).

The deformed rocks of the Potomac terrane were intruded by tonalitic to granitic rocks during the Ordovician Taconian orogeny (Drake, 1989). The highly deformed rocks of the Westminster terrane also may have been subjected to late Taconian deformation and may have been transported westward onto Cambrian rocks of the Frederick Valley along the Martic fault during this tectonic event (Southworth, 1996). Mylonitic Keedysville marble at the base of the Cambrian carbonate rock sequence (Tomstown Formation) in the Blue Ridge province and Great Valley section of the Valley and Ridge province is interpreted to be a regional detachment that formed during the Taconian orogeny (Brezinski and others, 1996). Other evidence of the Taconian orogeny is the change in deposition from carbonate rocks to clastic rocks in the Ordovician Martinsburg Formation of the Great Valley section, indicating an uplifted source that was eroding. However, argon geochronology in the rocks of the Piedmont province suggests that deformation and metamorphism occurred in the Silurian, Devonian, and Mississippian (Krol and others, 1999; Kunk and others, 2004).

All of the pre-Mesozoic rocks were folded, faulted, and metamorphosed in several events throughout the Paleozoic, culminating in the late Paleozoic (Pennsylvanian to Permian?) Alleghanian orogeny. This orogeny resulted from the collision of the continental plates of Laurentia (North America) and Gondwana (Eurasia) that closed the Iapetus Ocean. The rocks were transported westward above the North Mountain thrust fault that crops out at the surface just northwest of the Frederick quadrangle. From west to east, the Massanutten synclinorium, Blue Ridge-South Mountain anticlinorium, Frederick Valley synclinorium, and Sugarloaf Mountain anticlinorium are a west-verging fold train above this thrust fault.

The Appalachian highlands that were created by the converging fold-and-thrust belt collapsed as the continent began to rift and pull apart, creating the Atlantic Ocean during the Triassic and Jurassic Periods. Alluvial-fan debris shed from scarps along normal faults filled the lowlands that eventually evolved into basins by possibly renewed listric fault movement along older thrust faults. Basalt flows were extruded and diabase was intruded in the last stages of the rifting prior to the formation of the Atlantic Ocean.

Drainage systems that flowed to the west into the Appalachian basin gradually reversed as a result of the rifting and flowed east toward the Atlantic Ocean. Debris that was shed from the eroding Appalachian highlands formed thick deposits of unconsolidated sediments that eventually became the Atlantic Coastal Plain. Modern rivers and their tributaries continue to erode bedrock and carry sediment down the Potomac River to the Chesapeake Bay.

Mineral Resources

Active quarries in the Frederick 30′ × 60′ quadrangle include those that mine (1) high-calcium limestone for cement and agricultural lime, (2) diabase, limestone, marble, shale, and serpentinite for aggregate, and (3) gneiss, schist, and quartzite for dimension building stone (Edwards, 1995). Only the locations of quarries, mines, and prospect pits for aggregate, precious metals, dimension and ornamental building stone, and iron or manganese minerals that existed in historical times are shown on the map.

Limestone and Aggregate

In the Great Valley section of the Valley and Ridge province, there are at least 26 quarries in the Great Valley that mine high-calcium limestone of the Cambrian Tomstown Formation, Waynesboro Formation, and Elbrook Limestone; and the Ordovician Stonehenge Limestone. In the Blue Ridge province, small pods of calcitic to dolomitic marble were quarried historically in four places for agricultural lime and ornamental stone. In the Frederick Valley of the western Piedmont province, there are seven quarries that produce crushed stone and Portland cement. In the Westminster terrane of the central Piedmont, more than 10 small quarries and pits in marble were recognized and they often were in close proximity to historical kilns that were used to heat the marble to produce agricultural lime.

Several quarries are located in sills of Early Jurassic diabase and in beds of basalt, which are used for aggregate in road metal and for concrete in Loudoun County, Va. Shale and limestone are quarried and crushed for aggregate in the Frederick Valley. Serpentinite is crushed for aggregate in Montgomery Co., Md., in the eastern Piedmont.

Building and Ornamental Stone

Historic homes and other structures in the area were constructed from virtually every type of locally exposed indigenous rock. Those rocks mined for commercial quantities are mostly in the eastern Piedmont and were quarried and used for the construction of canals, bridges, and buildings in the early 1800s. The most popular dimension stones used have included (1) Kensington Tonalite, Georgetown Intrusive Suite, and Sykesville Formation (known as “Potomac blue stone”), (2) serpentinite, (3) sandstone of the Poolesville Member of the Manassas Sandstone (often called “Seneca red sandstone”), (4) quartzite of the Weverton Formation and Sugarloaf Mountain Quartzite, and (5) various limestones in the Great Valley. Slate of the Ijamsville Phyllite was quarried in at least six locations for roofing material in the early 1900s (Dale and others, 1914).

Gneiss of the Sykesville Formation, limestone conglomerate of the Leesburg Member of the Bull Run Formation, and marble of the Swift Run and Catoctin Formations have been the most popular ornamental stones. Conglomerate of the Leesburg Member (called the “Potomac marble” or “Calico rock”), quarried in Loudoun County, Va., and Frederick County, Md., was used in 1815 by Benjamin Latrobe for the columns in Statuary Hall of the U.S. Congress on Capitol Hill (U.S. Geological Survey, 1998).

Metals

In the late 1700s and 1800s, there were abundant prospects for limonite, hematite, and manganese for the production of iron located throughout the quadrangle. In the Blue Ridge-South Mountain anticlinorium, near the contact of the Antietam Formation with the overlying Tomstown Formation, are at least 24 manganese prospects. On the eastern side of the Frederick Valley, there are at least five limonite prospects along the contact between the Araby Formation and the overlying Frederick Formation.

Both gold mines and placer deposits (Bernstein, 1980; Kuff, 1983) may be found within the Piedmont province. Vein quartz was mined for gold near Great Falls, Md. (Reed and Reed, 1969). Gold was also a byproduct of mining for lead, zinc, and silver from marble and metavolcanic rocks in the Linganore mining district of the Westminster terrane in the central western Piedmont (Heyl and Pearre, 1965). There are three reported occurrences of gold in the Blue Ridge province: one placer deposit, one associated with metabasalt of the Catoctin Formation, and a third located in rocks of the Chilhowee Group near the border fault of the Gettysburg basin. Gold, silver, and copper prospects were located in sandstone and diabase in the Culpeper basin in Virginia and Maryland (Robinson and Sears, 1988).

Aeromagnetic Map

Introduction

A digital aeromagnetic grid of the Frederick 30′ × 60′ quadrangle was assembled from data resulting from 10 aeromagnetic surveys that were flown between 1958 and 1989. Three of the surveys were recorded and processed digitally; the remainder were analog surveys, and the magnetic values were digitized from hand-drawn contour maps. Surveys in Maryland and Virginia were flown along east-west flightlines, with the spacing between the flightlines ranging from 0.125 to 1 mile (mi) (200–1,600 m). All but one survey were flown at 500 feet (ft) above ground. In West Virginia, flightlines trended northwest to southeast at 1,000 ft above ground with 2 mi of separation.

The total magnetic field measurements from each survey were interpolated into separate grids. The International Geomagnetic Reference Field was then calculated in grid form for the time and altitude of each survey and subtracted from the corresponding grids of observed magnetic data. The resulting residual grids were then compared with adjacent grids and adjusted for level differences. Finally, the adjusted grids were joined into one grid.

The Shaded-Relief Map

The residual magnetic field grid is displayed as a shaded-relief map overlain with selected geologic features (fig. 3). The synthetically produced illumination is from the east at a simulated sun angle of 45º; therefore, shadows appear along the western sides of the magnetic anomalies. The relative intensities of the magnetic anomalies are displayed as gray scales. see Southworth and others (2002) for a color-shaded-relief map with red corresponding to higher magnetic values and blue corresponding to lower magnetic values. The shading technique greatly enhances small-amplitude magnetic anomalies.

Correlation of Magnetic Data With Geology

The aeromagnetic anomalies correlate closely with the mapped geology because some lithologic units have contrasting magnetic properties. The dominant features of the aeromagnetic map are (1) a series of large-amplitude magnetic anomalies in parallel belts that are associated with metabasalt of the Catoctin Formation in the Blue Ridge province and (2) a broad swath of high-amplitude values corresponding to metasedimentary, metavolcanic, and mafic rocks of the Mather Gorge Formation in the eastern Piedmont. Lower amplitude magnetic anomalies are associated with metabasalt of the Sams Creek Formation and metasedimentary rocks of the Urbana Formation in the western Piedmont. The complex pattern of segmented magnetic highs within the Catoctin Formation may represent individual or groups of basalt flows. Smaller wavelength high-amplitude magnetic anomalies are associated with Mesoproterozoic gneiss units (Southworth and others, 2006) in the western part of the Blue Ridge province and with Jurassic diabase dikes and sills.

