Digital Geologic Map and Database of the Frederick 30′ x 60′ Quadrangle, Maryland, Virginia, and West Virginia

Version 1.0

Compiled by Scott Southworth[1]

Geology by Scott Southworth, David K. Brezinski[1], Avery Ala Drake, Jr.[1],
William C. Burton[1], Randall C. Orndorff[1], and Albert J. Froelich[2]

Aeromagnetic map and digital topographic map by David L. Daniels[1]

Digital compilation by James E. Reddy[1] and Danielle Denenny[1]

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[1]U.S. Geological Survey, Reston, Virginia.
[2]U.S. Geological Survey, deceased.

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INTRODUCTION

The geology of the Frederick 30 by 60 minute quadrangle, Maryland, Virginia, and West Virginia, was mapped on 1:24,000-scale base maps from 1989 to 1994. The geologic data were manually compiled at 1:100,000-scale in 1997 and were digitized from 1998 to 1999. The geologic map and database are intended for application to land use decisions, soil mapping, groundwater availability and quality, aggregate resources, and engineering and environmental studies. For site specific studies, the detailed 1:24,000-scale geologic maps should be consulted (see index).

The Frederick 30 by 60 minute 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 inVirginia; and Jefferson and Berkeley Counties in West Virginia (Figure 1).

The map area covers distinct geologic provinces and sections of the Central Appalachian region that are defined by unique bedrock and resulting landforms (Figure 2). From west to east, these are the Great Valley section of the Valley and Ridge Province, the Blue Ridge Province, the Piedmont Province, and in the extreme southeast corner is a small part of the Atlantic Coastal Plain Province. The Piedmont Province is comprised of several sections; from west to east are the Frederick Valley synclinorium, the Culpeper and Gettysburg basins, the Sugarloaf Mountain anticlinorium, the Westminster terrane and the Potomac terrane. The geology is discussed by geologic province and sections based on decreasing age of bedrock units and tectonic origin.

The Blue Ridge Province contains billion-year-old (Mesoproterozoic) paragneiss and granitic gneisses intruded by a swarm of 570 million year old (Neoproterozoic) 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). Deposited paraconformably upon the Neoproterozoic rocks are clastic metasedimentary rocks of the newly formed continental margin.

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

The early Paleozoic carbonate platform became unstable in response to the Ordovician Taconic orogeny. Deformation associated with this tectonic event is recorded in rocks of the Piedmont Province to the east. These rocks of the Potomac terrane were thrust westward onto rocks of the Westminster terrane, and 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).

This early Paleozoic sea eventually was destroyed 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 (Figure 3a, Figure 3b, Figure 3c). The Massanutten synclinorium underlies the Great Valley, the Blue Ridge-South Mountain anticlinorium 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 were once connected to form a large down-faulted basin filled with sediments eroded from the adjacent Blue Ridge and Piedmont highlands. Continued rifting resulted in igneous intrusions and extrusive volcanic rock about 200 million years ago, and eventually resulted in the opening of the Atlantic Ocean. Sediments eroded from the Appalachian highlands were deposited by river systems and transgressing seas that now form the Atlantic Coastal Plain.

BLUE RIDGE PROVINCE

Geologic Setting

The Blue Ridge Province in the Frederick 30 by 60 minute quadrangle consists of rocks of the Blue Ridge-South Mountain anticlinorium, 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 Formations) 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 Early Cambrian Chilhowee Group (Weverton, Harpers, and Antietam Formations). This “cover rock sequence” of metasedimentary and metavolcanic rocks mostly underlies the 3 limbs of the Blue Ridge-South Mountain anticlinorium; Catoctin Mountain, Black Oak Ridge-Short Hill-South Mountain, and Blue Ridge-Elk Ridge, from east to west. Several outliers of cover rocks in the core of the anticlinorium are also preserved from erosion of folds and faults. The boundary between the Blue Ridge and Great Valley to the west is the stratigraphic contact between the ridge-forming metasandstone of the Antietam Formation and the overlying limestone and dolomite of the Tomstown Formation. At the northern part of Pleasant Valley in Washington County, Md., the Rohrersville fault (Southworth and Brezinski, 1996a), separates Cambrian limestone of the Great Valley from metasedimentary and metavolcanic rocks of the Blue Ridge forms 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 are found east and south of Furnace Mountain near the Potomac River in Loudoun County, Va., where carbonaceous phyllite 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.

Paragneisses

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 prior to 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 almandine garnet suggest an impure sandstone or graywacke as the protolith (Burton and Southworth, 1996). Amphibolite (Ya) is a spotted, massive to well-foliated hornblende-orthopyroxene-plagioclase gneiss that contains subordinate sill or dike-like bodies of metanorite, metadiorite, and hornblende-biotite gneiss. Amphibolite is interpreted to be mafic metavolcanic rock. Quartzite and quartz tectonite (Yq) have rounded grains of quartz and zircon, seams of black carbonaceous phyllonite, and pods of garnet-graphite paragneiss. It is interpreted to be a sedimentary quartzite that locally has been sheared.

Granitic Gneiss and Metagranite

There are at least four groups of orthogneisses based on isotopic age data (Aleinikoff and others, 2000): 1) 1153+- 6 Ma layered granitic gneiss (Ylg), 1149+-19 Ma hornblende monzonite gneiss (Yhm), >1140+-4 to 1144+-2 Ma porphyroblastic metagranite (Ypg), and about 1140 Ma coarse-grained metagranite (Ymc); 2) 1111+-2 Ma biotitic and 1112+-3 Ma leucocratic Marshall Metagranite (Ym); 3) 1077+-4 Ma quartz-plagioclase gneiss (Yqp) and 1077+-4 garnetiferous metagranite (Ygt); and 4) 1060+-2 Ma white leucocratic metagranite (Yg), 1059+-2 Ma pink leucocratic metagranite (Yml), 1055+-4 Ma biotite granite gneiss (Ybg), and 1055+-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 the Marshall Metagranite (Ym) (Jonas, 1928; Espenshade, 1986), garnetiferous metagranite (Ygt), white leucocratic metagranite (Yg), pink leucocratic metagranite (Yml), and coarse-grained metagranite (Ymc). 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 and it is the oldest.

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 at 1153+-6 Ma, 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 10 per cent hornblende. Porphyroblastic metagranite (Ypg) is characterized by ovoid porphyroblasts of microcline as much as 3 cm long and 1 cm garnet. Garnetiferous metagranite (Ygt) and Marshall Metagranite (Ym) also occur in the western Blue Ridge as dikes and sills, and garnetiferous metagranite occurs as a large body near the Potomac River.

Neoproterozoic Rocks

Robertson River Igneous Suite

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

Metasedimentary Rocks of the Fauquier Group and Swift Run Formation

Unconformably overlying the Mesoproterozoic gneisses and Neoproterozoic Cobbler Mountain Alkali Feldspar Quartz Syenite is a sequence of clastic metasedimentary rocks. Rocks of the Fauquier Group and the 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 these rocks and those of the Swift Run Formation are two transverse normal faults that were actice during deposition of the strata (Kline and others, 1991).

Fauquier Group

The stratigraphic nomenclature of Kasselas (1993) and Lyttle and others (in press) is adopted for rocks of the Fauquier Group formerly called the Fauquier Formation by Espenshade (1986). These rocks are now called the Swains Mountain Formation and Carter Run Formation. The Swains Mountain Formation consists of a local, basal boulder conglomerate (Zsmc) overlain by gray metamudstone and meta-arkose (Zsm). The boulder conglomerate is a clast-supported conglomerate of boulders and cobbles of Mesoproterozoic granite gneiss that is interpreted to be a debris flow deposit. Coarse to fine-grained gray meta-arkose and finer-grained metamudstone overlie the boulder conglomerate, and they are overlain by gray metasiltstone and meta-arkose of the Carter Run Formation (Zcrs). The rocks of the Fauquier Group increase in thickness dramatically to the south, 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., is also interpreted as being deposited in a fault-bounded basin.

Swift Run Formation

Rocks of the Swift Run Formation (Stose and Stose, 1946) consist of metasandstone and schist (Zss), phyllite (Zsp), and marble (Zsl). The clastic rocks fine upward and cross-bedding suggests a fluvial origin, but the marble and some phyllite may be lake or shallow marine deposits. These rocks are not present in the same stratigraphic positions everywhere due to facies variations.

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

Metadiabase and Metarhyolite Dikes

Intruding the Mesoproterozoic and some Neoproterozoic rocks are a northeast-trending swarm of tabular dikes that range in thickness from 0.5 m to 5m. The dikes are mostly green metadiabase (Zmd) but a few are gray metarhyolite (Zrd) (Southworth and others, in press). Texturally, the metadiabase is fine-grained (most common), to coarse-grained, to porphyritic. Metarhyolite is fine-grained to porphyritic with phenocrysts of plagioclase in a matrix of microcrystalline quartz and potassium feldspar. Near Middletown, Md., one of these dikes appears to cut greenstone of the lower part of the Catoctin Formation. Zircons from a metarhyolite dike along the Potomac River yielded an 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 (Zc) (Keith, 1894) is characterized by green aphanitic, massive to schistose, amygdaloidal metabasalt and chlorite schist. In several places at or near the base are bodies of white calcitic marble (Zcm) similar to, but more extensive than, the marble within the underlying Swift Run Formation. Locally, metabasalt breccia has blocky masses of light green epidosite. Interbedded with the metabasalt are thin, discontinuous finely-laminated phyllitic metasiltstone and thin metasandstone (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 changes along strike. In Maryland, metabasalt gives way northward to phyllite, and in Pennsylvania metarhyolite is the dominate 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 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. Rocks of the Chilhowee Group are a fluvial to shallow marine transgressive sequence exhibiting a depositional transition from rift to passive continental margin, the latter officially marked by the conformably overlying carbonate rocks.

