Geology of the Chesapeake and Ohio Canal National Historical Park and Potomac River Corridor, District of Columbia, Maryland, West Virginia, and Virginia

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PLATE [Plate is in Chapter A]

1. Geologic map of the C&O Canal National Historical Park and Potomac River Corridor, District of Columbia, Maryland, West Virginia, and Virginia.

Cover: Photograph of the “Devil’s Eyebrow”, an anticline of shale, sandstone, and limestone of the Silurian Bloomsburg Formation at the site of the Round Top Cement Mill, west of Hancock, Md. Photograph taken in 1897 by C.D. Walcott, Director of the USGS.

INTRODUCTION

The Chesapeake and Ohio (C&O) Canal National Historical Park, herein called the C&O Canal, is unique in that it is the only land within the National Park system that crosses 3 physiographic provinces along a major river. From Georgetown, District of Columbia (D.C.) to Cumberland, Maryland (Md.), the C&O Canal provides an opportunity to examine the geologic history of the central Appalachian region and how the canal contributed to the development of this area.

This report and the companion geologic map cover the 184.5-mile long park in a 2-mile-wide corridor centered on the Potomac River (see plate). The geologic guide is presented east to west, from Georgetown to Cumberland, by provinces and sections, such as Piedmont (Potomac terrane, Culpeper basin, Westminster terrane, Frederick Valley synclinorium), Blue Ridge, and Valley and Ridge (fig. 1). Geologic features are keyed to the NPS mile markers (MM) that are found along the river side of the towpath from Georgetown (MM 0) to Cumberland (MM 184.5). Distances shown are approximate and taken from Claque (1977). Included in the guide are references to detailed geologic information. Additional historical information is found in other guidebooks of the C&O Canal (Boy Scouts of America, 1983; National Park Service, 1991; Hahn, 1995; High, 1997; Davies, 1999).

HISTORICAL BACKGROUND

Colonial development of the mid-Atlantic region was established along the Chesapeake Bay and its tributary rivers which allowed passage inland of large ships. West of where the Coastal Plain sand and gravels were deposited is the crystalline bedrock of the Piedmont province, where waterfalls and rapids exist that prevented further travel. This area of waterfalls called the

"Fall Line" or "Fall Zone" became the nucleus for settlement and commerce, precipitating growth and development of cities such as Baltimore, Md., Georgetown, D.C., and Fredericksburg and Richmond, Virginia (Va). As population in the tidewater region grew and expanded westward, the Potomac River became one of the most viable means to cross the Appalachians Mountains to the fertile Ohio River valley and beyond. In 1785, the Patowmack Company under the leadership of George Washington, began a series of "skirting" canals and riverbed improvements from Georgetown to Harpers Ferry (Brown, 1963; Garrett and Garrett, 1987). The skirting canals and sluices of the Patowmack Company connected iron ore prospects, furnaces, and foundaries with the armory at Harpers Ferry (fig. 2). The Patowmack Company's failure of passage of the Great Falls of the Potomac in Virginia, and the success of the Erie Canal (1817-1825) provided momentum for the "Great National Project" -- to build a canal along the Potomac River to eventually reach the Ohio River at Pittsburgh, Pennsylvania.

Construction of the canal, towpath, and associated structures began July 4, 1828. The canal was open to Seneca, Md., by 1831, to Harpers Ferry, W.Va., in 1834, to near Woodmont, Md., in 1839, and was completed to Cumberland, Md., in 1850. Although work on the C&O Canal and Baltimore and Ohio (B&O) Railroad began on the same day, the B&O Railroad had been operating for 8 years along essentially the same route when the canal reached Cumberland, Md. The C&O Canal was used to transport mainly coal that was mined from the Mississippian and Pennsylvanian age rocks (about 300 million years old) of the Appalachian Plateaus province west of Cumberland, Md., to heat homes and buildings in the eastern parts of Maryland, Virginia, and District of Columbia.

A typical canal trip took 4.5 days one way or 9 days round trip. Mules towed a 92 foot long boat that when loaded weighed more than 120 tons. At peak activity the canal saw 540 boat trips a year. Beginning with the " Johnstown" (Pennsylvania) flood in 1889, a series of devastating floods ruined the canal and there was insufficient money to rebuild it. The B&O Railroad purchased and operated the canal until 1924 when again it was flooded and then drained. The B&O Railroad gave the canal property to the U.S. Government in 1938 in lieu of a $2 million debt. Justice William Douglas successfully campaigned in the 1950's to prevent filling the canal for construction of a scenic highway. The C&O Canal was designated a National Monument by President Eisenhower in 1961, and a National Historical Park by President Nixon in 1971. George Washington s vision of an industrial corridor along the Potomac River fortunately did not happen. Manufacturing plants powered by the Potomac River were obsolete when electricity was developed, and local iron production was replaced by steel mills near Pittsburgh, Pa. This industrial failure resulted in a river valley nearly restored to its natural state in the backyard of the nation s capital. Enjoy it!

GEOLOGIC SETTING

PHYSIOGRAPHY

The C&O Canal extends from Rock Creek in Georgetown, D.C. (MM 0), to the confluence of the North Fork Potomac River and Wills Creek at Cumberland, MD (MM 184.5). It is located along the northern bank of the Potomac River in Maryland. The easternmost 5-mile section lies within the city limits of Washington, D.C. The Potomac River drainage basin encompasses 14,670 square miles of Virginia, Maryland, West Virginia, Pennsylvania, and the District of Columbia. The river valley transects five major physiographic provinces and at least five subprovinces, called sections. From east to west are the Coastal Plain, the Piedmont (which includes the Potomac terrane (eastern Piedmont), the Westminster terrane (Central Piedmont), Culpeper basin, and Frederick Valley (western Piedmont)), the Blue Ridge, the Valley and Ridge (Including the Great Valley), and the Appalachian Plateaus (fig. 1). The provinces and sections are unique due to the underlying bedrock, surficial deposits, and resultant landscape. The C&O Canal traverses three of these provinces (the Piedmont, Blue Ridge, and Valley and Ridge) and uniquely provides access to study them.

Coastal Plain deposits are scattered in this region due to erosion. The boundary between the Piedmont and Coastal Plain is not a sharp "Fall Line" but is a "Fall Zone", with water falls in the Potomac River from Georgetown, D.C., (Little Falls) west to Seneca, Md., (Seneca Falls), a distance of about 17 miles. The Piedmont province, "at the foot of the hill", is the relatively low-relief area east of the Blue Ridge that extends from Georgetown, D.C., to Point of Rocks, Md. In general, the Culpeper basin and Frederick Valley form a lowland and the Westminster and Potomac terranes form dissected uplands. The boundary between the Piedmont and Blue Ridge provinces is at the foot of Catoctin Mountain and Furnace Mountain. West of the Blue Ridge province, the Great Valley section of the Valley and Ridge province contains the Shenandoah Valley (Virginia), or Hagerstown Valley (Maryland). The boundaries of the Great Valley section are Blue Ridge-Elk Ridge on the east and North Mountain on the west. From the east side of North Mountain west to Cumberland, Md., is the Valley and Ridge province proper.

How the Potomac River eroded the rocks of these distinctive provinces and sections had a direct bearing on the landscape evolution of the river valley and thus upon the engineering of the C&O Canal. The majority of the canal was excavated in Quaternary alluvium adjacent to the Potomac River, so good exposures of bedrock are not always evident. Elsewhere alluvium was thin or absent, and manual drilling and blasting using black powder was necessary to excavate the canal and its towpath through bluffs of bedrock.