The aeromagnetic anomalies also correlate with mapped faults. The most obvious anomaly is associated with the Pleasant Grove fault that places rocks of the Mather Gorge Formation against rocks of the Marburg Formation in the central Piedmont. The fault zone is marked by magnetite-bearing phyllonites and schists. The Plummers Island fault (rocks of the Mather Gorge Formation juxtaposed against rocks of the Sykesville Formation) is roughly coincident to a boundary between large- and small-amplitude anomalies. The low-amplitude lineament to the east of the highly magnetic phyllonites of the Mather Gorge Formation corresponds to weakly magnetic rocks of part of the Sykesville Formation. The Mather Gorge Formation in the Potomac terrane of the

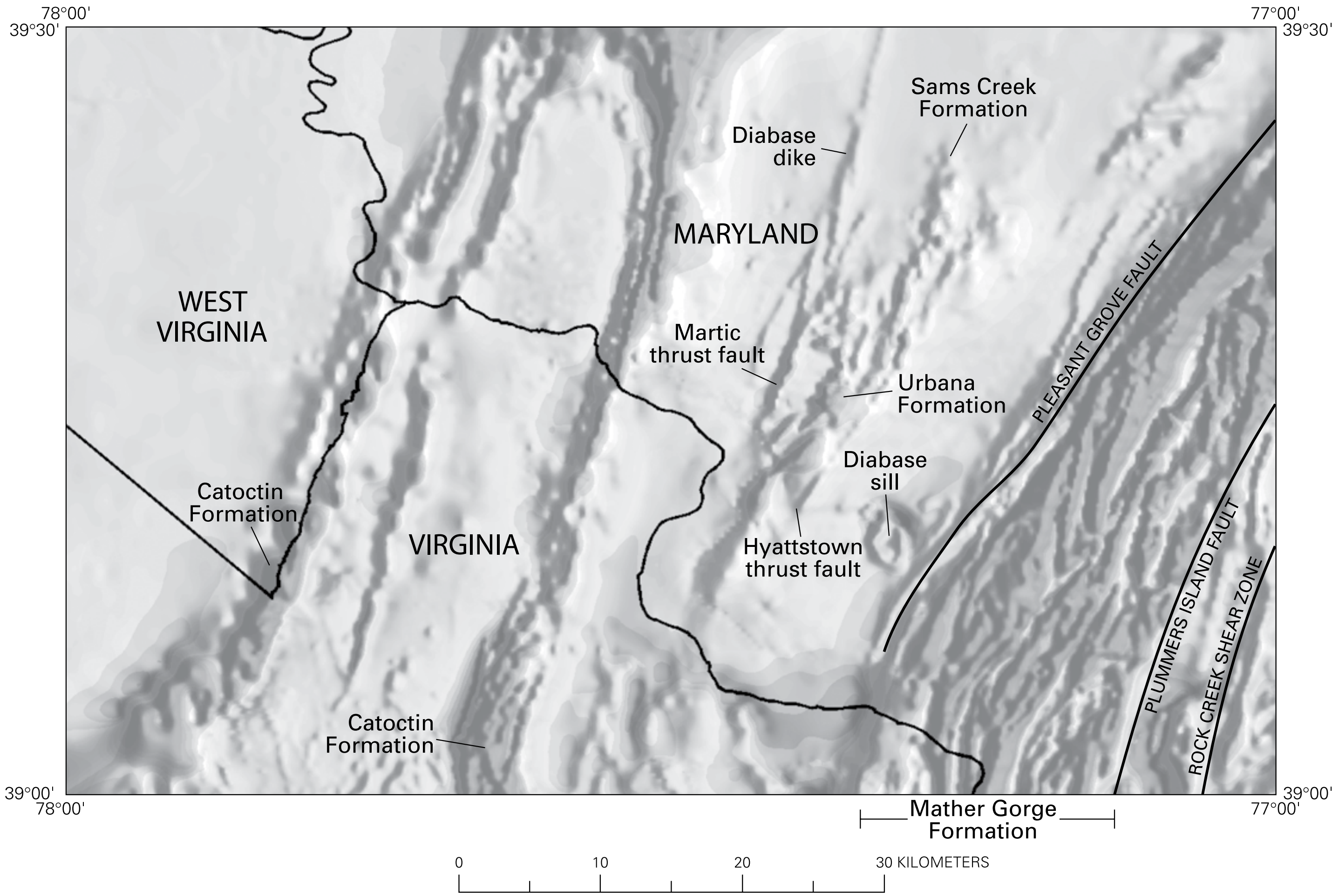

Figure 3. Gray-scale shaded relief image of residual aeromagnetic field grid data. High magnetic anomalies are displayed as dark gray (values as much as 430 nanotestlas). Geologic features that correlate with the magnetic data are shown.

Piedmont has irregular, short-wavelength anomalies that indicate an internal complexity. In the eastern Piedmont, the Rock Creek shear zone is marked by a prominent large-amplitude aeromagnetic anomaly associated with highly magnetic schists of the Laurel Formation and Loch Raven Schist. In the western Piedmont, the Barnesville-Monrovia and Hyattstown faults, and segments of the Martic fault are marked by moderate-amplitude linear anomalies that are spatially associated with magnetite-bearing phyllonites.

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Description of Map Units

[For thickness of units, see cross sections.]

Unconsolidated Surficial Materials

Qa **Alluvium (Holocene)**—Well to poorly sorted, stratified mixtures of unconsolidated clay, silt, sand, gravel, and cobbles underlying flood plains of nearly all rivers and tributaries. Channel of tributary commonly is incised into bedrock with alluvium exposed along the banks. Thickness of alluvium is highly variable and is a function of bedrock, topography, and land-use practices. Locally, thick deposits of alluvium resulted from erosion due to agricultural practices of the 19th century; mill dams also caused a buildup of eroded sediment in places. Recent suburban development has introduced large quantities of sediment into tributaries

Qt **Terrace deposit, low level (Holocene and Pleistocene)**—Sand, gravel, and boulders on flat benches located as much as 50 meters (m) above the flood plain

Colluvium (Holocene and Pleistocene)

Qcf Fine colluvium—Lensoid aprons of poorly sorted, subangular clasts of quartzite, phyllite, metabasalt, epidosite, and vein quartz supported in a silt matrix. Covers bedrock of the western margin of the Culpeper basin along the lower slope of Catoctin Mountain

Qcc Coarse colluvium—Cobbles and boulders of predominantly quartzite, concentrated in hillslope depressions on Blue Ridge-Elk Ridge, Short Hill Mountain-South Mountain, Catoctin Mountain, and Sugarloaf Mountain. Emplacement was by gravity, debris flows, and freezing and thawing

Qr **Residuum (Holocene and Pleistocene)**—Unconsolidated mixture of moderately reddish-brown soil, and pebbles and cobbles of grayish-pink to white, angular, locally euhedral quartz derived from in situ weathering of underlying carbonate rocks. Located primarily in the Frederick Valley north of Potomac River. Thickness ranges from a thin veneer to 3 m. Superficially resembles terrace deposits (Qt and QTt)

Ql **Lag gravel (Holocene and Pleistocene)**—Distinctive residuum formed from in situ weathering of the Goose Creek Member (J^ccg) of the Catharpin Creek Formation, the Poolesville Member (^cmp) of the Manassas Sandstone, and the upper member (O_gu) of the Grove Formation. Natural surface accumulations consisting of rounded quartz pebbles and cobbles superficially resemble terrace deposits (Qt and QTt). Excavations reveal a thick regolith of saprolitized cobbles and boulders around bedrock pinnacles

QTt **Terrace deposit, high level (Pleistocene and Tertiary)**—Conspicuous, high-level terraces of the ancestral Potomac, Shenandoah, and Monocacy Rivers preserved locally on isolated hillocks. Composed of rounded sandstone and quartzite whose sources are Lower Cambrian and younger rocks of the Valley and Ridge province; rock fragments contain remains of trace fossil *Skolithos linearis*. Deposits are isolated remnants of former, more extensive terraces. Some of the highest deposits, such as Mount Sterling in Loudoun County; one east of Lucketts, Va.; and one south of Dickerson, Md., are the result of topographic inversion of an ancient channel