Loudoun Formation

The Loudoun Formation (Keith, 1894; Stose and Stose, 1946) is a thin, discontinuous sequence of predominantly phyllite (Clp) and minor quartz-pebble conglomerate and pebbly metasandstone (Clc) that locally occurs between the Catoctin and Weverton Formations. The lower phyllite unit is gradational into the underlying rocks of the Catoctin Formation and is interpreted to include metamorphosed volcanic tuff, mudstone, and(or) fossil soil (Reed, 1955; Nickelsen, 1956). The discontinuous and lensoid, quartz-pebble conglomerate is probably a local alluvial fan deposit. Locally, cross-stratified beds of quartzite occur between the conglomerate and underlying phyllite and show that the conglomerate is transitional into the overlying quartzite of the Weverton Formation. Rip-up clasts of phyllite, metabasalt, and red jasper from the Catoctin Formation record a period of erosion before deposition of the Loudoun Formation.

Weverton Formation

The Weverton Formation (Keith, 1894) (Cw) is divided into three members, the Buzzard Knob Member (Cwb) (lowest), the Maryland Heights Member (Cwm) (middle), and the Owens Creek Member (Cwo) (upper) (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, cross-bedded quartzite and quartz pebble conglomerate interbedded with dark metasiltstone. The Maryland Heights Member on Catoctin Mountain contains a thick bed of vitreous quartzite mapped separately (Cwmq).

Harpers Formation

The Harpers Formation (Ch) (Keith, 1894) is predominantly 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 that underlie Catoctin Mountain are more strongly foliated and phyllitic than the metasiltstone and metashale of Short Hill-South Mountain and Blue Ridge-Elk Ridge. On Blue Ridge-Elk Ridge, the lower Harpers Formation is transitional above the underlying Weverton Formation as it contains thin beds of pebble conglomerate. It is also transitional with the overlying rocks of the Antietam Formation, since it contains thin beds of clean *skolithus*-burrowed metasandstone mapped separately (Chs).

Antietam Formation

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

Carbonaceous Phyllite

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

Cambrian Tomstown Formation East of Catoctin Mountain

Light gray dolostone of the Tomstown Formation (Stose, 1906) (Ct) extends from near Furnace Mountain south of the Potomac River in Loudoun County, Va., north along Catoctin Mountain to west of Frederick. The dolostone is exposed along U.S. Route 15, in a pasture south of the Potomac River, and is marked by sink holes, small outcrops in streams, and recorded in drill core (Hoy and Shumaker, 1956) northward in Maryland. This dolostone resembles the Bolivar Heights Member exposed north of Harpers Ferry, W.Va.

Structure

Mesoproterozoic

Mesoproterozoic foliation is defined by granulite-facies metamorphic mineral assemblages. At least three episodes of deformation affected the oldest rocks (Burton and others, 1995; Aleinikoff and others, 2000). Northwest-trending foliation (D1), locally parallel to unit contacts, is cut by a weaker foliation with mineral lineations and southeast-plunging sheath folds (D2), which was later deformed into broad, northwest-trending folds (D3). D1 is younger than the 1145 Ma age of crystallization of the oldest granitic gneisses, but older than the weakly foliated 1077+-4 Ma granite that cuts it. D2 occurred after the latest intrusion at 1055 Ma, and D3 was still later. Outcrops of ductile folds in gneiss are rare. Quartz tectonite (Yq) that parallels Butchers Branch in the southwestern part of the western Blue Ridge may be a silicified fault rock of Mesoproterozoic age since 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 suggests that these rocks were not in proximity 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 Fauquier Group and Swift Run Formation against

Mesoproterozoic gneiss. These are interpreted to be syn-depositional normal faults (Kline and others, 1991). The faults do not appear to cut the rocks of the Catoctin Formation so they were active prior to deposition of the metabasalt.

The metadiabase dike swarm of the Blue Ridge basement is strong evidence of about 50 per cent extension during crustal rifting, even though few normal faults have been recognized in the basement gneiss complex. Beginning with the emplacement of the anorogenic granite of the Robertson River Intrusive Suite about 722 Ma and continuing through volcanism of the Catoctin Formation about 565 Ma, there was a long protracted period of Neoproterozoic continental extension that 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.

Paleozoic

The rocks of the Blue Ridge Province were deformed and metamorphosed in the Paleozoic to produce the Blue Ridge-South Mountain anticlinorium. We interpret this event to be the Late Paleozoic (Permian?) Alleghanian orogeny, although some argon data suggests a Devonian-Mississippian thermal event (Kunk and Burton, 1999). The anticlinorium is a broad, asymmetrical west-verging and gently north-plunging fold complex. There are gently-plunging folds on the homoclinal east limb, and more complexly deformed and tightly-folded rocks on the overturned west limbs. Stratigraphy on the west limb of the anticlinorium is repeated by the Short Hill fault, 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 (F1) and associated axial planar cleavage (S1), and a later, minor fold phase (F2) and associated crenulation cleavage (S2).

Folds

The Blue Ridge-South Mountain anticlinorium is a large west-verging F1 Fold. The east limb underlies Catoctin Mountain and Furnace Mountain, and the fault-repeated west limbs underlie Blue Ridge-Elk Ridge and Black Oak Ridge-Short Hill-South Mountain. Map-scale parasitic folds include the folds on Purcell Knob on the 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 first-order parasitic F1 folds have second-and third-order folds such as the tight recumbent F1 folds of the Weverton Formation that verge up the west limb of the anticlinorium along the Potomac River gorge.

Later deformation produced open to tight F2 folds accompanied by axial planar crenulation cleavage and spaced cleavage, that may have been a continuum of the earlier phase of deformation (Nickelsen, 1956; Southworth and others, in press). F2 folds superimposed on F1folds and S1 cleavage are exposed on Blue Ridge from Wilson Gap to the terminus north of Rohrersville, Md., and on Catoctin Mountain south of Point of Rocks, Md.

Cleavage

Axial planar to the Blue Ridge – South Mountain anticlinorium and coeval with its formation is a regional penetrative northeast-striking, southeast-dipping S1 cleavage (South Mountain cleavage of Cloos (1951) and Mitra and Elliott (1980)) that overprints Mesoproterozoic foliation and bedding in Neoproterozoic and Cambrian rocks. The S1 foliation is slaty to schistose, depending on the host rock.

The S2 cleavage is discontinuous, did not involve extensive recrystallization, and is mostly a pressure solution cleavage. It has about the same strike as S1, but a slightly steeper dip. It is commonly axial planar to F2 folds.

Faults

Faults were mapped on the basis of stratigraphic truncation and omission as well as 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 km from a shear zone in Mesoproterozoic rocks in Fauquier Co., Va., to the Rohrersville, Md., area where limestone of the Middle Cambrian Elbrook Formation structurally overlies metabasalt of the Neoproterozoic Catoctin Formation along a flat-lying fault that plunges northward with the anticlinorium. This fault is interpreted to be an early Paleozoic normal fault that was contractionally reactivated as a thrust fault and folded with the anticlinorium (Southworth and Brezinski, 1996a). The Keedysville marble bed is mylonite of the Bolivar Heights Member of the Tomstown Formation that is interpreted to be a regional detachment between the carbonate rock sequence and the underlying Chilhowee Group prior to folding of the anticlinorium (Brezinski and others, 1996). Other intraformational thrust faults, strike-slip faults, and normal faults are synchronous with or post-date F1 folding of the anticlinorium. Within the Mesoproterozoic gneiss are zones of mylonite and phyllonite that superficially resemble fine-grained metasedimentary rocks but instead are ductile fault rocks. The mylonite contains lower greenschist-facies minerals and is probably contemporaneous with the development of S1 cleavage that is coplanar. Several shear zones are as much as 0.6 mi wide and juxtapose different basement gneiss units.

Mesozoic

Several small normal faults in the Mesoproterozoic rocks may be early Mesozoic (Burton and others, 1995), because they are similar to the family of 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 structure is north-trending Early Jurassic diabase dikes.

Metamorphism

Mesoproterozoic

Plutonism, metamorphism, and deformation spanned about 150 million years from about 1153 to 1000 Ma. Mesoproterozoic deformation and metamorphism ended no earlier than about 1055 Ma, the age of the youngest deformed unit, megacrystic metagranite (Ypb). Granulite-facies mineral assemblages of orthopyroxene and microcline (in charnockitic granite) and orthopyroxene and brown hornblende (in amphibolite) shows granoblastic texture and triple-junction grain boundaries. Monazite ages indicate that there was no regional thermal event hotter than 720 C that affected the rocks after the Grenville orogeny. 40Ar/39Ar of hornblende provide a cooling age of 1000 to 920 Ma (Kunk and others, 1993), suggesting a minimum age for regional metamorphism in this area.

Paleozoic

Paleozoic deformation was accompanied by recrystallization under lower greenschist-facies metamorphic conditions. Formation of S1 cleavage was accompanied by growth of fine-grained muscovite, chlorite, biotite, epidote, actinolite, and accessory minerals in the rocks of the cover sequence. Biotite is only recognized in cover rocks on the east limb of the anticlinorium. Some of the cover rocks show multiple generations of white mica, suggesting a complex metamorphic history. Retrograde mineral assemblages of muscovite, biotite, and chlorite grew at the expense of feldspar, brown biotite, and garnet in Mesoproterozoic gneisses. Neoproterozoic metadiabase dikes and metabasalt have actinolite, chlorite, and epidote. The age of metamorphism and deformation is poorly constrained but usually attributed to the late Paleozoic Alleghanian orogeny (Mitra and Elliott, 1980). These rocks were transported westward in the Alleghanian orogeny (Evans, 1988) but the metamorphism and deformation may be older.