GEOLOGY

BEDROCK

For over 100 years, the bedrock exposures along the Potomac River valley have been utilized as a basis to help unravel the geological history of the central Appalachian region. There are more than 100 bedrock formations identified along the Potomac River. Of these, there are 27 type-localities along the river, 21 type-localities near the river, and 24 type-localities within the drainage basin. The type-localities are areas where the rocks were named and described because of good exposure. These rocks record a complex developmental history of ocean basin creation and destruction in response to plate tectonic processes. A summary tectonic map showing type-localities is shown in fig .3. Tectonic events of this part of the central Appalachian region are illustrated in fig. 4 and will be described from oldest to youngest.

The Blue Ridge province exposes some of the oldest rocks known from this region. These granitic gneisses were formed more than a billion years ago during the Mesoproterozoic Grenville orogeny (fig. 4A). These billion year old plutonic rocks were intruded in several stages over a period of 100 million years (My)(Aleinikoff and others, 2000) to form a basement upon which all other rocks of the Appalachians were deposited. Metadiabase and metarhyolite dikes that intrude these basement rocks and extrusive flows that overlie them, are the result of Neoproterozoic (700-545 My) continental rifting that produced the Iapetus Ocean. These volcanic rocks were intruded through cracks in the granitic gneisses and extruded onto the land surface during the break-up of the continental land mass (fig. 4B).

Sedimentary rock of fluvial and shallow marine origin were deposited on the newly formed margin of the continent (fig. 4C). Today these rocks are exposed on Catoctin Mountain, Short

Hill-South Mountain, and Blue Ridge-Elk Ridge (east to west). They also occur in the western Piedmont (Sugarloaf Mountain anticlinorium and Frederick Valley synclinorium) and Great Valley section of the Valley and Ridge province. The Cambrian and Ordovician (545-480 My) carbonate rocks that comprise much of the Great Valley section represent a grand platform in a shallow sea that deepened to the east (fig. 4D). These shelly carbonate rocks are overlain by shale of the Ordovician (450 My) Martinsburg Formation. The shale reflects initiation of deposition of debris shed from a rising highland to the east (fig. 4E). This highland resulted in the creation of the Appalachian basin which was centered in what is now West Virginia. During the Late Ordovician, oceanic sediments of the Iapetus Ocean (Potomac terrane of the eastern Piedmont) were thrust westward onto other deepwater sediments of the western Piedmont (Westminster terrane), along the Pleasant Grove fault. Moreover, rocks of the Westminster terrane were concurrently thrust onto the continental margin rocks of the Sugarloaf Mountain anticlinorium and Frederick Valley synclinorium along the Martic fault. Sandstone, shale, siltstone, quartzite, and limestone were then deposited in a shallow marine to deltaic environment of the Appalachian basin. These rocks currently underlie the Valley and Ridge province. Such shallow marine to fluvial sedimentation continued for a period of about 200 My during the Ordovician, Silurian, Devonian, Mississippian, Pennsylvanian, and Permian Periods (fig. 4F). Many of these rocks are sediments shed from highlands that were rising to the east as the result of tectonic events in the Ordovician (Taconian orogeny) and Devonian (Acadian orogeny).

The Iapetus Ocean was destroyed during the Late Paleozoic as the North American continental plate collided with the African continental plate to form the Appalachian mountain belt (fig. 4G). This mountain building episode is called the Alleghanian orogeny. The rocks were deformed by folds and faults to produce the Sugarloaf Mountain anticlinorium and the Frederick Valley synclinorium in the western Piedmont, the Blue Ridge-South Mountain anticlinorium, the Massanutten synclinorium in the Great Valley, and the numerous anticlinoria and synclinoria of the Valley and Ridge province. During this orogeny, rocks of the Great Valley, Blue Ridge, and Piedmont provinces were transported westward onto younger rocks of the Valley and Ridge along the North Mountain fault (fig. 4G). Rocks that were already deformed in the eastern Piedmont at this time were also folded and faulted and existing thrust faults were reactivated as both strike slip and thrust faults.

After the Alleghanian orogeny, the deformed rocks of the joined continents began to break apart from about 230-200 My in the Mesozoic. This episode of rifting or crustal fracturing initiated the formation of the current Atlantic Ocean. Large alluvial fans and streams carried debris shed from the earlier uplifted Blue Ridge and Piedmont provinces and deposited it in fault-created troughs such as the Culpeper basin in the western Piedmont. The large faults which formed the western boundary of the basin provided an escarpment that quickly became covered with such eroded debris. Igneous rocks were intruded into these strata as sub-horizontal sheets (called sills) and near-vertical dikes that extend beyond the basin into adjacent rocks (fig. 4H). After these molten igneous rocks were emplaced at 200 My ago, the region underwent a period of slow uplift and erosion. Thick deposits of unconsolidated gravel, sand, and silt shed from the eroded mountains were deposited as part of the Atlantic Coastal Plain (fig. 4I). The erosion continues today, stripping the Coastal Plain deposits, lowering the mountains, and depositing alluvium on terraces of the river, thereby creating the landscape of the present valley (fig. 4J). For additional technical information and abundant references, see the summaries in Hatcher and others (1989).

CENOZOIC LANDSCAPE AND SURFICIAL DEPOSITS

Introduction

The landscape and geomorphology of the Potomac River valley is the result of erosion and deposition from about the mid-part of the Cenozoic Era to the present, or at least the last 5 My. The distribution of flood plain alluvium and ancient fluvial terraces of the Potomac River and adjacent tributaries record the historical development of the drainage system (fig. 5). There is no evidence that the river migrated laterally across a broad region; rather it has cut downward using its early course for the most part.

The distribution, thickness, and height above the present river level of terraces and sediments deposited on them varies from province to province and from rock type to rock type (fig. 6). Elevations of terraces along the river show that the slope values of the ancient and modern river valley are similar which suggests that the terraces formed as the result of either eustatic sea level drop or uplift (Zen, 1997a and 1997b). The 5.3 My Miocene-Pliocene fluvial deposits at Tysons Corner, Va., occur over 330 feet above the Potomac River (470 to 500 feet above sea level [asl]), 3 miles away above Great Falls. Mount Sterling is about 270 feet above (450 feet asl) and 3 miles away from the Potomac River in the Culpeper basin. By analogy then some of the high terraces along the Potomac River could be as old as Miocene-Pliocene. In the absence of supportive data, the landforms and deposits are probably late Tertiary to Quaternary in age when a wetter climate, sparse vegetation, and frozen ground caused increased precipitation to run into the ancestral river enhancing downcutting and erosion (Zen, 1997a and 1997b).

River Morphology

The morphology of the Potomac River changes as it drops about 610 feet in elevation as it flows more than 190 miles from the western part of the Valley and Ridge province to the Coastal Plain in the District of Columbia (figs. 5 and 6). From the tidal part of the Potomac near Memorial Bridge to the Culpeper basin at Seneca Falls, the Potomac River has cut a gorge into bedrock. From Great Falls west to Seneca Falls the gorge has numerous islands and a considerable amount of alluvium is preserved. Around Great Falls Tavern of the C&O Canal and Great Falls Park, Va., are numerous flat-topped islands that are bedrock strath terraces that the Potomac River has cut across and then down into. The bed of the river is rock with channels and depressions as much as 80 feet deep (Reed, 1981). There is a little alluvium deposited on the bedrock terraces and radiocarbon dates suggests that they have been vegetated for more than 10,000 years (Reed, 1981). At Great Falls the Potomac River drops 70 feet from Olmstead Island, a strath terrace at 140 feet asl. The Potomac River then drops about 180 feet in elevation to sea level.