Great Valley Section of the Valley and Ridge Province

Om **Martinsburg Formation (Upper and Middle Ordovician)**—Light-brown shale, calcareous shale, and siltstone. Contains thin to medium beds of sandstone and metagraywacke in the upper part; gray argillaceous limestone at base

Oc **Chambersburg Limestone (Middle Ordovician)**—Light-gray, argillaceous, nodular limestone

Osnr **St. Paul Group (New Market and Row Park Limestones, undivided) (Middle Ordovician)**—Light- to medium-gray, thick-bedded micritic limestone and bioclastic limestone containing bedded black chert nodules

Beekmantown Group

Obps **Pinesburg Station Dolomite (Middle Ordovician)**—Light-gray, medium- to thick-bedded dolostone and dololaminate containing white and light-gray chert nodules. Characteristic "butcher-block" weathered surface (caused by cross-hatched joints). Irregular bedding resulting from collapse breccia and paleokarst near top

Obrr **Rockdale Run Formation (Middle and Lower Ordovician)**—Light- to dark-gray, fine- to medium-grained, thin- to medium-bedded, fossiliferous limestone and crystalline dolostone. Contains gray chert nodules

Obs **Stonehenge Limestone (upper part) (Lower Ordovician)**—Dark-gray, fine- to medium-grained, thick-bedded, fossiliferous limestone with minor black chert. Contains algal bioherms, intraformational conglomerates, bioclastic beds that alternate with minor dolostone beds

Obss Stoufferstown Member—Light-gray, laminated, silty limestone containing thin interbeds of platy limestone and coarse-grained bioclastic limestone

O_c **Conococheague Limestone (Lower Ordovician and Upper Cambrian)**—Interbedded dark- to light-gray, laminated, algal limestone; dolomitic limestone; light-brown dolostone and sandstone

_cb Big Spring Station Member (Upper Cambrian)—Light-gray, calcareous to dolomitic sandstone; medium-gray, fine-grained limestone with intraformational conglomerate; and light-gray, fine-grained dolostone

_e **Elbrook Limestone (Upper and Middle Cambrian)**—Medium-gray, thinly bedded limestone interbedded with (1) white, mylonitic marble; (2) light-brown, laminated dolostone; and (3) thin, calcareous shale to shaly dolostone

Waynesboro Formation (Lower Cambrian)

_wac Chewsville Member—Interbedded dusky-red shale, mudstone, and argillaceous sandstone; light-gray sandstone; and light-brown sandy, dolomitic limestone and dolostone

_wact Cavetown Member—Interbedded gray, bioturbated dolostone, dolomitic limestone, and laminated limestone, with a few thin, sandy limestone beds near the middle

_war Red Run Member—Interbedded light-olive-gray shale; light-gray, fine-grained sandstone; and medium- to dark-gray, sandy, dolomitic limestone

_wa Undivided—Shown in cross section only

_t **Tomstown Formation (Lower Cambrian)**—Light- to dark-gray, limestone, dolostone, and marble

_td Dargan Member—Lower part is dark-gray, bioturbated dolostone interbedded with intervals of dark-gray, laminated dolostone and dark-gray limestone. Upper part is dark-gray, bioturbated, oolitic dolostone, interbedded with laminated limestone and silty dolostone

_tb Benevola Member—Light-gray, very thick bedded to massive, sugary dolostone with faint cross-bedding. Base is gradational with the underlying bioturbated dolostone of the Fort Duncan Member (_tf). Pure and massive dolomite is quarried as aggregate

_tf Fort Duncan Member—Dark-gray, thick-bedded, burrow-mottled dolostone. Base is probably an erosional surface on top of Bolivar Heights Member (_tbh)

_tbh Bolivar Heights Member—Dark-gray, fine-grained, thin-bedded limestone with wispy dolomitic burrows that increase in abundance upsection. Base is a 15-m-thick interval of gray to white, mylonitic marble (informally known as Keedysville marble bed) interpreted to be a regional thrust fault that detached the carbonate rocks from the underlying rocks of the Antietam Formation (_ca) (Brezinski and others, 1996)

Blue Ridge Province

_t **Tomstown Formation (Lower Cambrian)**—Poorly exposed medium-light- to medium-gray, saccharoidal dolostone and dolomitic marble containing thin layers of sericite

_cp **Carbonaceous phyllite (Lower Cambrian)**—Medium- to dark-gray, fine-grained muscovite-graphite phyllite. Locally contains alternating light- and dark-gray thin beds ranging from several mm to 1 cm in thickness. Produces distinctive light-gray soil. Found only as float or as small, slumped outcrops in discontinuous lenses above Antietam Formation (_ca) near Furnace Mountain. Interfingers laterally with dolostone of the Tomstown Formation

Chilhowee Group

_ca **Antietam Formation (Lower Cambrian)**—Light-olive- to olive-gray, medium- to coarse-grained, medium-bedded, locally ferruginous, micaceous, silty metasandstone interbedded with very fine grained, silty metasandstone to sandy metasiltstone. Local ferruginous horizons with abundant botryoidal hematite and limonite are located near contact with overlying Tomstown Formation (_t) or carbonaceous phyllite (_cp)

_ch **Harpers Formation (Lower Cambrian)**—Dark-greenish-gray to brownish-gray, fine- to very fine grained, laminated to massively bedded chlorite-muscovite-quartz phyllitic metasiltstone. Magnetite-rich, sandy metasiltstone, fine-pebble conglomerate, and thin-bedded metasandstone (_chs) found locally in the western Blue Ridge. On Catoctin Mountain, the rock is a phyllite with transposed bedding and metamorphic foliation consisting of alternating millimeter-scale quartzose and micaceous laminae

_chs Metasandstone—Light-gray to brown, thin-bedded metasandstone, with *Skolithos linearis* burrows. Interbedded with metasiltstone of the main body of the Harpers (_ch) west of Blue Ridge-Elk Ridge near Harpers Ferry, W. Va.

Weverton Formation (Lower Cambrian)

_cwo Owens Creek Member—Dusky-blue to dark-gray to dark-purplish-gray, very coarse grained quartzite and quartz-pebble conglomerate. Poorly sorted, thick bedded, with graded beds and crossbeds; contains local accumulations of magnetite, ilmenite, and pebbles of red jasper, red and purple quartz, and phyllite. Interbedded with poorly exposed, dark-greenish-gray, phyllitic metasiltstone. Gradational with overlying Harpers Formation

_cwm Maryland Heights Member—Greenish-gray to light-gray, medium-grained to granular, massive quartzite in beds 5 to 10 m thick. Forms topographic ledges but is not well exposed. Includes unnamed thick quartzite bed (_cwmq) mapped separately on Catoctin Mountain in Maryland

_cwb Buzzard Knob Member—Light- to medium-gray, fine- to medium-grained, well-sorted, graded, variously bedded (crossbedded, thick bedded, or massive), vitreous quartzite interbedded with light-gray metagraywacke and metasiltstone; locally arkosic where unconformable to Mesoproterozoic gneiss on Blue Ridge. White to gray, massive to thickly bedded, vitreous quartzite with thin (less than 0.3 m thick) interbeds of dark phyllite is restricted to Catoctin Mountain in Virginia

_cw Undivided—Found only in southern part of quadrangle, west of Bull Run Mountain fault

Loudoun Formation (Lower Cambrian)

_clc Conglomerate—Dark-gray to dusky-blue, very coarse pebble conglomerate containing pebbles of rounded to subrounded white, blue, and red quartz; gneiss(?); red jasper; and variegated phyllite in grayish-black, iron-rich, silty matrix; local interbeds of fine-pebble conglomerate and graded and crossbedded quartzite conglomerate is locally transitional into overlying Weverton Formation

_clp Phyllite—Gray-black and light-olive-gray to dark-purple-gray phyllite containing tuffaceous clasts and elongated blebs. Dark-gray- to greenish-gray-weathering chlorite-quartz-graphite-muscovite phyllite and lesser white- to gray-weathering pebbly metasandstone with thin phyllite interbeds are on Catoctin Mountain. Base of unit is transitional into the underlying Catoctin Formation; top of unit is in sharp contact with conglomerate (_clc) or overlying Weverton Formation (_cwb)

Catoctin Formation (Neoproterozoic)

Zcm Metabasalt—Light-green to dark-greenish-gray to medium-bluish-gray, fine-grained to aphanitic, massive to schistose, amygdaloidal metabasalt composed of actinolite, chlorite, epidote, albite, and rare quartz. Contains lenses and layers of apple-green, fine-grained, hard, massive epidote-quartz rock (epidosite). Contains local interlayers of agglomeratic metabasalt breccia