PIEDMONT PROVINCE

Geologic Setting

The Piedmont, meaning "foot of the mountain", is the province east of the lower slope of Catoctin Mountain of the Blue Ridge Province. There are at least three sections of the Piedmont Province within the Frederick 30 by 60 minute quadrangle. In the eastern part, crystalline rocks of the Potomac terrane have been thrust onto metamorphic rocks of the Westminster terrane along the Pleasant Grove fault. The metasedimentary and metavolcanic rocks of the Westminster terrane have been 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 physiography of 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. Unconformably overlying these rocks, are Mesozoic sedimentary rocks of the Culpeper and Gettysburg basins that were intruded by dikes and sills of diabase.

Eastern Piedmont

Potomac Terrane

Metagabbro, Ultramafic Rocks, the Soldiers Delight Ultramafite and Metatuff

Dark green, fine- to medium-grained metagabbro containing layers of metapyroxenite (CZg), as well as serpentinite, soapstone, chlorite-tremolite-epidote schist, talc-chlorite schist, and talc-calcite-actinolite schist (CZu), constitute blocks of mafic and ultramafic rock interpreted to be emplaced during deposition of turbidites of the Mather Gorge Formation (CZms). The Soldiers Delight Ultramafite (Drake, 1994) (CZs) 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 (Cs) on the west, from the Loch Raven Schist (CZl).

Chemical data suggests that the rock was pyroxenite that formed beneath the ocean floor (Drake, 1994). Metatuff (CZmt) consists of hornblende-plagioclase, epidote-plagioclase-actinolite, and quartz-muscovite-plagioclase. It is interpreted to be part of a sparse sequence of interlayered mafic and felsic metavolcanic rocks near Great Falls, Va.

Metasedimentary Rocks

Mather Gorge Formation

The Mather Gorge Formation (Drake and Froelich, 1997) mostly consists of quartz-rich schist containing minor mica gneiss and metagraywacke (CZms), metagraywacke containing schist (CZmg), migmatite (CZmm), and phyllonite (CZmp). Locally there are blocks of calc-silicate rock and metatuff within the metagraywacke and schist that are too small to portray on the map. The metagraywacke and schist are interpreted to be deep water 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 (CZms) locally is muscovite gneiss, and has interbedded metagraywacke and some small blocks calc-silicate rock. Mineral assemblages of the schist include biotite-muscovite-plagioclase-quartz, quartz-muscovite-chlorite-plagioclase-epidote-magnetite-hematite, quartz-muscovite-biotite-garnet-staurolite-magnetite, and quartz-biotite-plagioclase-sillimanite-magnetite.

Metagraywacke (CZmg) is well-bedded with semi-pelitic schist, quartzose schist, and some calc-silicate rock interbeds. Beds of metagraywacke range from 3 cm to as much as 3 m thick but average about 15 cm. The metagraywacke beds are graded and have sole marks and slump features that are preserved at sillimanite grade (Hopson, 1964).

In the eastern part of the map unit, some of the schist and metagraywacke was partially melted to form stromatic and less commonly phlebitic migmatite (Mehnert, 1971)(CZmm) consisting of a quartz-plagioclase leucosome and a muscovite-rich schist paleosome.

Lustrous fine-grained chlorite-sericite phyllonite (CZmp) containing knots and pods of white vein quartz resulted from the local shearing of rocks of the Mather Gorge Formation in broad fault zones in the extreme eastern part of the map unit.

Northwest Branch Formation

The Northwest Branch Formation (CZn) (Drake, 1998) consists of well-bedded meta-arenite and lesser quartzite and calc-silicate rock. Beds range from 1 cm to 7 cm in thickness and are interbedded with schist similar to that in the overlying Loch Raven Schist.

Loch Raven Schist

The Loch Raven Schist (CZl) (Crowley, 1976) is a thin-bedded, lustrous, quartz-muscovite-biotite-plagioclase schist that at places contains garnet, staurolite, and (or) kyanite. The schist is interbedded with meta-arenite (CZlm) that is similar to meta-arenite of the overlying Oella Formation into which it grades.

Oella Formation

The Oella Formation (Crowley, 1976)(CZo) 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.

Laurel Formation

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

Sykesville Formation

The Sykesville Formation (Cs) (Hopson, 1964) is also a sedimentary melange consisting of a quartzo-feldspathic matrix that contains distinctive round, eye-shaped quartz lumps and blocks of phyllonite (CZmp), migmatite (CZmm), metagraywacke (CZmg), mafic and ultramafic rocks (CZu), metagabbro (CZg), 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 quartz bodies of Cambrian and Ordovician age, the Bear Island Granodiorite of Early(?) Ordovician age and the Middle Ordovician Georgetown Intrusive Suite, Dalecarlia Intrusive Suite, Kensington Tonalite and Norbeck Intrusive Suite, as well as the Guilford Granite and pegmatites of Devonian age.

Quartz Bodies

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

Bear Island Granodiorite

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 moderate- sized sheets, sills, and dikes in migmatite and phyllonite of the Mather Gorge Formation a distance of 5 km from Bear Island east to the Plummers Island fault.

Dalecarlia Intrusive Suite

The Dalecarlia Intrusive Suite (Drake and Fleming, 1994) consists of biotite monzogranite and granodiorite (Odm), leucocratic monzogranite (Odl), and muscovite trondhjemite (Odt), that has intruded rocks of the Sykesville Formation, Georgetown Intrusive Suite, and the Norbeck Intrusive Suite. Biotite monzogranite and lesser granodiorite (Odm) contain lenses, zones, and irregular pods of leucocratic biotite-muscovite monzogranite (Odl). Muscovite trondhjemite (Odt) forms an irregular shaped body within the biotite monzogranite.The monzogranite has a U-Pb single crystal SHRIMP age of 480+-5 Ma (J.N. Aleinikoff, U.S.Geological Survey, written communication, 1999).

Norbeck Intrusive Suite

The 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 (Ont) contains many xenoliths and (or) autoliths of more mafic rock and locally has a strong flow foliation. This rock has a concordant conventional U-Pb age of 467+-4 Ma and a single crystal SHRIMP age of 459+-8 Ma (J.N. Aleinikoff, U.S.Geological Survey, written communication, 1997). Quartz gabbro (Ong) forms small bodies within biotite-hornblende tonalite (Ont). Ultramafic rocks (Onu) include small bodies of serpentinite and soapstone. Small bodies of trondhjemite (Ontr) are very siliceous and consist largely of plagioclase and quartz.

Georgetown Intrusive Suite

The Georgetown Intrusive Suite (Fleming and others, 1994) consists of biotite-hornblende tonalite (Ogh), quartz gabbro (Ogg), and metapyroxenite (Ogp) that intrudes rocks of the Sykesville Formation in Washington, D.C. Biotite-hornblende tonalite (Ogh) has a strong relict igneous flow foliation in places. The unit contains many ultramafic and mafic xenoliths and (or) autoliths, as well as xenoliths of metasedimentary rocks. It typically is composed of 50 percent mafic minerals. It has a concordant conventional U-Pb age of 466+-3 Ma and a single crystal U-Pb age of 483+-4 Ma (J.N. Aleinikoff, U.S.Geological Survey, written communication, 1999). Quartz gabbro (Ogg) contains lesser diorite and much lesser quartz norite. At many places, it contains thin cumulate layers of metapyroxenite and augite-hornblende rock. Metapyroxenite (Ogp) has been altered to dark grayish-green serpentinite. Small pods and a swarm of xenoliths of metapyroxenite occur within or along the borders of the larger tonalite and quartz gabbro plutons.

Kensington Tonalite

The Kensington Tonalite (Cloos and Cooke, 1953; Fleming and others, 1994)(Ok) intruded rocks in the eastern belt of Sykesville Formation near the Rock Creek shear zone and Brinklow thrust fault. In and near these fault zones it 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 462+-4 Ma (J.N. Aleinikoff, U.S.Geological Survey, written communication, 1999).

Guilford Granite

The Guilford Granite (Dg) (Cloos and Broedal, 1940) is a nonfoliated, very homogeneous monzogranite that forms thin sheets that crosscut bedding and schistosity in the Sykesville Formation east of the Rock Creek shear zone. The Guilford Granite has a

U-Pb age of 368+-4 Ma (J.N. Aleinikoff, U.S.Geological Survey, written communication, 1996).

Pegmatite

Pegmatite (Dp) is composed of coarse grains of muscovite, microperthitic microcline, albite, and quartz. It is non-foliated and crosscuts schistosity and foliation in the Sykesville and Laurel Formations east of the Rock Creek shear zone.

Central Piedmont

Westminster Terrane

Prettyboy Schist

The Prettyboy Schist (Crowley, 1976) (CZp) is quartz-muscovite-chlorite-albite schist and muscovite-quartz-albite schist with 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) at a higher metamorphic grade, making the gradational contact between the two units a metamorphic isograd (Fisher, 1978). The Prettyboy Schist crops out in two antiforms within the northeastern part of the Westminster terrane. Massive to schistose metabasalt (CZpg) forms a lensoidal body within the schist of the northern antiform. Granular quartzite (CZpq) as much as 1 m thick is interbedded with the schist in sequences as much as 30 m thick.

Marburg Formation

The Marburg Formation (Drake, 1994) (Marburg Schist of Jonas and Stose, 1938b) is an assemblage of phyllite and metasiltstone (CZmb) that contain small bodies of metagraywacke (CZmbg), greenstone (CZmbgs), and quartzite (CZmbq). Quartz-sericite-chlorite phyllite contains chloritoid and albite porphyroblasts, and chlorite-albite metasiltstone contains ribbons and laminae of quartz 1-2 cm thick. Both of these units are impregnated with vein quartz and highy folded. Thin layers and lens of hematite-bearing chlorite-paragonite-muscovite-phyllite, 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 sedimentation (turbidites) and metamorphic processes.