From Seneca Falls to Point of Rocks the Potomac River drops about 300 feet in elevation and is about 5 feet deep and flows on bedrock with scattered cobbles and boulders in the bed. The deepest part of the channel, called the thalweg, is between the northern shore and the islands in the center of the river. The modern flood plain is broad. Bedrock is exposed in tributaries suggesting that the alluvium is tens of feet thick at most. Terraces also are broad and can be as much as 270 feet above the present river and at least 3 miles away from it.

From Point of Rocks to Harpers Ferry, the Potomac River flows across resistant bedrock ledges in the Blue Ridge province. There are islands and flood plains of alluvium but the few terraces preserved are along the north shore and slope to the flood plain. The river drops about 40 feet in elevation from 250 feet to 210 feet asl.

From Harpers Ferry west to McCoys Ferry the Potomac River drops about 130 feet in elevation. It is entrenched in meanders cut into a plateau with near vertical bluffs of carbonate rock of the Great Valley. The largest meander occurs in the shale of the Martinsburg Formation at Williamsport where extensive terraces are preserved as much as 220 feet above the river. There are no falls and there is a lack of coarse alluvium.

The most abandoned incised meanders, entrenched meanders, and broadest terraces adjacent to the modern flood plain of the Potomac River are from McCoys Ferry west to Cumberland in the Valley and Ridge province. Here the Potomac River is about 5 feet deep and flows on bedrock with lots of coarse alluvium in the bed. The Potomac River drops about 230 feet in elevation from 610 feet to 380 feet asl in this region.

Recent Flood Plain Alluvium

The areal distribution of the modern flood plain (Qal) was mapped using debris deposited by the floods of January and September, 1996. The flood plain of the Potomac River is relatively broad (fig. 5) in areas above downstream constrictions, such as 1) west of Patterson Creek anticlinorium at Spring Gap near Cumberland, 2) west of Broadtop Mountain at Oldtown, 3) west of North Mountain at McCoys Ferry, 4) where the river meanders 90 degrees to the south across rocks of the Martinsburg Formation at Williamsport, 5) where the river crosses rocks of the Culpeper basin west of Seneca Falls, 6) upstream of where the river turns south 90 degrees near Swains Lock (MM 16), and 7) at the tidal Potomac River in the Coastal Plain.

The thickness and size of the alluvial material also varies. Along the shores and islands (fig. 7) as much as 20 feet of silt overlies several feet of gravel, and drill holes on the flood plain north of Whites Ferry show depths of 21 and 22 feet (Froelich, 1975). This material was probably deposited about 10,000 years ago as the climate warmed at the end of continental glaciation, and radiocarbon dates support this (Reed, 1981; Froelich and others, 1992). Modern floods like those in 1996 tend to scour existing deposits and then redeposit the material elsewhere. During such floods the surface of the towpath is locally scoured and sometimes breached through to the canal. Thick deposits of silt and mud in the canal have been accumulating since the canal was drained in 1928. Along the river, coarse gravel and cobbles tend to be deposited in areas where there is high energy flow. Fine silt and sand tends to be deposited in areas of low energy flow.

Alluvial Terraces

On the geologic maps (plate and figures), terraces that occur at different elevation levels are shown as one group since as many as four distinct terrace elevation levels are difficult to correlate.

How the terraces formed can be understood by study of the modern river system. The channel bottom, or bed, of the Potomac River is a nearly flat surface where the bedrock has been eroded by running water. The bedrock surface has local irregularities such as ridges, swales, and potholes (figs. 8 and 9) that have been formed by differential erosion of various rock types. A veneer of boulders, cobbles, gravel, sand, and some silt, is on the channel bottom. In areas of low hydraulic energy (slack water) there are thick deposits of fine material, whereas only a little coarse material remains on the bedrock bed where the river current is torrential. Fish weirs constructed in the 18th century (Guzy, 1999) and perhaps earlier by Native Americans (fig. 10) near Shepherdstown, Sandy Hook, Brunswick, and near the Monocacy River indicate that the river bed is shallow, and that erosion and deposition in the bed has not been significant to their construction in the last 300 years or more.

Through time the river migrates across the alluvial plain and cuts down into the bedrock in response to changing climatic or tectonic conditions. As a new channel is cut into bedrock, the elevated former river bed is exposed to weathering and becomes vegetated. Subsequent erosion leaves an irregular patchwork of terraces that represent stages in the river's history.

One of the more common types of terrace of the Potomac River is an inclined surface created as the river migrated or moved down from a higher to a lower elevation along a continuous slope. Commonly there is little alluvial material preserved on these slopes. Good examples are along the South Branch Potomac River, the Cacapon River, Little Cacapon River, and on the meanders of the Potomac River north of Paw Paw, and east of Four Locks in the Great Valley (MM 104).

In general, alluvial terraces and deposits of mainly quartz gravel, cobbles, and boulders are best developed and preserved on areas underlain by bedrock of siltstone and shale (fig. 11A). This relationship holds true in the Valley and Ridge, Great Valley, and Culpeper basin section of the Piedmont province. Large alluvial boulders may have been rafted by ice or tree roots (fig. 11B). The most extensive deposits are found upstream of ridges capped by resistant sandstone in the Valley and Ridge province. This suggests that the former river may have been impounded by the water gaps through the ridges. Such examples can be seen around Cumberland where just west of the Patterson Creek anticlinorium (MM 175) are broad terraces that underlie the town, the municipal airport, Mexico Farm Landing Field, and Death Valley (see fig. 5). The same may hold true for modern flood plain deposits.

Abandoned Entrenched Meanders

Abandoned entrenched meanders of the ancestral Potomac River demonstrate how the river locally migrated into its present position. An outstanding example of a former riverbed can be seen near Paw Paw, W.Va., where Highway 51 follows Purslane Run. The distribution of strath terraces and material deposited on them provide the chronologic development of the landscape in this area (Braun, 1976; Fitzpatrick, 1987).

The meander at Reckley Flat and Purslane Run was abandoned when the ancestral Potomac River eroded into the ancestral valley of the Little Cacapon River (fig. 12, loc. A). The meander at Paw Paw was abandoned as the meander neck was narrowed and eroded through (fig. 12, loc. B). In addition, the canal at Four Locks (MM 109) occupies an abandoned fluvial channel that bypassed a meander loop. And there is an "island" within an abandoned river meander adjacent to Conococheague Creek at Williamsport.

There is a well developed abandoned channels at Great Falls called Widewater. In Great Falls Park, Va., the Potomac River flowed around an island known as Glade Hill (fig. 13). The boulder deposit on the crest of the hill indicates that the river previously flowed at that higher level (fig. 14) (Reed and others, 1980; Zen, 1997a; Southworth and others, in press b).