Zcs Metasedimentary phyllite—Light-gray to variegated, finely laminated quartz-graphite-muscovite phyllite. Five thin bodies mapped within main body of Catoctin around and north of Paeonian Springs

Zcp Tuffaceous phyllite—Darkly variegated to lustrous and silvery white, metarhyolitic, vesicular, blebby phyllite and fine-grained quartz-sericite phyllite interpreted as felsic metatuff

Zcr Metarhyolite—Light-gray and tan, vesicular, blebby phyllite; massive, silvery white schist with feldspar phenocrysts; and aphanitic quartz-muscovite schist

Zcma Marble—Pinkish-white and light-green, massive to schistose marble; and white, gray- to buff-weathering, fine- to medium-grained, massive to schistose calcitic marble. Margins of marble locally contain coarse-grained actinolite, tremolite, and chlorite. Two thin bodies mapped within metabasalt unit south of Potomac River

Zmd **Metadiabase dike (Neoproterozoic)**—Dark-greenish-gray, fine- to medium-grained, massive to schistose metadiabase and schistose metabasalt composed predominantly of chlorite, albite, epidote, and actinolite. Coarser grained variety has stubby, 2- to 8-millimeter (mm)-long actinolite pseudomorphs after clinopyroxene that produce distinctive nubbly texture. Rare aphanitic metadiabase has relict euhedral plagioclase laths. Compositionally similar to metabasalt of the Catoctin Formation (Zcm). Metadiabase dikes that are too narrow to portray as green polygons at 1:100,000 scale are portrayed as short red lines. Commonly, these dikes shown in red range from 0.5 to 5 m thick

Zrd **Metarhyolite dike (Neoproterozoic)**—White- to gray-weathering, aphanitic to fine-grained quartz-sericite schist and very fine grained, flinty rock with plagioclase-feldspar phenocrysts in a felted groundmass consisting of quartz, feldspar, biotite, and epidote

Swift Run Formation (Neoproterozoic)

Zsm Marble—White, pink, and tan, gray- to buff-weathering, medium- to fine-grained, calcitic and dolomitic marble with local thin, discontinuous, sandy layers

Zsp Phyllite—Grayish-reddish-purple phyllite, grayish-green finely laminated phyllite, dark-greenish-gray to brownish-gray, sandy, sericitic phyllite; and medium-dark-gray slate in fining-upward sequence. Pinkish-gray to light-brownish-gray, fine-grained, dolomitic marble locally found near top

Zss Metasandstone and schist—Pinkish- to greenish-gray, very coarse to medium-grained, crossbedded metasandstone and quartzite containing quartz phyllite and sandstone pebbles and cobbles; brownish-green chlorite-sericite-feldspar-quartz metagraywacke; and lustrous, silvery quartz-sericite schist in fining-upward sequence. Grayish-brown arkosic metasandstone (fossil soil?) locally found at lower contact with basement rocks

Fauquier Group

Zfcr **Carter Run Formation (Neoproterozoic)**—Light- to medium-gray and olive-gray, light-yellowish-gray-weathering, coarse- to fine-grained sericite-potassium feldspar-quartz metasiltstone and arkosic metasandstone. Beds range from 0.3 to 2 m thickness and are defined by fining-upward sequences; tangential and trough crossbeds are common. Gravel and isolated, cobble-sized clasts occur locally. Mapped south of Steptoe Hill in Virginia, near southern edge of quadrangle

Swains Mountain Formation (Neoproterozoic)

Zfsm Metamudstone—Light-gray, light-brown-weathering, thinly laminated (less than 2 cm) sericite-quartz metamudstone containing very fine quartz sand; and lustrous sericitic phyllite. Upper contact is gradational with rocks of the Carter Run Formation (Zfcr)

Zfsc Boulder conglomerate—Light- to dark-gray, boulder and cobble conglomerate and metasandstone with biotite-chlorite-sericite-potassium feldspar-quartz matrix. Bedding thickness varies from 0.5 to 6 m and is defined by fining-upward sequen- ces. Boulders and cobbles consist of locally derived Mesoproterozoic granite gneiss. Trough crossbeds of coarse- to medium-grained sandstone are common. Lower contact is an unconformity that has as much as 100 m relief and is distinct and abrupt; elsewhere, it is obscured within a zone of schist that is possibly metamorphosed fossil soil. Upper contact is gradational into metasandstone

Zrc **Cobbler Mountain Alkali Feldspar Quartz Syenite of the Robertson River Igneous Suite (Neoproterozoic)**—Gray- to buff-weathering, medium-grained, massive alkali-feldspar quartz syenite. Consists of stubby, euhedral mesoperthite grains (2–4 mm in diameter) intergrown with anhedral quartz; amphibole breaks down into quartz, plagioclase, and oxides; and minor interstitial plagioclase. Mesoperthite crystals conspicuous on weathered surface. Locally cut by dikes of fine-grained granite of presumably coeval magma source. Mapped only in southwestern corner of quadrangle

Ypb **Megacrystic metagranite (Mesoproterozoic)**—Light- to medium-gray, medium- to coarse-grained quartz-monzonite gneiss with large, pink potassium-feldspar porphyroblasts. Strong Paleozoic schistosity is the dominant foliation. Mapped only along the southern edge of the quadrangle in the southwestern corner

Ybg **Biotite granite gneiss (Mesoproterozoic)**—Pink, orange- to gray-weathering, medium-grained, well-foliated or well-lineated biotite-plagioclase-quartz-microcline gneiss. Biotite is 10 to 15 percent by volume. Middle Proterozoic foliation expressed by planar aggregates of biotite; locally, foliation is weak or absent and replaced by a lineation expressed by biotite streaks and rodded quartzofeldspathic grains. Occurs interlayered with two varieties of leucocratic metagranite (Yg and Ygt)

Yml **Pink leucocratic metagranite (Mesoproterozoic)**—Pink, medium- to medium-fine-grained, massive to moderately foliated plagioclase-quartz-microcline metagranite. Biotite is locally present (0 to 10 percent). Foliation defined by flattened quartz and feldspar grains and local, thin, biotite-rich layers

Yg **White leucocratic metagranite (Mesoproterozoic)**—White, medium- to medium-fine-grained, massive to moderately foliated plagioclase-quartz-microcline metagranite. Biotite is locally present (0 to 5 percent). Middle Proterozoic foliation defined by biotite where present, by flattened grains of quartz and feldspar, and by thin aplite layers

Ygt **Garnetiferous metagranite (Mesoproterozoic)**—White, medium- to medium-fine-grained, massive to moderately foliated garnet-plagioclase-quartz-microcline metagranite. Dusky-red garnets commonly transition to dark-green due to rim alteration to biotite and chlorite

Yqp **Quartz-plagioclase gneiss (Mesoproterozoic)**—White, medium- to medium-fine-grained, weakly to moderately well-foliated quartz-plagioclase gneiss. Biotite content varies from 0 to 5 percent. Foliation defined by biotite where present, by flattened quartz and feldspar grains, and by thin aplite layers. Strongly resembles leucocratic metagranite (Yg) but potassium feldspar is rare or absent

Ym **Marshall Metagranite (Mesoproterozoic)**—Light gray and pink, medium-grained, weakly to moderately well foliated and (or) lineated biotite-plagioclase-quartz-microcline metagranite with a leucocratic phase and a biotitic phase. Biotite content ranges in abundance from 10 to 15 percent. Layering locally produced by veins of pink pegmatite parallel to foliation

Ymc **Coarse-grained metagranite (Mesoproterozoic)**—Gray to pink, medium- to coarse-grained, massive to well-foliated biotite-plagioclase-quartz-microcline metagranite. Characterized by white or pink, 1- to 2-cm-long microcline porphyroblasts and aggregates of blue quartz; biotite content ranges from 0 to 10 percent. Commonly contains pronounced augen texture due to overprinting by Paleozoic schistosity

Ypg **Porphyroblastic metagranite (Mesoproterozoic)**—Yellowish-brown-weathering, medium- to coarse-grained garnet-biotite-plagioclase-quartz-microcline metagranite. Characterized by megacrysts of orange to pink microcline or microcline-rich aggregates that are deformed into rounded ovoids 1 to 3 cm in diameter; garnet, biotite, plagioclase, opaque minerals, and distinctive clots of blue quartz occur interstitially. Flattened ovoids define foliation, which is locally cut by dikes of garnetiferous metagranite (Ygt)