Metagraywacke (CZmbg) is a dark quartz-rich granular rock locally interbedded with the chlorite phyllite and metasiltstone unit. Actinolite-plagioclase schist and metabasalt (CZmbgs) is interpreted to be epiclastic deposits and metamorphosed basalt. Lenticular quartzite (CZmbq) is coarse- grained with a high chlorite content. The contact between the rocks of the Marburg Formation and Sams Creek Formation is a thrust fault but rocks of the Marburg Formation may stratigraphically underlie rocks of the Sams Creek Formation at the north 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 hematite-phyllite that resembles rocks of the Ijamsville Phyllite, but nowhere do the rock units come into contact. The Marburg Formation contains some fine-grained albite schist that is similar to the coarse-albite schist of the Prettyboy Schist. Because of these two lithologic similarities, the Marburg Formation may be transitional facies between the Ijamsville Phyllite and Prettyboy Schist but otherwise, they are a unique assemblage of rocks. The rocks mapped as Marburg Formation have been called the Wissahickon Formation by Fisher (1978) and the Gillis Group by Edwards (1986, 1994).

Ijamsville Phyllite

The Ijamsville Phyllite (Jonas and Stose, 1938b) consists of phyllite, phyllonite, and slate (undifferentiated) (CZi), chlorite phyllite (CZip), greenstone (CZig), quartzite (CZiq), conglomeratic metagraywacke (CZic), metalimestone (CZil), marble (CZim), and phyllite conglomerate (CZid), in four belts of rock. One belt is mapped from the type locality, another belt is confined to a klippe of the Martic fault west of Sugarloaf Mountain, another belt is between the klippe and rocks of the Sams Creek Formation near Chestnut Grove, and another belt is mapped above the Martic fault east of Sugarloaf Mountain.

The muscovite-chlorite-paragonite-chloritoid phyllite often has composite foliations and abundant vein quartz 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 seen as thin bands of opaque minerals on cleavage surfaces. The dark color of the phyllite and slate results from abundant minute crystals of hematite. Chlorite phyllite and metasiltstone (CZip) are interlayered with the hematite-phyllite at the type locality of the formation. Northward the phyllite is conglomeratic containing phyllite clasts, clasts and lens of marble, and is interbedded with quartzite of the Sams Creek Formation. Near Lake Linganore, phyllite interbedded with 0.5 m thick quartzite is transitional northward with thick-bedded quartzite interbedded with thin layers of phyllite and rip-up clasts of phyllite. Metabasalt (CZig) contains nodules of epidosite and sparse flattened pillows crop out north of Beallsville, Md. Locally, centimeter-thick metabasalt is interlayered with phyllite. White, massive, medium-grained quartzite (CZiq) is interbedded with phyllite but the bodies are discontinuous and are probably channel deposits. Thin-bedded metalimestone (CZil) containing black carbonaceous metashale is surrounded by phyllite near the mouth of the Monocacy River. The thin argillaceous metalimestone may be large clasts deposited in deep water mud. The metalimestone resembles the Silver Run Limestone of Jonas and Stose (1938b) and Fisher (1978) (Southworth, 1998). Pods of sandy marble (CZim) 10 cm to 3 m long are found within conglomeratic phyllite (CZi) west of the type locality at Ijamsville. The marble is also interpreted to be clasts deposited by debris flows in deepwater mud. A unique outcrop of phyllite-clast conglomerate (CZid) north of Bush Creek and west of Monrovia 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, magnetite, sphene, tourmaline, and rutile. The protolith of this rock is interpreted to be a submarine debris flow. Chlorite phyllite and metasiltstone interbedded with conglomeratic metagraywacke (CZic) near Chestnut Grove is mapped as Ijamsville Phyllite. The conglomeratic metagraywacke (CZic) 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. Interestingly, the detrital material in this rock was derived from greenschist-facies metasedimentary rocks with abundant vein quartz and the source is unknown.

Sams Creek Formation

The Sams Creek Formation (Jonas and Stose, 1938b) consists of metabasalt (CZscg), felsic schist (CZscf), marble (CZscm), tuffaceous phyllite (CZsctp), muscovite phyllite (CZscmp), hematite phyllite (CZscmp), metalimestone (CZscl), quartzite interbedded with phyllite (CZscqs), quartzite (CZscq), metasiltstone (CZscs), and calcareous metasandstone (CZscc). Metabasalt (CZscg) is mostly massive, porphyritic with calcite filled amygdules and epidosite nodules. In several places the metabasalt is a hyaloclasite breccia of fragmented metabasalt, conglomerate of elongated clasts of metabasalt, and epiclastic deposits of weathered greenstone. The metabasalt is interpreted to be metamorphosed basalt flows that were intercalated with beds of quartzite, metasiltstone, phyllite, and marble. They are chemically identical to tholeitiic basalt of the Catoctin Formation of the Blue Ridge-South Mountain anticlinorium to the west (Southworth, 1999). Metavolcanic and metavolcaniclastic schist (CZscf) of intermediate composition is interlayered with metabasalt in several places. Massive to thin-bedded calcite and dolomite marble (CZscm) occurs as linear pods in 3 different types of phyllite as well as metabasalt and quartzite in different stratigraphic positions. The marble clasts are interpreted to be olistoliths and several bodies as much as 1 km long and 0.5 km wide are within a “calico” phyllite-clast conglomerate. Tuffaceous phyllite (CZsctp) is a metavolcaniclastic phyllite and schist that was formerly called the Libertytown Metarhyolite (Jonas and Stose, 1938b). Muscovite phyllite (CZscmp) is extensive in the eastern belt of Sams Creek Formation adjacent to the thrust sheet of rocks of the Marburg Formation. Hematite phyllite (CZschp) closely resembles rocks of the

Ijamsville Phyllite but is inter-layered with tuffaceous phyllite that is not recognized in Ijamsville Phyllite to the south. Metalimestone (CZscl), identical to metalimestone of the Ijamsville Phyllite, occurs mostly within phyllite (muscovite, tuffaceous, or hematite varieties), but one body is adjacent to metabasalt and another body is above marble.

The quartzite interbedded with phyllite unit (CZscqs) is mostly medium-grained quartzite interbedded with phyllite, phyllite-clast conglomerate, and tuffaceous phyllite in an important area of rock transition near Lake Linganore. The quartzite, 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, elsewhere.

Medium- and coarse-grained quartzite of the Sams Creek Formation (CZscq) is crossbedded, locally calcareous and are probably channel deposits within all the other units of the formation. Metasiltstone interbedded with quartzite and calcareous metasandstone (CZscs) resembles rocks of the Urbana Formation (Jonas and Stose, 1938a), but they contain metabasalt. Friable, coarse-grained calcareous metasandstone (CZscc) with large, high angle cross beds appears to be overlain by greenstone south of Monrovia.

Wakefield Marble

The Wakefield Marble (Jonas and Stose, 1938b)(CZwm) is a calcite-dolomite marble that can be traced continuously from the northern edge of the map area to the type locality in Wakefield Valley in the adjacent New Windsor 7.5′ quadrangle, where it stratigraphically overlies metabasalt of the Sams Creek Formation (Fisher, 1978). The Wakefield Marble is interpreted to be shallow water deposits on submerged islands of basalt (Fisher, 1978). The Wakefield Marble is identical to large clasts of marble within the Sams Creek Formation and Ijamsville Formation, therefore, the significance of the stratigraphic position is uncertain.

Sugarloaf Mountain Anticlinorium and Bush Creek Belt

Sugarloaf Mountain Quartzite

The Sugarloaf Mountain Quartzite (Jonas and Stose, 1938b) is a medium- to coarse-grained quartzite cemented by silica and sericite. Cross-bedding, graded beds, and sparse ripple marks show that these are continental margin deposits laid down by running water. Poorly exposed laminated metasiltstone is interbedded with the quartzite. The Sugarloaf Mountain Quartzite is subdivided into informal lower (Csql), middle (Csqm), and upper (Csqu) members. The upper member is well exposed at the summit of Sugarloaf Mountain, the middle member forms the prominent ridge north of the summit that is followed by the "Northern Peaks trail", but the lower member is poorly exposed (Southworth and Brezinski, in press).

Urbana Formation

The Urbana Formation (Edwards, 1986) (Urbana Phyllite of Jonas and Stose, 1938b) conformably overlies the Sugarloaf Mountain Quartzite and is structurally overlain by rocks of the Ijamsville Formation along the Martic fault. The Urbana Formation consists of quartzite, calcareous metasandstone, metagraywacke, conglomeratic quartzite, and metasiltstone, that cannot be differentiated (Cu), and mappable bodies of marble (Cum), and quartzite (Cuq). Most of the rock units in the Urbana Formation are discontinuous lenses that are sandy, calcareous, friable, deeply weathered, and thus are poorly exposed. The quartzite, metasandstone, and meta-siltstone are crossbedded and ripple-marked reflecting deposition by running water. Schistose to massive sandy chlorite marble (Cum) is interbedded with metasiltstone and metasandstone. Massive quartzite interbedded wth vuggy calcareous metasandstone (Cuq) mapped within broader belts of meta-siltstone are probably local channel deposits and not a continuous stratigraphic horizon. Along Bush Creek is metasiltstone, calcareous metasandstone, marble, and quartzite. 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 are interpreted to be Urbana Formation exposed beneath the Martic thrust sheet in the Bush Creek window (Southworth, 1999).