Alluvial and Colluvial Terraces

On the west limb of the Patterson Creek anticlinorium east of Cumberland (MM 180), are fan-shaped deposits of coarse colluvial boulders of sandstone that are intermixed with alluvial deposits. Along Mill Run northwest of Oldtown (MM 167), are extensive fans of fine colluvial cobbles of sandstone derived from Warrior Mountain that have been transported by alluvial processes. Similar deposits and landforms are found from Licking Creek to Fort Frederick.

Colluvium

Colluvium is abundant on all slopes adjacent to ridges that are underlain by sandstone, quartzite, and other resistant rocks. The slopes have thin to thick veneers of colluvial boulders and blocks that have been transported by gravity and freeze-thaw processes. Large rock streams and block fields are locally portrayed on the geologic map but none are found near the canal. Near Rosslyn and Georgetown, gravel derived from the Cretaceous and Tertiary deposits of the Coastal Plain have been transported down slope as colluvium.

Karst Landforms

Karst landforms, like sinkholes and caves, occur in the Great Valley, the Valley and Ridge, and the Frederick Valley, Culpeper basin, and Westminster terrane in the western Piedmont province where there is limestone, dolomite, and marble (fig. 15).

Sinkholes are developed throughout most of the formations of carbonate rock in the Great Valley but are more concentrated in the Elbrook and Conococheague formations, Stonehenge Limestone, Rockdale Run Formation, and the Chambersburg Limestone. There are caves along the canal and some have emergent springs (fig.16). Karst is rare in the Blue Ridge province because marble occurs as small bodies.

Karst occurs in three different sections of the Piedmont province. Kanawha Spring, east of Point of Rocks, flows from limestone of the Frederick Formation underlying the flood plain. Limestone cobbles within the conglomerate of the Leesburg Member of the Balls Bluff Siltstone southeast of Point of Rocks dissolves to form hummocky topography with abundant sinkholes and springs. Here, as well as in the Great Valley, are travertine and tufa deposits. Springs and streams supersaturated with calcite discharge and flow over rough channels and calcite is deposited (White, 1988). In addition, marble and limestone of the Westminster terrane exposed along Monocacy River north of Indian Flats underlies linear valleys and forms abundant sinkholes to the north.

Fossils Along the C&O Canal

Introduction

The rocks that are exposed along the C & O Canal contain a variety of fossils, the remains, trace, track, or imprint of ancient plants and animals that are preserved in rocks. While the Triassic and Jurassic age rocks of the Culpeper basin in the western Piedmont province have been known to contain foot prints of dinosaurs as old as 210 million years, many of the rocks farther to the west, in the Valley and Ridge province contain fossils that are much older, ranging in age from 530 to 340 million years old. Along the C & O Canal the most common types of fossils are shells of creatures that inhabited ancient seas that covered this region hundreds of millions of years ago. Less commonly remains of animals and plants that lived on land are also preserved in some of the younger rocks exposed.

For an animal or plant to become a fossil several things must occur. First, the animal or plant must inhabit an environment that is conducive to preservation. As a general rule, dark gray, organic-rich, fine-grained rocks such as shale and limestone preserve fossils better than do light-colored, coarse-grained rocks such as sandstone and conglomerate. A second prerequisite for fossilization is rapid burial. Some of the best-preserved fossils are of animals and plants that were buried alive by storms, landslides, or that fell into sinkholes or tar pits. Once entombed in sediment, the animal, plant or imprint must remain undisturbed while the sediment becomes lithified into rock, commonly over millions of years.

Piedmont Province

Rocks are fossiliferous in the Frederick Valley and Culpeper basin in the western Piedmont.

No fossils are known within the rocks of the Westminster and Potomac terranes to the east. These rocks were either deposited prior to the development of shelly organisms or extreme deformation and metamorphism may have destroyed any fossils that were present.

Frederick Valley

Rocks of the Frederick Valley contain fossils, but they are uncommon. The Cambrian Frederick and Ordovician Grove formations were deposited on the continental slope and edge of a continental shelf, respectively. Well-preserved fossils in the limestone are mainly parts of trilobites (fig. 17) but because these rocks were deposited in deep water the abundance is low. Conodonts in the Frederick and Grove formations are small tooth-shaped fossils between 0.1 and 1.0 mm long (fig.17). They were the teeth of an extinct group of marine animals related closely with early vertebrates. They are present in both formations, but are too small to be seen. Conodont fossils are made up of phosphatic material much like human teeth.

Culpeper basin

The red sandstone and shale exposed from Seneca west to Monocacy River has yielded abundant fossils in Virginia and northern Maryland (Kranz, 1989). Rocks of the Poolesville Member of the Manassas Sandstone in the eastern part of the basin south of Seneca in Fairfax County, Va., have yielded footprints of crocodiles and a small bird like animal (Weems and Kimmel, 1993). Sandstone and siltstone of the Balls Bluff Siltstone near Dulles Airport have yielded bones and teeth of a crocodile-like parasuchian (phytosaur) (Weems, 1979) and a large coelacanth fish (Weems and Kimmel, 1993). Shale beds that are interlayered with the Balls Bluff Siltstone to the south were deposited in a lake and preserve remains of arthropods and fish as well as probable lizard footprints (Gore, 1988). Rocks exposed to the south in the Culpeper quarry yield parasuchian (phytosaur) teeth and footprints of a medium-size carnivorous dinosaur (fig. 18), two small carnivorous dinosaurs, a primitive sauropod dinosaur, a small ornithischian dinosaur, a prosauropod dinosaur, and a large armadillo-like aetosaur (Weems, 1987, 1992).

Lower Jurassic strata that overlie the Balls Bluff Siltstone to the south in Virginia also contains fossils. Siltstone of the Midland Formation yields abundant remains of fish in Fauquier County, Va. (Olsen and others, 1982), and shale of the Turkey Run Formation has yielded footprints of a small carnivorous dinosaur, large prosauropod dinosaurs, and a crocodile (Weems, 1992, 1993). The ephemeral lakes and river banks were sites where reptiles and dinosaurs lived. Rocks in the Culpeper basin also contain plant impressions, pollen and spores.

Blue Ridge Province

There are few fossils known in rocks of the Blue Ridge province. Most shelly fossils did not appear until about 560 million years ago. Rocks of the Catoctin Formation have been dated at about 565 million years old (Badger and Sinha, 1988), but preserved fossils have not been recognized in these ancient lava flows or the overlying quartzites of the Weverton Formation.

The interval of time when the rocks of the Weverton Formation and overlying rocks of the Harpers and Antietam formations were deposited represents a major biologic evolutionary episode. While no fossil shells have been recovered from rocks of either the Weverton or Harpers Formation, some of the most ancient trilobites have been found within the Antietam Formation. In places, metasiltstone of the Harpers Formation contains abundant burrows of ancient soft-bodied animals. The most common burrow trace is known as Skolithus. Skolithus burrows are oriented perpendicular to the stratification suggesting that they represent sites where the animal once lived (see figs. 94 and 133).

Valley and Ridge Province

From the Great Valley section westward to the Valley and Ridge the rocks generally become younger, and this is reflected in the fossils present and their abundance. For instance, fossils are extremely rare in rocks of the Lower Cambrian Tomstown and Waynesboro formations at the eastern margin of the Great Valley because not many types of shelly animals lived during this period of time. Progressing farther to the west, younger rocks are encountered and the fossils are more abundant and diverse. This general trend continues through the Ordovician and into the Silurian and Devonian (fig. 19).