Yhm **Hornblende monzonite gneiss (Mesoproterozoic)**—Gray-weathering, medium-fine- to fine-grained, well-foliated hornblende-quartz-microcline-plagioclase monzonite gneiss. Foliation defined by strongly flattened quartz and feldspar grain aggregates and by prismatic hornblende; quartz content ranges from 10 to 20 percent; hornblende content as much as 30 percent. Rarely occurs as a more massive, spotted rock. Biotite and orthopyroxene are rare mafic constituents

Ylg **Layered granitic gneiss (Mesoproterozoic)**—White, gray, or pink, medium- to fine-grained, well-layered garnet-biotite-plagioclase-quartz-microcline granitic gneiss. Millimeter- to centimeter-scale layering defined by concentrations of biotite and aplite. Garnets up to 1 cm in diameter scattered throughout rock. Folded layering and swirly, migmatitic texture suggest partial melting; protolith is interpreted to be a felsic volcanic rock

Yc **Charnockitic granite (Mesoproterozoic)**—Dark-green and brown, yellow-brown-weathering, medium- to coarse-grained, massive to well-foliated quartz-hornblende-orthopyroxene-microcline-plagioclase charnockitic granite. Poorly exposed underlying topographic knolls; mapped primarily on the basis of float of fresh black rock having a distinctive orange crust and orange soil. Charnockitic granite occurs as discontinuous lensoid and pluglike bodies

Ya **Amphibolite (Mesoproterozoic)**—Dark-green and brown, gray-weathering, medium- to coarse-grained, massive to weakly foliated, spotted hornblende-orthopyroxene-plagioclase amphibolite gneiss. Contains subordinate sill- or dike-like bodies of metanorite, metadiorite, and hornblende-biotite gneiss

Yp **Garnet-graphite paragneiss (Mesoproterozoic)**—Reddish-brown (rusty-weathering), medium-fine- to fine-grained, well-foliated to layered graphite-biotite-garnet-plagioclase-quartz gneiss and schist. Layering defined by alternating millimeter-scale, garnet-rich zones containing garnets 0.1 to 1 cm in diameter, garnet aggregates, and centimeter-scale quartzofeldspathic layers. Garnets (almandine) typically deformed and retrograded to green, lensoid clots of fine-grained chlorite and muscovite. Graphite occurs as disseminated, small, rounded flakes. Distinctive orange-red stain produced by secondary hematite after accessory magnetite. Retrograded schistose varieties include quartz-chlorite-magnetite schist and carbonaceous phyllonite. Probably the remnant of sedimentary rock that predates Mesoproterozoic granites

Yq **Quartzite and quartz-sericite tectonite (Mesoproterozoic)**—Light-gray to white, fine- to medium-grained, massive quartzite and quartz-sericite tectonite. No primary textures recognized such as bedding or early metamorphic foliation. Rounded zircons in a quartz mylonite are seen in thin section; commonly contains strong Paleozoic penetrative cleavage. Thin lenses of graphite may be seen in outcrop; contains larger mappable pods of paragneiss (Yp) as seen along Butchers Branch, east of Bluemont, Va.

Piedmont Province

Culpeper and Gettysburg Basins

Jd **Diabase dikes and sills (Early Jurassic)**—Medium- to dark-gray, medium crystalline and equigranular, massive diabase with characteristic orange-brown-weathered surface. Derived from several magma types as follows: (1) olivine-normative (olivine-plagioclase-pyroxene) tholeiitic diabase was intruded as dikes (Jd); (2) low-titanium, quartz-normative tholeiitic diabase containing centimeter-size phenocrystic clusters of calcic plagioclase in a fine-grained groundmass of pyroxene and plagioclase also was intruded as dikes (Jd); and (3) high-titanium, quartz-normative tholeiitic diabase was intruded as differentiated sheets (Jdh). Igneous differentiation of unit Jdh produced early-stage, bronzite-bearing cumulates (Jdc) lower in the sheets and late-stage differentiated bodies higher in the sheets such as granophyre (Jdg), ferrogabbro, diorite, syenite, and aplite, all of which contain pink potassium feldspar, albite, hornblende, biotite, and quartz. Dike dimensions vary from a wedge edge to more than 150 m wide. Diabase sheets exceed 600 m in thickness

J^tm **Thermally metamorphosed rocks (Lower Jurassic and Upper Triassic)**—Variegated hornfels, quartzite, marble, meta-arkose, and metaconglomerate occurring as zoned contact aureoles adjacent to diabase intrusions. Includes dark-gray to olive-black, cordierite-spotted hornfels; bluish-gray epidote and chlorite hornfels; white to pinkish-gray tourmaline granofels or quartzite; greenish- to purplish-gray epidote and chlorite meta-arkose; and white, light-gray, and pink, crystalline marble. Contact aureoles a few meters thick adjoin narrow dikes, but can be more than 213 m thick and as much as 1.6 km wide adjacent to thick diabase sheets; rocks closer to the contacts are hard, brittle, fractured, and unweathered; sedimentary structures commonly preserved

Meriden Group

Jms **Sander Basalt (Lower Jurassic)**—Dark-gray to bluish-gray, finely to moderately crystalline, porphyritic to equigranular basalt with plagioclase, augite, and pigeonite phenocrysts. Tops of flows are locally vesicular and amygdaloidal. Lower basalt flows locally separated from stratigraphically higher basalt flows by poorly exposed reddish-brown sandstone and siltstone (Jmss). Both the lower and upper basalts are characterized by distinctive curved columnar joints locally overprinted by closely spaced fractures. Apparently paraconformable with underlying and intercalated sedimentary rocks. Estimated thickness less than 300 m. Single occurrences of Jms and Jmss west of U.S. Route 15, south of Oatlands, Va.

Jmt **Turkey Run Formation (Lower Jurassic)**—Reddish-brown and dark-gray sandstone, siltstone, conglomerate, and shale, interbedded in cyclic sequences. Sandstone is fine to coarse grained, locally pebbly and crossbedded, poorly sorted, and micaceous. Siltstone is ripple laminated and contains very fine detrital muscovite. Shale is fissile, laminated, fossiliferous, and carbonaceous. Conglomerate is mapped separately (Jmtc) and consists of variegated, subrounded boulders, cobbles, and pebbles of metabasalt, quartzite, marble, quartz, and subangular basalt clasts derived from the Goose Creek Member (J^ccg) of the Catharpin Creek Formation. Cycles consist of meter-scale, coarser layers alternating with finer grained layers. Unit is deeply weathered and poorly exposed. Mapped west of U.S. Route 15, south of Oatlands, Va.

Jmh **Hickory Grove Basalt (Lower Jurassic)**—Medium- to dark-gray, finely to moderately crystalline, microporphyritic to equigranular basalt with plagioclase, augite, and pigeonite phenocrysts. Tops of flows are locally vesicular and amygdaloidal; vugs are filled by zeolites, calcite, and prehnite. Consists of two or three separate flows of basalt (Jmh) locally separated by poorly exposed, reddish-brown sandstone and siltstone (Jmhs). Unit is locally disconformable (but regionally paraconformable) to underlying and overlying sedimentary rocks. Mapped along U.S. Route 15 around Oatlands, Va.

Jmm **Midland Formation (Lower Jurassic)**—Reddish-brown and light- to dark-gray siltstone, sandstone, and shale (Jmm) and conglomerate (Jmmc) interbedded in cyclic sequences. Siltstone is micaceous and commonly ripple laminated; locally bioturbated, calcareous, carbonaceous, and fossiliferous. Sandstone is fine to coarse grained, locally pebbly, crossbedded and ripple-laminated, and feldspathic. Shale is silty, microlaminated, burrowed (with dessication cracks), carbonaceous, pyritic, calcareous, and fossiliferous. Lenticular deposits of variegated cobble and pebble conglomerate and coarse-grained conglomeratic, arkosic sandstone locally are near border fault of both basins. Unit is poorly exposed but is paraconformable to basalt formations above and below. Mapped east of Bull Run Mountain fault, south of Leesburg, Va.

Chatham Group

Jcm **Mount Zion Church Basalt (Lower Jurassic)**—Dark-gray to black, aphanitic to very finely crystalline, microporphyritic, high-titanium, quartz-normative tholeiitic basalt. Contains phenocrysts of augite and plagioclase. Tops of flows are vesicular and contain amygdules filled by calcite, zeolites, and prehnite. Weathers to reddish-brown or gray saprolite in uplands. Unit is poorly exposed but probably conformable or paraconformable to underlying and overlying sedimentary rocks. Mapped east of U.S. Route 15, south of Oatlands, Va.