Western Piedmont

Frederick Valley Synclinorium

Araby Formation

The Lower and Middle Cambrian Araby Formation (Car) (Reinhardt, 1974; 1977) consists of argillaceous, burrow-mottled sandy metasiltstone and phyllitic metashale 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 northeast part of the Frederick Valley within the map area, metashale beds thicken near the top of the unit and are mapped as the Cash Smith Formation.

Cash Smith Formation

The Cash Smith Formation (Edwards, 1988)(Ccs) is a dark metashale that grades up into thin-bedded calcareous metashale with limestone nodules. The rocks are transitional between the metasiltstone of the Araby Formation and the limestone of the Rocky Springs Station Member of the Frederick Formation.The Cash Smith Formation is similar to the dark shale beds within the Rocky Springs Station Member (Cfrs) but 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 thin- to medium-bedded limestone, dolomite, and thin intervals of shale and sandstone. The Frederick Limestone was renamed Frederick Formation by Southworth and Brezinski (in press) and the three members of Reinhardt (1974; 1977) are shown on the map. The Rocky Springs Station Member (Cfr) is characterized by intervals of polymictic breccia that are traced locally. This lower member was deposited by off-shelf submarine slides that accumulated at the toe of a paleo-slope (Reinhardt, 1974). An interval of gray to black shale (Cfrs) is similar to the shale of the Cash Smith Formation, which locally underlies the unit to the north.

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

Grove Formation

The Grove Formation (Stose and Jonas, 1935; Jonas and Stose, 1938b: Reinhardt, 1974) is an interval of Upper Cambrian and Lower Ordovician carbonate rock in the center of the Frederick Valley. Two informal members were mapped. The lower member (OCgs) consists of crossbedded dolomitic sandy limestone and sandstone that is distinctively different from the underlying and overlying strata. These rocks were probably deposited on the shelf edge as a sand wave complex.

Above the basal sandstone member are medium- to thick-bedded limestone and dolomite of the upper member (OCgu). The strata are arranged in cycles consisting of thrombolitic and stromatolitic limestone and laminated dolomite, that were deposited in a peritidal environment.

Structure

The Piedmont province is subdivided into the eastern, central, and western 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 under *Metamorphism,* on-going argon geochronology (Kunk, USGS, 2001, oral and written communication) and fabric studies (R. P. Wintsch, Indiana University, 2001, oral and written communication), will attempt to unravel this complex history.

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 of the Mather Gorge Formation were emplaced on previously undeformed sediments of the Sykesville Formation along 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 migmatite, schist, folded metagraywacke and phyllonite of the Mather Gorge Formation within the Sykesville Formation demonstrate that deformation and metamorphism of the Mather Gorge Formation predated sedimentation of the Sykesville Formation (Drake, 1989; Muller, 1994). From the Plummers Island fault west to Bear Island, ductile fault fabrics are restricted to phyllonite, 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. Exposures along the Potomac River just south of the map area of strongly sheared rocks in both Mather Gorge and Sykesville Formations across the steep west-dipping Plummers Island fault suggests 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; Kunk, USGS, 2001, oral communication).

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, which contains locally abundant olistoliths of previously deformed rocks. The Loch Raven thrust sheet was emplaced during deposition of the Laurel Formation along the Burnt Mills thrust fault. These rocks have been 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 consists of phyllonitized and mylonitized rocks as much as 3 km wide that contain kinematic indicators of thrust, 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 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 1-2 km wide that initially formed as a thrust fault during deformation associated with the Ordovician Taconic orogeny (Drake, 1989). K-Ar geochronology suggests that deformation-induced recrystallization was associated with shear band foliation having dextral strike-slip kinematics in the late Paleozoic (Pennsylvanian-Permian, 311.4 +- 3.2 Ma), Alleghanian orogeny (Krol and others, 1999).

40Ar/39Ar data of white mica in the shear zone also define a 364-348 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.

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 District of Columbia. 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 at many places has been overprinted by a spaced cleavage. Rocks of the Sykesville and Laurel Formations have a crude foliation defined commonly by aligned clasts, that at many places is overprinted by schistosity. 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 spaced shear band cleavage with kinematics of dextral strike slip motion of undetermined displacement. Similar kinematic indicators are only locally 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 has intersected beds and forms a prominent intersection lineation. Later schistosities in these rocks have intersected the first schistosity forming 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 showing that the rocks have been stretched. Many of the rocks of the Georgetown, Dalecarlia, and Norbeck Intrusive Suites have a down-dip 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 late strike slip transpression.

Central Piedmont

Thrust Sheets and Faults

The rocks of the Westminster terrane are lithotectonic units in a stack of imbricate thrust sheets floored by the Martic fault (Southworth, 1996). The thrust sheets were 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 in all 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 up section westward, placing 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. There are early (now folded) and late (cut existing faults) thrust faults, reactivated thrust faults, and numerous small intraformational faults of limited displacement.

Foliation

Rocks of the Ijamsville Phyllite of the Martic thrust sheet have 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 F1 folds were deformed by westward-verging, inclined F2 folds that plunge steep to gentle in all directions. These F2 folds have attendant northeast-dipping axial planar pressure solution crenulation cleavage.

In the Barnesville-Monrovia thrust sheet, foliated metabasalt is structurally aligned parallel to the fault. Sheath folds of greenstone plunge moderately south-southeast in a zone of high strain near Monrovia. Here, the map pattern is 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 axial planar to F2 folds plunges steeply and gently northeast and southwest. The entire belt of Marburg Formation is considered to be a fault zone.

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 3 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 show refolded folds in the north central part of the Sams Creek Formation between the Hyattstown and Martic faults. Here, the early schistosity is vertical and trends east to west, and is folded with northeast-striking cleavage axial planar to steep F2 antiforms that plunge in all directions. Similar high strain between the Barnesville-Monrovia fault and Hyattstown fault has produced tubular sheath folds of greenstone and phyllite of the Sams Creek Formation.

The Sugarloaf Mountain Quartzite and stratigraphically overlying Urbana Formation were folded to create the doubly-plunging Sugarloaf Mountain anticlinorium that 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 and to the south the structure ends as a plunging anticline. An intraformational thrust fault places the main anticlinorium onto its west limb, and numerous small normal faults that cut folded beds of quartzite are interpreted to be related to Mesozoic extension associated with the Culpeper basin.

The Sugarloaf Mountain Quartzite and Urbana Formation have a cleavage that is axial planar to a single fold phase that constitute 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 rocks mapped as the Urbana Formation in the Bush Creek window plunge gently south.

Western Piedmont

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

Metamorphism

The rocks of the Piedmont were metamorphosed at both different times and grades and they have been subsequently juxtaposed and transported westward during Paleozoic orogenies. In general the rocks are highest grade (sillimanite) in the east and lowest grade (chlorite-sericite) in the west. However, it is not a simple Barrovian sequence as has been described along discrete sections of the Potomac River near Great Falls (Fisher, 1970; Drake, 1989). On-going investigations using argon geochronology suggests a complex metamorphic history (Kunk, USGS, 2001, oral and written communication). Therefore the metamorphic history of the rocks is presented by geographic region and no attempt is made to relate the metamorphic history of the rocks.

Eastern Piedmont

Rocks of the Mather Gorge Formation are polymetamorphic. They experienced a prograde metamorphic event characterized by mineral assemblages ranging from chlorite zone in the west to sillimanite zone in the east (Fisher, 1970; Drake, 1989). In the sillimanite zone the rocks are migmatites. This Barrovian metamorphism occurred prior to the intrusion of the Early Ordovician Bear Island Granodiorite and Middle Ordovician Taconic 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 which crystallized chloritoid, muscovite, and biotite from shimmer aggregate formed during the retrograde event. 40Ar/39Ar white mica dates suggest that rocks of the Mather Gorge Formation immediately above the Pleasant Grove fault record thermal evidence of the Taconic (Ordovician), Acadian (Devonian), and Alleghanian (Pennsylvanian-Permian) orogenies (Krol and others, 1999).

The Sykesville Formation is at biotite+-garnet+-staurolite grade, but its olistoliths were metamorphosed and deformed prior to deposition. The Loch Raven Schist and Laurel Formation east of the Rock Creek shear zone appears to have experienced two prograde events and the foliation contains biotite and garnet. 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, Georgetown, Dalecarlia, and Norbeck Intrusive Suites, and Bear Island Granodiorite have been Metamorphosed, but the Guilford Granite has not been metamorphosed.

Central Piedmont

Rocks of the Westminster terrane have had a complex metamorphic history under greenschist-facies conditions. Phyllite of the Ijamsville Phyllite, Marburg Formation, and Sams Creek Formation contain varying proportions of muscovite-chlorite-paragonitequartz-magnetite, and calcite, of a first metamorphic event. Greenstone contains varying proportions of actinolite, epidote, and stilpnomelane. Quartzose rocks contain sericite and chlorite. Phyllitic rock in fault zones has been retrogressively metamorphosed and sheared into phyllonitic diaphthorites (Knopf, 1931). Rocks described by Knopf (1931) as "sick-looking" have multiple shades of green chlorite, white quartz, and abundant leucoxene. Phyllites of the Ijamsville Phyllite, Sams Creek Formation, and Marburg Formation locally contain chloritoid or albite of a later prograde metamorphic event that overgrows the early foliation. The contacts between the phyllite of the Sams Creek Formation, rocks of the Marburg Formation, and 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 it is rotated by pressure solution cleavage. Albite porphyroblasts also increase in size and abundance to the east from rocks of the Marburg Formation into Prettyboy Schist. Locally, albite encloses crinkles of the Wakefield and Marston fold phases, so the peak of metamorphism postdates the major folding events.