Cambrian fossils-- The oldest rocks of the Valley and Ridge Province are Cambrian in age and are restricted to the Great Valley section. Deformation associated with the formation of the Blue Ridge-South Mountain anticlinorium destroyed most of the fossils. As a result, the best Cambrian fossils have been recovered from the Elbrook and Conococheague formations on the western side of the Great Valley (fig. 20).

The most common type of Cambrian fossils are trilobites and algal colonies called stromatolites. Many of the trilobite species that are found in the Conococheague Formation are also known from the Frederick Formation of the Frederick Valley in the western Piedmont province. That similar trilobite remains are found in both formations indicates that these two different units are equivalent in time, i.e., they are 'correlative'. Even though trilobites are the main biostratigraphic tool for correlating Cambrian rocks, conodonts appear in the Late Cambrian, and they supplant the trilobite as the most useful fossil for correlation.

Ordovician fossils.-- Rocks that were deposited during the early part of the Ordovician contain fossils that are very similar to those found in the Late Cambrian (fig. 20). Thus, fossils of the Stonehenge Limestone are mainly trilobites and conodonts. However, younger Ordovician rocks contain fewer trilobites and more snails, brachiopods and cephalopods. During the Ordovician they became a dominant part of the marine fauna. This change in fossil types is evident in the Rockdale Run Formation that contains many snails and only a few trilobites, but is most obvious in the diverse fauna present in the *Echinosphaerites* beds of the Middle Ordovician Chambersburg Limestone. This interval which is named for the ancient echinoderm *Echinosphaerites*, contains abundant brachiopods, bryozoans, and only a few trilobites.

The changes observable in the macrofossils are further illustrated by rapid changes in conodonts through the Ordovician. Figure 21 illustrates the changes in conodonts through Ordovician time as they are reflected in rocks along the C&O Canal.

The diverse numbers of organisms that had inhabited the clear waters during limestone deposition were replaced by a group of organisms that could live in the muddy sea bottoms that existed during deposition of the Martinsburg Formation in the Late Ordovician. These include snails and clams, and practically no brachiopods and bryozoans. To exist on the muddy sea floor it was necessary for animals to be able to filter out clay and silt.

Silurian fossils.- The Silurian was a time of great diversity in brachiopods, and many of the Silurian units contain abundant brachiopod remains. The units that best exemplify this are the Rose Hill Formation, McKenzie Formation, and Keyser Limestone. All of these formations were deposited in very shallow marine waters. Some of the thin beds of limestone within the McKenzie Formation are made up completely of brachiopod or snail shells (see fig. 19). This highly fossiliferous limestone can be seen along the abandoned Western Maryland railroad bed near MM 133. The limestone is interbedded with units such as the Silurian Bloomsburg and Wills Creek formations, which were deposited mostly above high tide and as a result contain almost no fossil remains. The exception is the large ostracode Lepertidia that is found in the Wills Creek Formation. The Tonoloway Limestone is known to contain the rare remains of extinct creatures known as euryterids. These arthropods lived in shallow marine water and looked like scorpions so they are commonly called sea scorpions. Eurypterids flourished in the late Silurian.

The Keyser Limestone was deposited during the latest Silurian. This limestone contains a very diverse fossil assemblage of brachiopods, bryozoans, corals, trilobites, and an ancient type of sponge-like colonial animals called stromatoporoids. Stromatoporoids are interesting because during the Late Silurian and Early Devonian they formed small reefs similar to what exists with corals today off the coast of Florida. Although no reefs are known from along the canal, Brezinski (1996b) described one north of the C&O Canal near the village of Flintstone, Md. Small stromatoporoids can be found along the abandoned Western Maryland railroad grade at Dam 6.

Devonian fossils.- Perhaps the most fossiliferous Lower Devonian formation is the Oriskany Sandstone. This white sandstone contains abundant molds of brachiopod shells. Because this sandstone is so porous, water has dissolved the shell material from these fossil fragments leaving molds where the shells once were (fig.19 C).

Many of the younger Devonian shales of the Needmore, Marcellus, Brallier formations as well as sandstones of the Mahantango and Foreknobs formations contain abundant clams, snails, brachiopods and cephalopods. Most of these fossil remains are preserved as molds, where the shell material has been dissolved (see fig. 19). Trilobites are uncommon in these Devonian rocks but conodonts occur.

Mississippian fossils.- Mississippian rocks occur at only one location along the C&O Canal. At the Town Creek Aqueduct, sandstone of the Riddlesburg Shale Member marine unit of the Mississippian Rockwell Formation is exposed. This earliest Mississippian sandstone was deposited as beach sand and as such contains no fossils. However, the black shale that is present immediately above this sandstone represents mud deposited in a nearshore lagoon and it contains a few brachiopods. Conodonts have been found in some of the rare limey horizons in this shale unit.

ENGINEERING GEOLOGY

Introduction

To fully understand the engineering achievement of the C&O Canal is to walk along the shore of the Potomac River in Virginia or West Virginia and envision what would be necessary in order to transport 120 tons of cargo in a 92 foot long boat in a waterway that parallels the river. A 6-foot deep canal 40 to 60 feet wide at the top had to be excavated, hopefully in silt that underlies the flood plain. Small tributaries of the river had to be crossed, and culvert archways made of stone and brick provided a channel for the tributary **beneath** the canal. Large tributaries required aqueducts. Where bedrock bluffs adjoin the river, hand drilling with sledgehammer, bit, and black powder was required to excavate a canal. Parallel to the canal and adjacent to the river, an elevated towpath needed to be constructed. Dams were required at strategic locations to divert river water into the canal. Locks were constructed at specific locations to lift and lower the boats as the canal changed in elevation along its length. Lock keepers needed lock houses to live in, in order to tend to the 24-hour operation. Necessary construction materials were dimension stone for locks, lock houses, culverts and aqueducts, stone rubble for towpath fill, clay to line the canal, cement for mortar, iron and manganese for the production of iron for lock fittings, and lumber for lock gates and forms. Some places required imaginative means to save time and money by utilizing local geology. Examples are tunnels through bedrock that route the canal through cutoff meanders, and the use of the river itself rather than any canal, as at Big Slackwater.

The 184.5-mile long canal and towpath required an infrastructure of over 74 lift locks and lock houses, 11 aqueducts, more than 182 culverts and waste weirs, 7 dams, and 1 tunnel through bedrock. Building stone was in great demand. The facing of all locks, aqueducts, and culverts required cut or hammer-dressed stone. Sandstone and limestone were desired because two sides would split along bedding surfaces. The location of locks, aqueducts, and culverts, the building stone used, and the known quarry sites of the stone is summarized in fig.22. Noteworthy is that the dimension stone and cement was transported to the canal by river barge, wagon, and rail. Subsequent repairs to these structures have used stone, brick, and concrete in modern time.

Excellent discussions and illustrations of the engineering and construction of the canal are provided in the Chesapeake and Ohio Canal Official National Park Handbook (National Park Service, p.32-37, 1991) and in Davies (1971, 1999).

Bedrock Excavation

Unlike the 363-mile Erie Canal in New York that was excavated from 1817 to 1825 in thick unconsolidated glacial till, outwash, and alluvium, not all of the C&O Canal could be dug. About 34 miles of the C&O Canal and towpath had to be drilled and blasted through bedrock using sledgehammers, star bit drill rod, and black powder (fig. 22). Many of the drill holes may still be seen along the bluffs and in the canal bed (fig. 23). Men roped to trees, hung over the cliff and used sledgehammers to pound steel rods held by other trustworthy men. Bedrock excavated for the adjacent railroad and canal berm was used as fill to create the towpath (fig. 23).