J^cc **Catharpin Creek Formation (Lower Jurassic and Upper Triassic)**—Very dark red to dusky-red sandstone, siltstone, and conglomerate; interbedded in cyclic sequences about 30 m thick. Sandstone is micaceous, arkosic, and pebbly; overlain by dusky-red and olive-gray, thin-bedded to ripple-laminated, calcareous, micromicaceous, sparsely fossiliferous, laterally persistent siltstone. Reddish-brown conglomerate deposits are lenticular and consist of rounded cobbles and pebbles of mainly quartzite and metabasalt in fine- to coarse-grained, arkosic sandstone matrix. Mapped south of Leesburg, Va.

J^ccg Goose Creek Member—Variegated, lenticular body of conglomerate and interbedded reddish-brown to grayish-green, pebbly sandstone. Conglomerate is thick bedded to massive, with subrounded pebbles and cobbles of mainly quartzite, metabasalt, metasiltstone, gneiss, vein quartz, and limestone in medium- to coarse-grained, arkosic and calcitic sandstone matrix. Sandstone is fine to coarse grained, poorly sorted, medium to thick bedded, micaceous, arkosic, pebbly, and silty. Deeply weathered to thick, orange-brown saprolite mantled by lag gravel. Intertongues laterally into main body of Catharpin Creek Formation. Mapped east of U.S. Route 15, south of Leesburg, Va.

Bull Run Formation (Upper Triassic)

^cbg Groveton Member—Light- to dark-gray, light-greenish-gray, and black, thin-bedded to laminated, locally ripple marked, mud-cracked, calcareous and dolomitic, sparsely fossiliferous, silty and sandy shale; interbedded with dusky-red, thin-bedded, calcareous, micaceous, feldspathic, bioturbated, clayey and sandy siltstone in cyclic sequences, 3 to 9 m thick. Grades northward into fluvial and deltaic sandstones and siltstones, but is partly repeated by faulting. Laterally equivalent to Balls Bluff Member (^cbb). Mapped along Broad Run and to its west in the southern part of the quadrangle

^cbb Balls Bluff Member—Reddish-brown, fine- to medium-grained, thin- to medium-bedded, locally crossbedded, feldspathic, silty sandstone interbedded with dusky-red, thin-bedded, calcareous, micaceous, feldspathic, bioturbated, clayey and sandy siltstone in repetitive sequences, 1 to 3 m thick. Intertongues laterally with carbonate conglomerate of Leesburg Member (^cbl) to the northwest and with the Groveton Member (^cbg) to the south

^cbl Leesburg Member—Variegated, light-gray-weathering, crudely bedded carbonate conglomerate containing conspicuous subangular to subrounded boulders, cobbles, and pebbles of grayish and reddish lower Paleozoic limestone and dolostone in a matrix of reddish-brown, pebbly sandstone and calcareous, sandy siltstone. Intercalations of calcareous sandstone and siltstone thicken to the southeast where they intertongue with the main body of sandstone and siltstone of the Balls Bluff Member (^cbb)

Manassas Sandstone (Upper Triassic)

^cmp Poolesville Member—Predominantly gray, pinkish-gray, and reddish-brown, fine- to coarse-grained, thick-bedded, arkosic, micaceous sandstone; locally pebbly and crossbedded where it fills channels; commonly interbedded with reddish-brown, calcareous siltstone in upward-fining sequences in upper part of unit. Thickness is as much as 900 m. Gradational and intertonguing contacts with overlying and underlying units

^cmt Tuscarora Creek Member—Light- to dark-gray and light-red, variegated conglomerate composed of very fine to very coarse grained, angular to subangular pebbles and cobbles of limestone and dolostone within a matrix consisting chiefly of limestone and dolostone granules and dusky-red to grayish-red clayey sand and silt with calcite cement. Limestone and dolostone clasts derived from Cambrian and Ordovician strata

^cmr Reston Member—Light-gray to pinkish-gray, variegated pebble, cobble, and boulder conglomerate containing clasts of phyllite, schist, quartzite, metagraywacke, and quartz in a poorly sorted, coarse-grained, arkosic sandstone matrix. Locally interbedded with pale-reddish-brown sandstone and siltstone. Basal conglomerate unconformably overlies metasedimentary rocks of the central and eastern Piedmont. Mapped as very small or thin bodies west of and south of Sugarloaf Mountain and around Seneca, Md.

Frederick Valley Synclinorium

Grove Formation (Lower Ordovician and Upper Cambrian)

O_gu Upper member—Thickly interbedded medium-light-gray, locally sandy, thrombolitic and stromatolitic, algal limestone; medium-gray, laminated, dolomitic limestone; and olive-gray dolostone

O_gl Lower member—Medium-light- to medium-gray, thick-bedded and crossbedded, sandy limestone; and sandy dolomitic limestone. Limestones contain 0.3-m-thick interbeds of medium-light-gray sandy dolostone

Frederick Formation (Upper Cambrian)

_fl Lime Kiln Member—Dark-gray, fine-grained limestone and calcareous shale. Interbedded with fine-grained, thinly laminated to thin-bedded and medium-bedded limestone near the base. More thickly interbedded toward the top with medium-dark-gray, fine-grained, wavy-bedded limestone locally containing stromatolitic algal beds. Near the top, interbedded with medium-light-gray, crossbedded, sandy limestone

_fa Adamstown Member—Medium-dark- to dark-gray, fine-grained, argillaceous limestone thinly interbedded with dusky-yellow to medium-dark-gray, silty dolostone. Several dark-greenish-gray to greenish-black, light-olive-brown-weathering, silty, calcareous shale intervals 2 to 15 m thick are present throughout the member

_fr Rocky Springs Station Member—Dark-gray, nodular to lumpy-bedded, argillaceous, dolomitic limestone at the base of the Frederick Formation. Contains an interval of grayish-black, platy shale (_frs) as much as 20 m thick that is mapped along the eastern flank of the Frederick Valley. Upsection becomes dark-gray, laminated to flaggy-bedded limestone with dusky-yellow to light-olive-gray, silty, dolomitic partings and laminations, and intervals as much as 10 m thick of medium-dark-gray, polymictic breccia that grade upsection into medium-gray, planar-bedded, arenaceous limestone. Clast sizes range from sand size to 0.5 m in diameter on the western side of the Frederick Valley and diminish to less than 1 cm in diameter on the eastern side of the Frederick Valley

_f Undivided—Light-gray limestone. Single occurrence along Potomac River just east of the U.S. Route 15 bridge

_cs **Cash Smith Formation (Upper and Middle Cambrian)**—Grayish-black, fissile, platy, cleaved shale and slate, grading upward into thin-bedded, calcareous shale with limestone nodules. Mapped only along northern edge of quadrangle in an anticlinal ridge adjacent to Israel Creek, near Walkersville, Md.

_ar **Araby Formation (Middle and Lower Cambrian)**—Light-olive-gray, mottled metasiltstone containing sandy intervals; pervasively cleaved bedding typically obscured by structural foliations

Sugarloaf Mountain Anticlinorium and Bush Creek Belt

_u **Urbana Formation (Lower Cambrian?)**—Medium-olive-brown to light-olive-gray, poorly sorted, calcareous metasandstone, metagraywacke, quartzite, and metasiltstone. Contains graded beds, crossbeds, and sparse ripple marks

_um Marble—Light-greenish-gray, thin-bedded, crystalline marble; and schistose to massive, chlorite-rich, sandy, calcitic marble. Poorly exposed; produces distinctive reddish-orange soil

_uq Quartzite—Light-olive-gray and light-brownish-gray, fine- to coarse-grained, thin- to medium-bedded, crossbedded, pitted, vuggy, friable, lensoidal and discontinuous, very calcareous metasandstone and quartzite. Interbedded with light-brown laminated metasiltstone

Sugarloaf Mountain Quartzite (Lower Cambrian)

_squ Upper member—Pink and white, medium-bedded to massive, well-sorted, cross-stratified quartzite with ripple marks

_sqm Middle member—White and purple to light-gray, fine-grained, massive quartzite interbedded with seldomly exposed medium-brown, quartzose metasiltstone and dusky-blue, laminated metasiltstone similar to that of the conformably overlying Urbana Formation (_u)

_sql Lower member—Poorly exposed, light-gray quartzite

_sq Undivided—Shown in cross section only

Westminster Terrane

_Zw **Wakefield Marble (Lower Cambrian? and Neoproterozoic?)**—Reddish-white, massive to finely bedded dolomitic to calcitic marble, marble rich in quartz sand, and sandy marble. Mapped only along northern edge of quadrangle around Sams Creek

Sams Creek Formation (Lower Cambrian? and Neoproterozoic?)