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 has sparse chlorite. Cleavage in metasiltstone and marble of the Urbana Formation is marked by aligned sericite crystals and chlorite porphyroblasts which give them a green hue.

Western Piedmont

Rocks of the Araby, Cash Smith, Frederick, and Grove Formations only 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 rocks of the overturned east limb of the synclinorium.

GREAT VALLEY

Geologic Setting

The Great Valley 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 the Great North Mountain. There, the Alleghanian North Mountain thrust fault places the Cambrian and Ordovician rocks of the Great Valley onto Silurian and Devonian rocks.

Paleozoic Sedimentary Rocks

Tomstown Formation

The carbonate rocks of the Tomstown Formation (Ctu) (Tomstown Dolomite of Stose (1906)) has been subdivided into the Bolivar Heights (Ctbh), Fort Duncan (Ctf), Benevola (Ctb), and Dargan Members (Ctd) (Brezinski, 1992). These rocks are the first evidence that the rifted continent had evolved into a passive margin. The vertical sequence of rocks suggests a change from shallow carbonate shelf to deep shelf to bank edge carbonate sand shoal.

The Bolivar Heights Member (Ctbh) is a thin-bedded limestone having wispy dolomitic burrows that increase upsection, where bioturbation was more prevalent. At the base of the member is a 15-m-thick interval of mylonitic marble. Termed the Keedysville marble bed, it was interpreted to define a regional thrust fault that detached the carbonate rocks from the underlying rocks of the Antietam Formation (Brezinski and others, 1996).

The Fort Duncan Member (Ctf) is a dark, burrow-mottled, thick- bedded dolomite whose base is probably an erosion surface on the Bolivar Heights Member.

The Benevola Member (Ctb) is a very thick-bedded to massive, sugary dolomite with faint crossbedding. The base is gradational with the under-lying bioturbated dolomite of the Fort Duncan Member. This rock is quarried as aggregate because it is pure and massive.

The Dargan Member (Ctd) consists of a lower bioturbated dolomite alternating with intervals of laminated dolomite. In the upper part, bioturbated and oolitic dolomite is interbedded with laminated limestone and silty dolomite.

Waynesboro Formation

The Waynesboro Formation (Cwa) (Stose, 1906) has been subdivided into the Red Run (Cwar), Cavetown (Cwak), and Chewsville (Cwac) Members (Brezinski, 1992). These members have distinctive physiographic expression that facilitate field mapping; sandstone of the lower Red Run and upper Chewsville Members underlie low hills with the intervening carbonate rock of the Cavetown Member underlying a swale between the hills.

The Red Run Member (Cwar) consists of interbedded calcareous sandstone and laminated, ribbony, sandy dolomite and silty, calcareous shale. The Cavetown Member (Cwak) underlies a broad swale and is typically not well exposed. It consists of a lower thick-bedded, massive, limestone and bioturbated dolomite; bioturbated dolomitic limestone and dolomite and thin calcareous sandstone and shale in the middle; and an upper part of thick-bedded, bioturbated dolomite with laminated ribbony dolomite at the top. The Chewsville Member (Cwac) is distinctive with its dark siltstone, sandstone, and shale. The siltstone is commonly rippled and mudcracked and the sandstone is cross bedded with *Skolithus* burrows. These rocks were deposited in a shallow subtidal to supratidal environment.

Elbrook Limestone

The Elbrook Limestone (Ce) (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 dolomite. 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, dolomite, and dolomitic shale. These rocks were deposited in a shallowing-upward peritidal environment.

Conococheague Limestone and Big Spring Station Member

The Conococheague Limestone (OCc) (Stose, 1910) consists of interbedded limestone, dolostone, dololaminite, and sandstone arranged in cycles. The lower 100 m consists of coarse-grained, calcareous sandstone, fine-grained limestone, and fine-grained dolostone of the Big Spring Station Member (Ccbs) that forms low ridges. Above the Big Springs 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

Stonehenge Limestone and Stoufferstown Member

The basal part of the Stonehenge Limestone, the Stoufferstown Member (Oss) (Sando, 1958), consists of silty, laminated limestone. The remainder of the Stonehenge Limestone (Os) (Stose, 1910) consists of thick-bedded, fossiliferous limestone. Algal bioherms, intraformational conglomerates, and bioclastic beds, alternate with thin dolomite beds. Unlike the peritidal environments of the underlying Conococheague Limestone, the Stonehenge Limestone was deposited in a subtidal environment.

Rockdale Run Formation

The Rockdale Run Formation (Orr) (Sando, 1957) consists of cyclically bedded limestone and dolostone. The limestone is thin- to medium-bedded, fossiliferous, with intraformational conglomerates, algal bioherms, bioclastic zones, burrow mottling, and chert nodules. The dolostone is laminated with abundant mudcracks. These rocks reflect an alteration between subtidal to peritidal environments similar to the Conococheague Limestone.

Pinesburg Station Dolomite

The Pinesburg Station Dolomite (Ops) (Sando, 1957) consists of dolostone and dololaminite that is medium- to thick-bedded containing chert nodules. Cross-hatched joints weather to form a diagnostic “butcher-block” habit. Thin intervals of fine-grained limestone occur in the lower part. Common near the top of the formation are irregular bedded brecciated dolomite that indicates paleokarst. These rocks reflect a restricted shallow-marine environment that was at times subaerial.

St. Paul Group

The St. Paul Group (Osp) 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. The New Market Limestone and Row Park Limestone are not differentiated on the map.

Chambersburg Limestone

The 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 passive continental margin carbonate platform to active margin shelf, possibly associated with the Taconic orogeny.

Martinsburg Formation

The Martinsburg Formation (Om) consists of shale, siltstone, and sandstone having argillaceous limestone at the base. Turbidites exhibiting typical Bouma cycles with load clasts are characteristic. The turbidites indicate foundering of the margin and its evolution into a foreland basin, 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 of the late Paleozoic Alleghanian orogeny. The core of the synclinorium is mostly 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.

The rocks of the Great Valley are highly folded with tight, upright, second, third, and fourth-order disharmonic folds that verge up the limbs of the higher order folds (see tectonic map). Axial planar cleavage is most evident in the shale of the Martinsburg Formation.

There are several late thrust faults on the inner limbs of the Massanutten synclinorium that truncate units, and high-angle tear faults and normal faults cut 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. 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.

EARLY MESOZOIC ROCKS

Culpeper and Gettysburg Basins

Triassic and Jurassic sedimentary and volcanic rocks of the Newark Supergroup

In the Frederick 30 by 60 minute quadrangle, rocks of the Newark Supergroup (Froelich and Olsen, 1984) were formerly called the Culpeper Group (Lee, 1979, 1980) and were divided informally into a lower part and an upper part. The former lower part has been revised to the Chatham Group and the former upper part has been revised to the Meriden Group (Weems and Olsen, 1997). The Chatham Group includes the mainly Upper Triassic sequence of continental sedimentary rocks. The Meriden Group includes the Lower Jurassic series of basalt flows and intercalated sedimentary rocks (Lee and Froelich, 1989).

Chatham Group

Manassas Sandstone

The Manassas Sandstone (Lee, 1977, 1979) is divided into the Reston Member (Lee, 1977)(Trmr), the Tuscarora Creek Member (Lee, 977)(Trmt), and the Poolesville Member (Lee and Froelich, 1989)(Trmp). In the southern part of the Gettysburg basin, the rocks classified here as the Tuscarora Creek Member and the Poolesville Member have been called the New Oxford Formation by workers in Maryland and Pennsylvania. These rocks were deposited by braided streams that flowed across a lowland. The Reston Member (Trmr) is the basal conglomerate that is faulted against and unconformably overlies metasedimentary rocks of the Potomac and Westminster terranes. The conglomerate is composed of cobbles and pebbles of micaceous quartz, metagraywacke, and schist in a matrix of sand, clay, muscovite, and feldspar. The deposits are lensoid and discontinuous as they probably reflect channel deposits of a river system.

The Tuscarora Creek Member (Trmt) is the basal conglomerate that unconformably overlies carbonate rocks of the Upper Cambrian Frederick Formation and rocks of the Urbana Formation at one locality. It is laterally equivalent to the Reston Member but the clasts are from different source rocks. The Tuscarora Creek Member is characterized by the presence of limestone and dolomite clasts derived from the Frederick and possibly the Grove Formations. The conglomerate is locally lensoidal and discontinuous as it represents debris-flow channels on an alluvial fan. In the subsurface along the west margin of the basin, the conglomerate is probably the base to the stratigraphically higher conglomerate of Leesburg Member of the Bull Run Formation.

The Poolesville Member (Trmp) is an arkosic, muscovite-rich sandstone containing sparse quartz pebbles that fines upward and is interbedded with siltstone. The unit is transitional with the basal conglomerate members. The Poolesville Member also grades up into the overlying Balls Bluff Member so the contact between the two units is gradational and approximately located.

Bull Run Formation

The Balls Bluff Siltstone of Lee (1977; 1979), has been revised to the Bull Run Formation, consisting of the Balls Bluff Member, the Groveton Member, and the Leesburg Member, respectively (Weems and Olsen, 1997). As the climate changed from wet to dry, alluvial fans extended from the highlands west of the border fault, to playas with lakes and intermittant streams resulting in conglomerate interbedded with sandstone and siltstone at every scale.

The Balls Bluff Member (Trbb) is predominately feldspathic, silty sandstone interbedded with clayey and sandy siltstone in cyclic sequences as much as 3 m thick. The unit is gradational with the Poolesville Member of the Manassas Sandstone, it intertongues laterally with rocks of the Groveton Member and Leesburg Member, and it is unconformably overlain by rocks of the Catharpin Creek Formation.