Locks

There were 74 locks that raised (west bound) and lowered (east bound) boats an average of 8 feet, to accomodate the change in elevation of 605 feet along the length of the canal. The locks are 100 feet long and 15 feet wide chambers made of stone on timber foundations with watertight wooden gates at both ends. The water did not flow in the canal from Cumberland to Georgetown like the water flows down the Potomac River. Water in the canal was impounded at a constant level that was released 74 times.

There were 12 river feeder locks and quard locks that regulated the flow of water from the Potomac River into the canal. Several of these river locks, such as at Goose Creek, Shenandoah, and Shepherdstown, were demanded by the Virginia Legislature in 1833 to provide a market for

Virginia products. The Goose Creek and Little River Navigation (Trout, 1991) provided canal access to as far west as Middleburg, Va. The Shenandoah Navigation at Harpers Ferry was built by the Patowmack Company. Skirting canals associated with the Patowmack Canal remain on the Virginia shore opposite Seneca and Weverton. River locks were also used to take boats into the Potomac River where bluffs prevented construction of a canal, such as the case at the Big Slackwater.

Lock Stone

The dominate building material required for the C&O Canal was dimension stone. Sandstone of the Lower Cretaceous Potomac Group, informally called "Aquia Sandstone", was quarried from Aquia Creek in Stafford County, Va., and barged over 35 miles up the Potomac River for use in Locks 1 to7 (fig. 24). Sandstone of the Upper Triassic Poolesville Member of the Manassas Sandstone, informally called "Seneca Red Sandstone", was quarried mostly at Seneca (fig.25) and used in Locks 7 to 13, and 15 to 27 (fig. 26). This sandstone was also used in Locks 28 to 30, 33, and 34, and some was quarried north of MM 46 east of Point of Rocks. Ordovician Ellicott City Granodiorite from the Patapsco River valley was used in Locks 14, and 28 to 30, 32, and 33 (fig.27). Quartzite quarried from the southern base of Sugarloaf Mountain was used in Lock 28.

Locks 31 and 33 used a combination of local Lower Cambrian stones that include quartzite of the Weverton Formation (fig. 28), limestone, metasiltstone of the Harpers Formation, and Triassic Manassas Sandstone. In the Great Valley section, locally quarried limestone (fig. 29) was used extensively from Lock 32 to Lock 53 as well as in Locks 56 and 57. Locks 53 to 57 used sandstone and limestone that was excavated along the canal. Locks 58 to 67 used Devonian sandstone and shale that were also locally excavated along the canal. Some of these locks were lined with wood planks (fig.30) to help seal water that leaked from this masonry stone.

Sandstone of the Devonian Oriskany Formation was used in Locks 68, 70, and 71, because it had to be excavated to build the canal.

Aqueducts

With exception to the Broad Run Aqueduct that was made of wood planks, the other 10 aqueducts were impressive structures made of stone that did not leak. The Alexandria Aqueduct carried boats over the Potomac River to the Alexandria wharf. The Seneca Creek Aqueduct (fig.31) was made of the Manassas Sandstone that was quarried to the immediate west. The Monocacy Aqueduct (fig.32) used quartzite of the Lower Cambrian(?) Sugarloaf Mountain Quartzite. This granular white rock was quarried at the base of Sugarloaf Mountain near the Frederick and Montgomery County line and hauled to the site by horse-drawn wagon and light rail. The Catoctin Creek Aqueduct, now in ruins, used Ordovician Ellicott City Granodiorite from the Patapsco River valley and Manassas Sandstone from Seneca. The aqueducts at Antietam Creek, Conococheague Creek, Licking Creek, Tonoloway Creek, Sideling Hill Creek, Fifteen Mile Creek, parts of Town Creek, and Evitts Creek each were made of limestone quarried nearby. The aqueducts at Sideling Hill Creek and Town Creek also used sandstone that was quarried locally.

Culverts and Waste Weirs

More than 200 culverts used mostly local stone and were lined with brick and dressed with cut stone. The culverts carried water from tributaries that drain into the Potomac River **beneath** the canal and towpath. Waste weirs were ditches and flumes lined with stone that were used to control the water level in the canal by diverting excess water around the locks.

Canal Prism and Towpath

The canal was a 6- foot deep prism 48 feet wide at the base and 60 feet wide at the surface and slightly smaller up river of Harpers Ferry. The canal was mostly excavated by pick and shovel in unconsolidated Quaternary alluvial gravel, sand, silt, and clay, that was placed on the river side to form the towpath. Flood scour in 1996 revealed that the towpath locally is a stone crib of vertical blocks filled with soil and capped with gravel. Stone embankments and berms were constructed locally along the river, adjacent to the towpath (fig.33), and sometimes even the far side of the canal to keep flood waters out; examples are at McKee-Beshers west of Seneca and Big Pool. The canal prism was lined with impervious clay to hold water (fig. 34). The source of the clay is not known. Karst in limestone must have been a local cause for water loss because today there are caves exposed in the dry canal.

Dams

Dams were constructed to raise the level of water in the river to feed the canal. The 7 dams have foundations that rest on bedrock and all of the dams were constructed where resistant bedrock (metagraywacke and sandstone) crops out as ledges to create shallow falls. Therefore, the dams were located near the top of natural steep gradients in the river. Rubble dams, made of blocks and boulders of local rock, were constructed for Dam 1 at Little Falls (1750's) in the eastern Piedmont, and at Dam 2 at Seneca Falls (1828) at the eastern margin of the Culpeper basin in the eastern Piedmont. Dam 3 at Harpers Ferry (1799) was a crib timber dam (fig.35) later replaced with masonry. Dams 4 (1832-1834), 5 (1833-1835), and 6 (1839)(fig. 36) were timber-framed dams that were filled with stone and covered with wooden planks. The wood burned from fires of fisherman. Dam 8 was a masonry dam at Cumberland that was removed in 1958 for flood control. Dam 7 was planned for near Paw Paw, W.Va., but was not constructed.

Bedrock Tunnel

A 3,118 foot-long tunnel (fig. 37) was excavated through folded siltstone and shale of the Devonian Brallier Formation north of Paw Paw, W.Va., from 1836 to 1841 and 1847 to 1850. The tunnel was the alternative chosen rather than constructing a canal along 6 miles of river meanders bordered by cliffs of bedrock. As many as 44 men excavated 10 to 12 feet of tunnel using hand drills, black powder, picks, and sledge hammers each week. There were 2 vertical shafts for access so the tunnel could be driven from 6 positions or faces. Debris hauled up the shafts was dumped in spoil piles above the north portal. The canal occupies a cut 890 feet long at the head of a ravine north of the tunnel.

Cement

Beginning in 1837, limestone was quarried and mined, and cement was made along the canal at Round Top (fig. 38) for the masonry of the C&O Canal (Hahn and Kemp, 1994). More than 500,000 barrels of cement were used to bond the stone in the locks and aqueducts. From 1828 to 1837, cement plants were built along the Potomac River at Tuscarora, Shepherdstown, Hooks Mill (Hancock), Round Top, Leopards Mill, below Dam 6, and at Cumberland (Hahn and Kemp, 1994). Cement made at Round Top was also used to construct the Washington Monument and Cabin John Bridge.