_Zsb Metabasalt—Dark greenish- to medium-bluish-gray, aphanitic to porphyritic, massive to schistose, vesicular metabasalt composed of chlorite, epidote, quartz, altered plagioclase, actinolite, hornblende, and albite. Igneous texture is locally preserved. Pods of epidosite are common. Includes some metaconglomerate composed of metabasalt pebbles and cobbles. Contains local pillow structures and hyaloclastite

_Zsf Felsic schist—Medium-bluish-gray, grayish-blue, very pale blue, and light-olive-gray, fine-grained, tuffaceous, fragmental, metavolcanic and metavolcaniclastic quartz-muscovite-feldspar schist of intermediate composition. Locally interbedded with metabasalt. Only one small occurrence mapped with muscovitic phyllite unit (_Zsmp) southwest of the intersection of Maryland State Routes 75 and 80 on either side of Fahrney Branch

_Zsm Marble—Brownish-gray to grayish-reddish-purple, massive to thin-bedded, calcitic and dolomitic marble containing quartz sand. Includes minor calcareous metasiltstone

_Zstp Tuffaceous phyllite—Variegated grayish-reddish-purple and bluish-gray, vesicular phyllite with light-gray streaks and blebs

_Zsmp Muscovitic phyllite—Light-bluish-gray, dusky-yellow, and medium-orangish-pink muscovite-chlorite phyllite containing albite porphyroblasts, quartz, and hematite dust. Contains minor metasiltstone. Lithologically distinct from rocks of the Ijamsville Phyllite and Marburg Formation by its lighter color

_Zshp Hematitic phyllite—Bluish-purple, hematite-rich phyllite. Resembles Ijamsville Phyllite

_Zsl Metalimestone—Light-gray, thinly layered, argillaceous metalimestone

_Zsqp Quartzite interbedded with phyllite—Light-gray quartzite interbedded with purple phyllite and slate; with variegated, conglomeratic phyllite; and with bluish-gray, tuffaceous phyllite

_Zsq Quartzite—Light-gray to grayish-green, medium-grained, thin-bedded to massive, crossbedded quartzite and minor calcareous sandstone containing detrital plagioclase, orthoclase, and polymictic quartz. Bedding is defined by concentrations of heavy minerals. Interbedded with other units of the Sams Creek Formation, including phyllite (_Zsmp), metabasalt (_Zsb), and metasiltstone and metagraywacke (_Zss)

_Zss Metasiltstone—Metasiltstone, phyllite, quartzite, and metagraywacke, undifferentiated. Contains other units of the Sams Creek Formation, including marble (_Zsm) and quartzite (_Zsq), and appears to overlie the metabasalt unit (_Zsb). Bedding can be recognized except where transposed in shear zones adjacent to faults. Muscovitic phyllite containing albite porphyroblasts and elongated blebs of chlorite is interpreted to be a metatuff. Locally, light-brown metasiltstone is interbedded with quartzite and calcareous metasandstone

_Zsc Calcareous metasandstone—Light-brown and gray, cross-stratified, calcareous metasandstone and quartzite. Mapped in two small areas just south of Bush Creek near Monrovia, Md.

Ijamsville Phyllite (Lower Cambrian? and Neoproterozoic?)

_Zip Phyllite—Dusky-blue, grayish-blue, very dusky reddish-purple, and greenish-gray to pale-olive phyllite; phyllonite containing abundant pods and folded stringers of white vein quartz; and minor slate. Intensely folded and sheared. Finely laminated beds seen only in slate. Phyllite consists mostly of muscovite and chlorite, but also contains paragonite and chloritoid. Paragonite (determined by X-ray diffraction) gives unit a lustrous sheen. Dark coloration is caused by abundant hematite dust

_Zib Metabasalt—Dark-green and schistose metabasalt composed of chlorite, epidote, and quartz. Rare pillows locally preserved. Mapped as thin unit east of Martic thrust fault contact with Urbana Formation (_u); one small body mapped in fault slice near confluence of Potomac and Monocacy Rivers

_Ziq Quartzite—Yellowish-gray, fine- to medium-grained, massive sericitic quartzite locally intervening between phyllite (_Zip) and metabasalt (_Zib). Mapped as very thin units east of the Martic thrust fault contact with Urbana Formation (_u)

_Zim Marble—Light-olive-gray, sandy limestone and dusky-red, calcareous quartzite occurs as three very small pods within phyllite (_Zip) on the southeast limb of the Sugarloaf Mountain anticlinorium

_Zil Metalimestone—Light-bluish-gray to medium-light-gray, thin-bedded, laminated, carbonaceous and argillaceous metalimestone; and minor, medium-dark-gray, finely laminated, carbonaceous phyllite. Thin unit mapped from confluence of Potomac and Monocacy Rivers for about 5 km to the southeast. Small body located above flood plain of Linganore Creek, east of Frederick, Md.

_Zic Phyllitic conglomerate—Light-olive-gray muscovitic phyllite clasts supported in a dark-gray matrix of chlorite, quartz, ilmenite, magnetite, and zircon. Occurs just north of Bush Creek to the west of Monrovia, Md.

_Zicm Conglomeratic metagraywacke—Light-gray and green, medium- to coarse-grained metagraywacke with white quartz pebbles and variegated phyllite chips, in a green, chloritic matrix. Found within chloritic phyllite unit (_Zicp)

_Zicp Chloritic phyllite—Light-olive-gray and greenish-gray chloritic phyllite and metasiltstone

Marburg Formation (Lower Cambrian? and Neoproterozoic?)

_Zmbs Metasiltstone—Greenish-gray to light-olive-gray, quartz-sericite-chlorite phyllitic metasiltstone containing thin (0.25 cm) light-gray quartz laminae and ribbons; and dusky-blue, grayish-blue, dusky-reddish-purple, and greenish-gray to pale-olive muscovite-chlorite-paragonite-hematite phyllite similar to that of Ijamsville Phyllite (_Zip). Porphyroblasts of albite and chloritoid occur locally. Much of unit is transposed, phyllonitized, and has abundant pods and folded stringers of white vein quartz

_Zmbg Metagraywacke—Grayish-green to black, massive graywacke interbedded with dark phyllite. Mapped in southernmost area of Marburg

_Zmbb Metabasalt—Dark-greenish-gray to dusky-yellowish-green, aphanitic to porphyritic metabasalt containing epidosite. Only one small body in quadrangle mapped along tributary to Bucklodge Branch south of Barnesville, Md.

_Zmbq Quartzite—Light-gray to grayish-green, coarse-grained, massive quartzite

_Zp **Prettyboy Schist (Lower Cambrian? and Neoproterozoic?)**—Dark-greenish-gray quartz-muscovite-chlorite-albite schist with white, euhedral albite crystals

_Zpb Metabasalt—Dark-green, massive, porphyritic metabasalt composed of chlorite, epidote, and quartz. Located only in northeastern corner of quadrangle

_Zpq Quartzite—Brown, medium-grained quartzite interbedded with quartz-muscovite-chlorite schist. Single occurrence on map along Interstate Route 26, just east of intersection with Maryland State Route 97

Potomac Terrane

Dp **Pegmatite (Late Devonian)**—Light-gray and white muscovite-microcline-albite-quartz pegmatite. Locally contains minor amounts of biotite, tourmaline, allanite, monzonite, magnetite, and pyrite. Most of the microcline is microperthitic. Crosscuts schistosity and foliation of the country rocks and is not deformed

Dg **Guilford Granite (Late Devonian)**—Gray, medium- to fine-grained, nonfoliated, homogeneous granite of monzogranite composition. About 90 percent of the rock consists of equal parts of microcline, plagioclase, and quartz; remainder consists of equal amounts of biotite and muscovite and minor amounts of apatite, garnet, clinozoisite, zircon, and magnetite. Forms thin sheets that crosscut bedding and schistosity in the Northwest Branch Formation (_Zn). Two small bodies mapped on north side of Burnt Mills fault along eastern edge of quadrangle

Oq **Quartz bodies (Ordovician)**—White, massive, and fractured quartz probably intruded as large veins which are now preserved as smaller remnants. Found scattered throughout map area east of Pleasant Grove fault

Norbeck Intrusive Suite (Late Ordovician)

Ont Biotite-hornblende tonalite—Gray, medium- to coarse-grained, fairly massive to foliated biotite-hornblende tonalite consisting largely of quartz, andesine, hornblende, and biotite; and lesser chlorite, epidote, apatite, and magnetite. In many places, has a strong relict-igneous-flow structure. Contains many xenoliths and (or) autoliths of more mafic rock. Petrographic and chemical data are given in Hopson (1964)

Ong Quartz gabbro—Dark-gray, medium-grained quartz-augite-hornblende metagabbro. Forms small bodies within biotite-hornblende tonalite (Ont)

Onu Ultramafic rocks—Dark-green, well-foliated serpentinite and lesser soapstone. Probably altered from pyroxenite. Forms three small bodies within biotite-hornblende tonalite (Ont)

Ontr Trondhjemite—Light-gray, medium-grained muscovitic trondhjemite. One small body mapped within biotite-hornblende tonalite southeast of Olney, Md.