The Groveton Member (Trbg) is predominately thin-bedded silty and sandy shale interbedded with clayey and sandy siltstone in cyclic sequences as much as 10 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 lacustrine shale was deposited in lakes. The shale is poorly exposed but was traced by shale chips in soil.

The Leesburg Member (Trbl) is a conspicuous carbonate conglomerate composed of subangular to subrounded boulders, cobbles, and pebbles of limestone and dolomite in a sandy siltstone matrix. The source of the carbonate rock clasts include the limestone and dolomite of the Tomstown, Frederick, and Grove Formations. The conglomerate inter-tongues with the sandstone and siltstone of the other members and forms a complex map pattern. This unit is like the conglomerate of the Tuscarora Creek Member of the Manassas Sandstone and is probably stratigraphically continuous in the subsurface. The sandstone and siltstone that intervene pinch-out to the west.

Catharpin Creek Formation

The Catharpin Creek Formation (JTrc) consists of cyclic sequences of interbedded sandstone, siltstone, and conglomerate, as much as 30 m thick. The contact with the underlying Bull Run Formation is gradational and intertonguing, but the contact with the overlying Mount Zion Church Basalt is a sharp disconformity. At this time, the climate became wetter and fluvial to lacustrine deposits accumulated.

The Goose Creek Member (JTrcg) of the Catharpin Creek Formation is a lenticular body of conglomerate composed of sub-rounded pebbles and cobbles of quartzite, greenstone, metasiltstone, gneiss, limestone, and vein quartz, derived from rocks of the Blue Ridge Province. The conglomerate is interbedded with arkosic sandstone with pebbles and the matrix locally is rich in calcite. Like the conglomeratic rocks of the

Tuscarora Creek Member of the Manassas Sandstone and the Leesburg Member of the Bull Run Formation, the Goose Creek Member probably is a debris-flow deposit on an alluvial fan; the distinction between the units are the source and composition of clasts. The resistant clasts in this unit remain as a lag gravel deposit.

Meriden Group

Mount Zion Church Basalt

The Mount Zion Church Basalt (Jmz) is a high-titanium, quartz-normative tholeiitic basalt with vesicular and amygdaloidal tops that mark one or two flows. The basalt underlies a low ridge but is poorly exposed.

Midland Formation

The Midland Formation (Jm) consists of cyclic sequences of interbedded siltstone, sandstone, shale, and conglomerate. Lenticular variegated cobble and pebble conglomerate and conglomeratic arkosic sandstone (Jmc) are mapped separately. The strata were deposited on alluvial fans (conglomerates) that extended eastward into lakes (shale and siltstone) situated on playas. Abundant and diverse fish lived in the lakes.

Hickory Grove Basalt

The Hickory Grove Basalt (Jhg) 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 (Jhgs) that in places are disconformable with both the underlying and overlying strata.

Turkey Run Formation

The Turkey Run Formation (Jtr) consists of cyclic sequences of interbedded sandstone, siltstone, conglomerate, and shale. The conglomerate (Jtrc) is composed of subrounded boulders, cobbles, and pebbles of greenstone, 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 Sander Basalt (Js) is the uppermost sequence of basalt flows and the youngest bedrock in the map area. The stratigraphically lower flows are high-titanium, high-iron, quartz-normative basalt that are separated by poorly exposed sandstone and siltstone (Jss) 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 are thermally metamorphosed rocks (JTrtm) in zoned contact aureoles adjacent to diabase intrusions. The largest contact aureoles are found adjacent to the diabase sills along the Dulles Greenway at Belmont Ridge in Loudoun County, Va., and near Boyds, Md. There are thin aureoles adjacent to narrow diabase dikes. Siltstone and shale are altered to cordierite-spotted hornfels in the inner aureole, and epidote-chlorite hornfels characterize the outer aureole. Sandstone is metamorphosed to tourmaline granofels and (or) quartzite, and carbonate conglomerate is metamorphosed to marble.

Jurassic Diabase Dikes and Sills

Three magma types of diabase are mapped in the Culpeper and Gettysburg basins (Froelich and Gottfried, 1988). Olivine-normative and low-titanium, quartz-normative tholeiitic diabase (Jd) occurs as dikes. High-titanium, quartz-normative (Jdh) tholeiitic diabase occurs as both narrow dikes and thick, differentiated sills that contain cumulates (Jdc) in the lower parts and late-stage differentiates in the higher parts. The differentiates include granophyre (Jdg), ferrogabbro, diorite, syenite, and aplite. The diabase sills and sheets are irregular in shape. The dikes are linear, discontinuous, and en echelon as they were emplaced along dilated fractures. The diabase dike exposed along the Potomac

River between Sandy Hook and Weverton, Md., has an 40Ar/39Ar age of 200 Ma (Kunk and others, 1992).

Structure

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

COASTAL PLAIN

Potomac Formation

Unconsolidated gravel, sand, silt, and clay that unconformably overlies rocks of the Laurel Formation in the extreme southeast corner of the map area near Silver Spring, Md., are assigned to the Lower Cretaceous Potomac Formation (Kp). This is the only remnant of a fluvial and deltaic deposit that may have extended as far west as the Blue Ridge Province.

FOSSILS

Some of the sedimentary rocks 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 *Skolithus* and the Cambrian Antietam Formation contains Olenellus (Walcott, 1896), the oldest trilobite fossils in the central Appalachian region. Cambrian rocks (Tomstown, Frederick, and Waynesboro Formations, and Elbrook and Conococheague Limestones) contain parts of trilobites, algal colonies called 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, and 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, as well as plant impressions, pollen, spores, insect parts, conchostracans, ostracodes, and fish scales. These fossils occur in the Manassas Sandstone, Bull Run Formation (Balls Bluff Member), Midland Formation, Turkey Run Formation, and Catharpin Creek Formation (Weems, 1987; 1993; Lyttle and others, in press).

SURFICIAL MATERIALS

Alluvium

Well to poorly sorted 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 is commonly on bedrock with alluvium exposed along the banks. Thickness of alluvium is highly variable as a function of bedrock, topography, and land-use practices. Locally, thick alluvium is related to mill dams and siltation associated with agricultural erosion in the 19th century, as well as recent development.

Alluvial Terrace Deposits

High level (QTt) and low level terraces (Qt) of the ancestral Potomac, Shenandoah, and Monocacy Rivers are preserved locally. Deposits underlying the conspicuous terraces include rounded sandstone and quartzite cobbles and boulders with *Skolithus* (trace fossil), and also rounded to angular chert pebbles, cobbles, and boulders, whose sources are Lower Cambrian and younger rocks of the Valley and Ridge Province. Old deposits may be a veneer of coarse clasts; younger more extant deposits may be several meters thick of cross. The deposits are isolated remnants of former more extensive terraces. Some of the highest deposits, such as Mt. Sterling, in Loudoun County and east of Lucketts, Va., and south of Dickerson, Md., are the result of topographic inversion of an ancient channel. The oldest deposits at Sterling, Va., were several meters thick and were deeply oxidized and leached.

Colluvium

Fine and coarse colluvium are slope deposits. Lensoid aprons of subangular clasts of quartzite, phyllite, greenstone, epidosite, and vein quartz are fine colluvium (Qcf) that covers the bedrock of the western margin of the Culpeper basin. The colluvium was derived from the escarpment of the east limb of the Blue Ridge-South Mountain anticlinorium.

Coarse colluvium (Qc) consists of cobbles and boulders of predominately quartzite that are concentrated in hillslope depressions on Blue Ridge-Elk Ridge, Short Hill-South Mountain, Catoctin Mountain, and Sugarloaf Mountain, by gravity, debris-flow, and freeze-thaw processes. Only the large 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 are clast supported with no visible matrix, but matrix-supported clasts may occur at depth.

Residuum

Pebbles and cobbles of angular to euhedal white quartz from *in situ* (?) weathering of the underlying carbonate bedrock superficially resembles terrace deposits but is instead lag concentrate from residual material (Qr). Presumably, the vein quartz originally filled fractures and cavities in the carbonate rock in the western and central Piedmont.

The limestone of the eastern Great Valley (Hack, 1965) and Frederick Valley (Southworth and Brezinski, in press), gneiss of the Blue Ridge, and schist on Piedmont uplands (Froelich, 1975) have a thick regolith that in part is a residuum of *in situ* weathered bedrock called saprolite. Some of the regolith is more than 30 m thick which accounts for the flat topography (see the digital topographic map) and lack of outcrop. A distinctive residuum called lag gravel (Ql) formed from *in situ* weathering of conglomeratic rocks of the Goose Creek Member of the Turkey Run 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.

GEOLOGIC HISTORY AND TECTONICS

The rocks of the Frederick 30 by 60 minute 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 continent that rifted 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 of the Ridge and Valley Province are deposits 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 shelf platform. And carbonate rocks of the Frederick Valley in the western Piedmont reflect the slope transition between the two settings. Rocks of the Potomac terrane in the eastern Piedmont are interpreted to be deepwater deposits containing debris of oceanic crust (Drake, 1989). Parts of this terrane show evidence of deformation and metamorphism not seen elsewhere (Drake, 1989). Early thrust sheets were emplaced during sedimentation in a deep oceanic trench, and rock debris was mixed with unconsolidated sediments to form sedimentary melanges, or mixtures of rocks. The thrust sheet and overridden mixture of sediment and debris fragments (olistoliths) have been interpreted as thrust sheet-precursory sedimentary melange pairs, and the composite pairs by Drake (1989), who introduced the term tectonic motifs for these composite allochthons.

The higher composite allochthon in the map area contains the Mather Gorge and Sykesville Formations. The lower composite allochthon in the map area contains the Loch Raven and Laurel Formations (Fleming and others, 1992, 1994).