Control of Geology on Engineering

Several interesting engineering features were devised to deal with the local geology.

1) From near MM 2 in Georgetown to Great Falls Tavern (MM 14), the canal and towpath are on an incised channel on a bedrock strath terrace of the Potomac River. From near Cropley (MM 12) to MM 14 the canal utilizes an abandoned channel of the Potomac River, called Widewater (fig.39). This channel was cut into the bedrock terrace by the river that later abandoned this

course and migrated south to its present course. Channels from Widewater to the present river have wooden dams to keep floodwaters away from the towpath and canal. The towpath was constructed along this rocky stretch of ground but thanks to the Potomac River a "canal" already existed. Because the channel was wider than the locks, abutments of timber were used to fill the gaps.

2) Dams were constructed at falls on resistant bedrock. Dam 2 (Seneca Falls) was located on metagraywacke of the Mather Gorge Formation near the margin of the Culpeper basin in the eastern Piedmont province, Dam 3 (Harpers Ferry), was located on sandstone of the Antietam Formation, and Dam 6 (east of Woodmont) was located on Oriskany Sandstone.

3) At 4 locations, bedrock bluffs prevented construction of a canal and towpath. From MM 85.5 to MM 88.8 south of Hagerstown, the north shore of the Potomac River is a cutbank with high bluffs of limestone and no flood plain. At Dam 4 and the "Big Slackwater" boats entered the Potomac River at Guard Lock 4 and rejoined the canal 4 miles up river at Lock 41. The towpath is a narrow bench that was drilled and blasted into the limestone bluff (fig. 40A). Beyond MM 154 the canal and towpath used a ravine of a tributary and made a 3,118 foot-long tunnel through shale and siltstone near Paw Paw, W.Va. The canal and towpath use the valley of Mill Run near Oldtown to bypass bedrock cliffs. Here the canal **and** towpath were excavated through shale (fig. 40B).

4) Four Locks (MM 108.5) routed the canal through an abandoned channel probably of a tributary of the Potomac River, to cut off the 7 mile “Neck”.

5) Big Pool (MM 113 to MM 114) and Little Pool (MM 120) are lakes that were created by building dikes, levees, and berms on a broad low-lying flood plain, and then filling them with water diverted from the canal and river. The towpath was placed on a higher ridge or intervening island, so a canal prism did not have to be excavated and constructed.

GEOLOGIC GUIDE

PIEDMONT PROVINCE

POTOMAC TERRANE

Georgetown, D.C., (MM 0) to Seneca (MM 23)

Access: Georgetown, Clara Barton Memorial Parkway,
Carderock, Mac Arthur Boulevard, Great Falls,
Watts Branch Park and Swains, Pennyfield, Violets,
and Rileys Locks off of River Road

Introduction

The Potomac River has cut a beautiful gorge through the complexly deformed crystalline metamorphic rocks of the Potomac terrane (fig. 41). The Potomac terrane consists of metasedimentary and metavolcanic rocks that were thrust along faults during deposition in a deep oceanic trench about 550 My ago in Neoproterozoic and Early Cambrian time. Debris from the thrust sheets was mixed with unconsolidated sediments being deposited to form a melange, or mixture of rocks. A modern analog would be the debris that calves off of the front of an advancing glacier.

Along the Potomac River is the Mather Gorge-Sykesville tectonic motif (Drake, 1989). Quartz-rich schist and metagraywacke of the Mather Gorge Formation were thrust onto the Sykesville Formation along the Plummers Island thrust fault. Rocks of the Mather Gorge Formation were sheared to phyllonite. Sediment rich in quartz and feldspar that contains fragments and blocks of phyllonite derived from the Mather Gorge Formation make up the underlying sedimentary melange called the Sykesville Formation. Rocks of the Mather Gorge Formation are turbidites that were deposited in a submarine fan (Drake and Morgan, 1980). The complexly deformed and polymetamorphosed unit locally contains rock that was partially melted called migmatite. The Mather Gorge Formation also contains map-scale bodies of ultramafic rock, such as serpentinite, talc, actinolite schist, and amphibolite, that were derived from oceanic crust. The Sykesville Formation also contains exotic blocks and cobbles of granitoids, schist, and vein quartz, that were incorporated into the giant submarine slide deposit (Drake and Morgan, 1980).

The Cambrian Laurel Formation of the Loch Raven-Laurel tectonic motiff is exposed only at the ramp of Roosevelt Bridge in D.C. These rocks resemble the Sykesville Formation but differ in the abundance and type of clasts.

East of the Plummers Island thrust fault near Cabin John Bridge, igneous plutonic rocks of Early Ordovician age intrude the Sykesville Formation. The four groups of igneous rocks there are called the Georgetown Intrusive Suite, Kensington Tonalite, the Dalecarlia Intrusive Suite, and the Bear Island Granodiorite. Regional metamorphism of rocks of the Mather Gorge Formation was interpreted to have occurred at 490 My (Becker and others, 1993), before the Taconian orogeny. Mineral assemblages in rocks of the Potomac terrane range from chlorite-zone in the west to sillimanite zone in the east. Rocks of the Sykesville Formation are at biotite+-garnet grade and rocks of the Laurel Formation are at biotite+-garnet grade with local overgrowth of staurolite. The deformation of these rocks started in Cambrian time during east-directed subduction (Drake, 1989). The rocks in the composite thrust sheets were then thrust onto the slope and rise deposits of the Westminster terrane during subduction related to the Ordovician Taconian orogeny (fig. 4).

The spectacular scenery of the Potomac Gorge is really a result of the fairly recent incision by the Potomac River. Several different levels of strath terraces are cut into the bedrock. They are mostly confined to the north shore of the Potomac River, but also include the islands. These terraces are nearly flat benches of bedrock with abundant potholes (see figs. 8 and 9) and channels (Zen, 1997a). Upland areas such as Carderock and the Palisades are built upon such terraces. Upstream of Great Falls, the river valley has a wide alluvial flood plain with the exception of Blockhouse Point, which forms a promontory into the river.

Cretaceous sand and gravel of the Potomac Formation occurs as erosional patches in Arlington, Va., and Washington, D.C. Overlying the Potomac Formation are marine clay, silt, and sand of the middle and early Miocene Calvert Formation (Tc). Elsewhere, gravel, sand, silt, and clay deposits are middle Miocene (T4), late Miocene (T3), and late Pliocene (T2 and T1). These older deposits are more weathered than the middle to late Pleistocene alluvial terrace deposits (Q5 and Q3) that occur at similar elevations.

Georgetown to Glen Echo Park Area

MM 0 to MM 7

The east end of the C&O Canal is at Tide Lock (sea level) at the confluence of Rock Creek and the Potomac River (figs. 41 and 42). Rock Creek was used as the canal for about 0.38 miles, and then the canal was excavated in bedrock. Near Lock 1 is a commemorative bronze plaque attached to a block of rock that shows rock fragments in a fine-grained matrix that make up the Sykesville Formation (fig. 43). Roosevelt Island and bluffs in D.C., and Arlington County, Va., are underlain by similar bedrock. The valley of the Potomac River that is floored by Coastal Plain deposits does not begin until further downstream. Rocks of the Sykesville Formation first crop out in the bed of the canal at the NPS visitor center in Georgetown. Westward to near Three Sisters Islands are igneous rocks of the Georgetown Intrusive Suite, mostly biotite-hornblende tonalite (Ogh) and some gabbro (Ogg) and biotite tonalite (Ogb). Outcrops show drill holes required to excavate the canal and locally the canal berm was constructed around bedrock (fig.44).