Ok **Kensington Tonalite (Middle Ordovician)**—Medium-gray, coarse-grained, weakly to moderately foliated, locally garnetiferous, muscovite-biotite tonalite. In and west of the Rock Creek shear zone and other sheared areas, the rock is intensely foliated to mylonitic muscovite-biotite granodiorite containing augen and coarse porphyroblasts of microcline that suggest metasomatism during the shearing event. Petrographic and chemical data are given in Hopson (1964) and Fleming and others (1994)

Georgetown Intrusive Suite (Early Ordovician)

Ogh Biotite-hornblende tonalite—Gray, medium- to coarse-grained, massive to foliated biotite-hornblende tonalite that has a strong relict-igneous-flow structure at many places. Unit contains many ultramafic and mafic xenoliths and (or) autoliths, and xenoliths of metasedimentary rocks. Typically contains 40 to 50 percent dark minerals. Petrographic and chemical data are given in Drake and Froelich (1997) and Fleming and others (1994). Mapped along southern edge of quadrangle

Ogg Quartz gabbro—Dark-gray, mostly medium- to coarse-grained quartz-augite-hornblende metagabbro, lesser quartz diorite, and much lesser quartz norite. In many places, the unit contains thin cumulate layers of metapyroxenite and augite-hornblende rock. Petrographic and chemical data are given in Fleming and others (1994). Mapped along southern edge of quadrangle

Ogp Metapyroxenite—Dark-green to black, medium- to coarse-grained, massive to well-foliated metapyroxenite occurring within metagabbro (Ogg). Much of the rock has been altered to dark-green to grayish-green serpentinite. Unit forms small pods and xenolith swarms within or along the borders of larger tonalite (Ogh) and quartz gabbro (Ogg) plutons. Mapped along southern edge of quadrangle

Dalecarlia Intrusive Suite (Early Ordovician)

Odm Biotite monzogranite and granodiorite—Medium-gray, medium- to coarse-grained, massive to well-foliated biotite monzogranite and lesser granodiorite. Locally contains plagioclase phenocrysts. Mapped bodies contain widespread lenses, zones, and irregular bodies of leucocratic muscovite-biotite monzogranite (Odl). Two small bodies are mapped, one within biotite-hornblende tonalite (Ont) where it is completely enclosed by muscovitic trondhjemite (Odt) and one at the southern edge of the quadrangle west of Maryland State Route 187

Odl Leucocratic muscovite-biotite monzogranite—Light-gray, leucocratic, medium- to coarse-grained, foliated muscovite-biotite monzogranite. Locally grades into monzogranite (Odm) with which it commonly occurs. Mapped only at southern edge of quadrangle west of Maryland State Route 355

Odt Muscovitic trondhjemite—Light-gray, fine- to medium-grained, sugary textured, massive to weakly foliated muscovitic trondhjemite dikes, sheets, and irregular bodies. Petrographic and chemical data are given in Drake and Fleming (1994). Mapped in one location within biotite-hornblende tonalite (Ont) where it encloses a small body of biotite monzogranite and granodiorite (Odm) east of Maryland State Route 97, south of Olney, Md.

Ob **Bear Island Granodiorite (Ordovician?)**—Light-gray, fine-grained muscovite-biotite granodiorite and related pegmatite composed largely of quartz, albite, and microcline. Forms small- to medium-size, crosscutting sheets and bodies in rocks of the Mather Gorge Formation

_s **Sykesville Formation (Lower Cambrian)**—Variegated, gray metamorphosed sedimentary mélange consisting of a quartzofeldspathic granofels matrix containing quartz and feldspar grains, and fragments and bodies of metamorphosed sedimentary, volcanic, and intrusive rocks

_l **Laurel Formation (Lower Cambrian)**—Light- to medium-gray, medium- to coarse-grained, moderately to well-foliated sedimentary mélange consisting of a quartzofeldspathic matrix that contains elliptical quartz fragments and fragments of meta-arenite and biotite schist. Typically spangled with very large porphyroblasts of muscovite. Upper part (_lu) contains more than 50 percent olistoliths of meta-arenite and muscovite-biotite schist that are locally as long as 5 to 10 m. Located only in the southwestern corner of the quadrangle

_Zo **Oella Formation (Lower Cambrian and (or) Neoproterozoic)**—Gray, fine- to medium-grained quartz-plagioclase-biotite-muscovite meta-arenite interbedded with lesser schist. Mapped adjacent to Loch Raven Schist (_Zl) south of Triadelphia Reservoir in Maryland

_Zl **Loch Raven Schist (Lower Cambrian and (or) Neoproterozoic)**—Medium-gray, medium- to coarse-grained, thin-bedded, lustrous quartz-muscovite-biotite-plagioclase schist that, in places, contains garnet, staurolite, and (or) chlorite. Contains some interbedded semipelitic schist and meta-arenite (_Zlm) similar to those of the underlying Northwest Branch Formation (_Zn)

_Zn **Northwest Branch Formation (Lower Cambrian and Neoproterozoic)**—Light-gray, medium-grained, well-bedded quartz-plagioclase-biotite meta-arenite and lesser quartzite and calc-silicate rock. Both the meta-arenite and quartzite have a good schistosity marked by biotite flakes. Beds range from 1.3 cm to 1.2 m in thickness. Contains interbedded schist similar to that of the overlying Loch Raven Schist (_Zl); upper contact grades into overlying Loch Raven Schist

Mather Gorge Formation (Lower Cambrian and (or) Neoproterozoic)

_Zms Quartz-rich schist—Greenish-gray to gray, reddish-brown-weathering, very fine grained, lustrous quartz-muscovite-chlorite-plagioclase-epidote-magnetite-hematite schist containing interlayers of phyllitic metasiltstone, muscovitic gneiss, metagraywacke, and calc-silicate rock. Thin to very thin beds are largely transposed into early cleavage and contain folded white quartz veins

_Zmg Metagraywacke—Light- to medium-gray, yellowish- to reddish-brown-weathering, fine- to medium-grained, generally well-bedded metagraywacke and semipelitic schist. Beds range from about 3 cm to as much as 3 m thick, averaging about 20 cm. Many beds are graded; sole marks and slump features are abundant. Contains interbedded quartzose schist and lenses of calc-silicate rock

_Zmm Migmatite—Light-gray quartz-plagioclase leucosome and dark-gray, quartz-rich schist

_Zmp Phyllonite—Greenish-gray, chlorite-sericite phyllonite containing white vein quartz. Highly folded

_Zmt Metatuff—Dark-gray, hornblende-plagioclase-quartz-muscovite, felsic, schistose metatuff. Only one small body is mapped near the southern edge of the quadrangle in Great Falls, Va.

_Zsd **Soldiers Delight Ultramafite (Lower Cambrian and (or) Neoproterozoic)**—Green serpentinite, talc schist, and soapstone. Interpreted to be mostly altered pyroxenite. Mapped adjacent to Loch Raven Schist north of Triadelphia Reservoir in Maryland

_Zu **Mafic and ultramafic rocks (Lower Cambrian and Neoproterozoic)**—Greenish-gray serpentinite, soapstone, and talc schist that occur as large bodies or smaller blocks within rocks of the Mather Gorge Formation

_Zg **Metagabbro and metapyroxenite (Lower Cambrian and Neoproterozoic)**—Dark-green and black metagabbro and metapyroxenite that occur as two small blocks within rocks of the Mather Gorge Formation. The larger body is located at the headwaters of Cattail Creek south of Interstate Route 70 in Howard County, Md.; the smaller body is located along Great Seneca Creek west of Gaithersburg, Md.

Coastal Plain Province

Kps **Potomac Formation (Lower Cretaceous)**—Unconsolidated, compact, well-sorted, stratified gravel, sand, silt, and clay that unconformably overlies rocks of the Laurel Formation (_l) in the extreme southeastern corner of the map area near Silver Spring, Md.