The deformed rocks of the Potomac terrane were intruded by tonalitic to granitic rocks and probably transported westward along the Pleasant Grove fault during the Ordovician Taconic orogeny (Drake, 1989). Some of the highly deformed rocks of the Westminster terrane also may have seen Taconic deformation and may have been transported westward onto Cambrian rocks of the Frederick Valley along the Martic fault during this tectonic event (Southworth, 1996) but argon geochronology in the extreme eastern part suggests Devonian to Carboniferous deformation (Krol and others, 1999). Mylonitic marble at the base of the Cambrian carbonate rock sequence (Tomstown Formation) in the Blue Ridge and Great Valley is interpreted to be a regional detachment that formed during the Taconic event (Brezinski and others, 1996). Other evidence of the Taconic orogeny is the change in deposition from carbonate to clastic rocks in the Martinsburg Formation of the Great Valley.

All of the rocks were folded, faulted, and metamorphosed during the late Paleozoic (Pennsylvanian to Permian?) Alleghanian orogeny, when the continental plates of Laurentia (North America) and Gondwana (Eurasia) collided to close 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 30 by 60 minute 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 created by the converging fold and thrust belt collapsed as the continent began to pull-apart to create the Atlantic Ocean during the Triassic Period. Alluvial fan debris shed from scarps along normal faults filled lowlands that eventually evolved into basins by renewed (?) listric fault movement along older thrust faults. Basalt flows and diabase intrusions formed in the last stages of rifting that extended to great crustal depths prior to the formation of the Atlantic Ocean.

As drainage systems reversed and flowed toward the Atlantic Ocean, debris shed from the eroding Appalachian highlands formed thick deposits of unconsolidated sediments that 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

Mineral resources that are currently being exploited in the Frederick 30 by 60 minute quadrangle are 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). Quarries, mines, and prospect pits for aggregate, precious metals, dimension and ornamental building stone, and iron/manganese minerals that have been exploited in historical times are shown on the map.

Limestone

There are at least 26 active and inactive quarries in the Great Valley for high-calcium limestone of the Cambrian Tomstown, Waynesboro, and Elbrook Formations, and the Ordovician Stonehenge, St. Paul Group, and Chambersburg Limestone. In the Blue Ridge, small pods of calcite-dolomite marble were quarried historically in 5 places for agricultural lime and ornamental stone. In the western Piedmont, there are 5 active quarries in Valley for crushed stone and the production of Portland cement. More than 20 small quarries and pits in marble were recognized in the Westminster terrane of the central Piedmont and they often were in close proximity to a historical kiln used to produce agricultural lime.

Aggregate

There are several active quarries in sills of Early Jurassic diabase and beds of basalt for use as aggregate for road metal and cement in Loudoun County, Va. Shale and limestone are quarried and crushed for aggregate in the Frederick Valley of the western Piedmont and serpentinite is crushed for aggregate in Montgomery Co., Md., in the eastern Piedmont.

Building Stone

Historic homes in the area are made of virtually every rock type exposed in the map area. Those exploited for commercial quantities are mostly in the eastern Piedmont and were quarried and used for construction of canals, bridges, and buildings in the early 1800's. The most popular dimension stone includes 1) gneiss, schist, and "flagstone" of the 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 6 locations for roofing material in the early 1900's (Dale and others, 1914).

Ornamental Stone

Diamictite of the Sykesville Formation, limestone conglomerate of the Leesburg Member of the Bull Run Formation, and marble of the Swift Run and Catoctin Formations are the most popular ornamental stone used. The most famous ornamental stone is the conglomerate of the Leesburg Member (called the "Potomac marble"and "Calico rock") that was quarried in Loudoun County, Va., and Frederick County, Md., and used in 1815 by Benjamin Latrobe for the columns in Statuary Hall of the U.S. Congress on Capital Hill (USGS, 1998).

Metals

In the late 1700's and 1800's, there were abundant prospects for limonite, hematite, and manganese for the production of iron. Near the contact of the metasandstone of the Antietam Formation and the overlying limestone of the Tomstown Formation are at least 17 prospects on the west limb, and at least 7 prospects on the east limb of the Blue Ridge-South Mountain anticlinorium. There are at least 5 limonite prospects along the contact between the metasiltstone of the Araby Formation and the overlying limestone of the Frederick Formation on the eastern side of the Frederick Valley.

There are abundant reports of gold as both mines and placers (Kuff, 1987; Bernstein, 1980). The best known area for gold mining was from vein quartz that intruded rocks of the eastern Piedmont Province near Great Falls, Md. (Reed and Reed, 1970). Gold was also a byproduct of mining for lead, zinc, and silver from marble and metavolcanic rocks in the "Linganore district" of the Westminster terrane in the central western Piedmont (Heyl and Pearre, 1965). There are several reported occurrences of gold in the Blue Ridge Province; one placer deposit, one associated with greenstone of the Catoctin

Formation, and another located in rocks of the Chilhowee Group near the border fault of the Gettysburg basin. Gold, silver, and copper prospects have been reported 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′ x 60′ quadrangle was assembled from data of 22 aeromagnetic surveys, flown between 1960 and 1989. Three of the surveys were recorded and processed digitally. The remainder are analog surveys and the magnetic values were digitized from hand-drawn contour maps. Surveys in Maryland and Virginia were flown along east-west flight lines, with the spacing of the flight lines ranging between 0.125 to 1 mile (200 - 1600 m). All but one survey were flown at 500 feet above mean terrain. In West Virginia flights were northwest-southeast at 1000 ft above mean terrain and 2 mile 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. The adjusted grids were joined into one grid.

The Color-Shaded Relief Map

The residual magnetic field grid is displayed as a color-shaded relief map using software from Geosoft Inc. (Figure 4). The synthetically produced illumination is from the east at a simulated sun angle of 45 degrees. Shadows therefore appear along the western sides of the magnetic anomalies. The relative intensities of the magnetic anomalies are displayed as spectral colors; red corresponds to higher values and blue corresponds to lower values. The shading technique greatly enhances small-amplitude magnetic anomalies. An overlay of selected geologic units provides a framework for relating magnetic anomalies to geologic features.

Correlation of Data and Geology

The aeromagnetic anomalies correlate closely with mapped geology because some lithologic units have contrasting magnetic properties. The dominant features of the magnetic map are a series of large-amplitude magnetic anomalies in parallel belts associated with metabasalt of the Catoctin Formation in the Blue Ridge Province, and metasedimentary, metavolcanic and ultramafic (?) 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. The complex pattern of segmented magnetic highs within the Sams Creek and Mather Gorge Formation are related to mapped faults.

Smaller wavelength high-amplitude magnetic anomalies are associated with Mesoproterozoic gneiss units in the western part of the Blue Ridge Province and Jurassic diabase dikes and sills.

The aeromagnetic anomalies also correlate with mapped faults. The most obvious aeromagnetic 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-bearingphyllonites and schists. The Plummers Island fault (rocks of the MatherGorge Formation thrust above 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 has irregular, short-wavelength anomalies indicating 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 and Loch Raven Formations. In the western Piedmont, the Barnesville-Monrovia, Hyattstown, and segments of the Martic faults have moderate-amplitude linear anomalies spatially associated with magnetite-bearing phyllonites.

DIGITAL TOPOGRAPHIC MAP

Introduction

A digital terrain grid of the Frederick 30′ x 60′ quadrangle was assembled from 32 USGS terrain files obtained by internet from the USGS EROS Data Center, URL: ftp://edcftp.cr.usgs.gov/pub/data/. Each of these files had been prepared from one USGS 7.5 minute topographic quadrangle in which the contours were digitized and converted to a smoothed grid of evenly-spaced points of digital elevation at an interval of 30 meters in x and y. The resulting grid is based on about 5.3 million data points.

The Color-Shaded Relief Map

The digital topographic grid was displayed as a color-shaded relief map using software from Geosoft Inc. designed to produce a color-shaded relief map (Figure 5). The synthetically produced illumination is from the east at a simulated sun angle of 45 degrees. Shadows therefore appear along the western sides of the topographic highs. The relative topographic elevations are displayed as spectral colors; red corresponds to higher topographic elevations and blue corresponds to lower topographic elevations. An additional enhancement is obtained by digitally brightening the slopes facing the “sun” direction. These techniques greatly enhance topographic relief. An overlay of selected geologic units provides a framework for relating topography to geologic features.

Correlation of Topography and Geology

Areas of highest topography (red) are the limbs of the Blue Ridge-

South Mountain anticlinorium and Sugarloaf Mountain in the western Piedmont Province that are underlain by resistant quartzite. Parrs Ridge, also in the central Piedmont of Maryland, is a broad area of relatively high relief. The bedrock there mostly consists of phyllonites with abundant vein quartz that are resistant to erosion. The rocks have a pervasive northeasterly foliation that imparts a grain to the drainage.

Areas of lowest topography (blue) are the Frederick Valley, Culpeper basin, and Gettysburg basin in the western Piedmont, and areas adjacent to the Potomac and Shenandoah Rivers. Within the Culpeper basin, the highest topographic areas (green) are those that are mantled by colluvial or alluvial gravel of quartzite or underlain by diabase and hornfels; these are hard materials that resist weathering. Quartz-bearing rocks that are resistant to erosion underlie linear ridges that are controlled by the strike of the inclined beds. There are good examples of these linear ridges in the eastern part of the Great Valley, the eastern part of the Frederick Valley, and locally in the Culpeper basin. In the Great Valley, some V-shaped ridges trace fold closures. A distinctive trellis drainage pattern developed on shale of the Martinsburg Formation can be readily seen in the Great Valley.

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