At the overpass of Key Bridge are remains of the Alexandria Aqueduct that carried boats across the Potomac River to Alexandria. The lock stones have quartz fragments in a sandy matrix that are typical of the Sykesville Formation. Near Foxhall Road the canal is partially excavated into a bedrock terrace and the towpath is elevated; here the “Crescent Trail” descends onto a younger lower terrace. Beginning about here are large bedrock terraces between Potomac-Palisades Parkway and MacArthur Boulevard that extend to near Widewater.

From MM 2 to MM 5 the canal traverses rocks of the Sykesville Formation with rare blocks of gabbro and amphibolite within it. The canal bed along here was locally excavated in bedrock but many cobbles of quartz derived from the Cretaceous and Pleistocene upland deposits litter it (fig. 45A). Some of these cobbles are cross-bedded sandstone (fig. 45B) that probably came from the Valley and Ridge province west of McCoys Ferry (MM 110).

Little Falls Dam is the first of originally 8 dams that provided water to the canal. Opposite Sycamore Island at about MM 6.5 are good outcrops of light-colored monzogranite of the Dalecarlia Intrusive Suite (Odm).

Glen Echo Park Area to Swains Lock
MM 7 to MM 16.6

From MM 7 to almost MM 10 the canal crosses rocks of the Sykesville Formation that locally were intruded by rocks of the Georgetown and Dalecarlia Intrusive Suites (fig. 46). From Cabin John Creek west to I-495 these rocks had to be drilled and blasted to create the canal. Just east of MM 9.5 is a major rock boundary within the Potomac terrane (see fig. 41). Metasedimentary rocks of the Mather Gorge Formation were transported westward over rocks of the Sykesville Formation along the Plummers Island thrust fault. From here west to Violets Lock, save an area near Cropley (MM 11.5), are metagraywacke and schist that were sediments deposited as turbidites in deep marine water. Phyllonite and migmatite also occur in this interval. Phyllonite was produced by shearing along the faults and migmatite was produced by partially melting rock. Some of the best outcrops of the region are along this section of the Potomac River on Bear Island; to see them take the Billy Goat Trail that begins here. Relatively undeformed rocks of the Sykesville Formation (fig. 47) become very sheared near the Plummers Island thrust fault (fig.48). On bedrock islands in the Potomac River the rocks are so sheared that the two formations cannot be readily distinguished. From about MM 9 to MM 11 the canal has been excavated into the margin of a broad bedrock terrace above the Potomac River (Carderock) and the berm is lined with rock.

Building stone of Sykesville Formation was quarried at the Potomac Granite Mill in the early 1900's near Cropley, and the abandoned pits are now part of the Marsden Tract. This sedimentary mélange with rock clasts was long thought by geologists to be granite with abundant xenoliths. The rocks of the Sykesville Formation, last seen just west of I-495, are exposed here again. The structurally overlying rocks of the Mather Gorge Formation have been eroded to expose the rocks beneath the Plummers Island thrust fault in a tectonic window (Drake and Froelich, 1997). Like the Plummers Island thrust fault near MM 9.5, the fault that frames the tectonic window here is a penetrative shear zone in the rocks on either side of the fault.

From the parking area opposite Old Anglers Inn to Great Falls Tavern is a classic area of the C&O Canal. Widewater is where the canal uses an abandoned channel of the Potomac River (figs.13 and 49). The towpath locally had to be constructed above the channel (see fig. 39) but elsewhere it was excavated in the bedrock terrace. Bedrock is well exposed in this region (Reed and others, 1980). Folded vein quartz and phyllonite show that deformation predates intrusion of the Ordovician Bear Island Granodiorite (fig. 50). Upright antiforms of isoclinal folds of metagraywacke are seen opposite the overflow of Widewater. Dismembered folds of metagraywacke in migmatite are exposed on both sides of Widewater (fig. 51). Bodies of dark amphibolite, and light-colored Bear Island Granodiorite and pegmatite are in contrast to the gray migmatite (fig. 52). The amphibolite is dark due to hornblende crystals (fig. 53).

Vein quartz intruded the migmatite near Lock 15 (fig. 54). To the immediate north, gold was discovered in similar vein quartz in 1861 and was mined sporadically until 1951 (fig. 55); trenches and pits of this gold mining activity remain today (Reed and Reed, 1970).

Near Rocky Islands is “Mary’ s Wall” (fig. 33A) where a rock berm was required to keep water in the canal and floodwater of the Potomac out of the canal. An elevated bedrock terrace formed across the islands and opposite shore where alluvial boulders were deposited at the crest of Glade Hill (figs.13 and 14) in Great Falls Park, Va. On Bear Island, Olmstead Island, and along Mather Gorge are some of the largest potholes of the Potomac River (see figs. 8 and 9). Exposed on the bluff of Mather Gorge are rare igneous dikes of Late Devonian age (fig. 56). The dikes are lamprophyres and are composed of fine-grained biotite, quartz, and plagioclase. The dikes intruded schist of the Mather Gorge Formation along a prominent set of fractures that have remained open for 360 My!

The complex deformation that occurred prior to the Ordovician Taconian orogeny is seen in many outcrops on Bear Island. There are isoclinal folds of metagraywacke and schist, refolded as upright antiforms, and intruded by Ordovician pegmatite and granodiorite (Drake, 1989) (fig.57). As you approach Great Falls Tavern and west to MM 16, the canal is excavated in alluvium deposited on a bedrock terrace.

Swains Lock to Seneca

MM 16.6 to MM 22.7

From MM 16 to Violets Lock bluffs of metagraywacke and schist of the Mather Gorge Formation were drilled and blasted to construct the canal. The most spectacular area to see this feat of labor is near MM 19 and at Blockhouse Point where bedded metagraywacke shows near vertical drill holes (see fig.23 B). The rocks along this section of the canal are complexly folded at all scales. The layers of metagraywacke and schist seen on the map and bluffs indicate folds that are best seen up close (fig. 59). Near Lock 23 the Late Triassic rocks of the Culpeper basin unconformably overlie schist and metagraywacke of the Mather Gorge Formation. This contact represents an interval of more than 320 My of geologic time!

CULPEPER BASIN

Seneca to Point of Rocks

MM 22.8 to MM 48.2

Access: Seneca, McKee-Besher Wildlife Management Area,

Edwards Ferry, Whites Ferry, Monocacy Bottom

Introduction

At the end of the late Paleozoic continental collision the Alleghanian orogeny formed the Appalachian Mountains. Some 10 My later during the Mesozoic, extensional tectonics created rift basins on the continent and eventually the Atlantic Ocean opened. These rift basins extend along the eastern edge of the Appalachian orogen from Florida to Newfoundland, Canada. One of these basins, the Culpeper basin, extends from central Virginia near Culpeper, to Frederick, Md. The Culpeper basin was once continuous with the Gettysburg basin to the north of Frederick, although the connecting rocks have since been eroded.

The Culpeper basin is a half graben made of strata that dip west into a border fault at the base of Catoctin Mountain. Faulting occurred while the rocks were deposited and after. Much later the Potomac River followed a southeasterly course from Edwards Ferry (MM 44.5) to the mouth of Monocacy River along such a fault.

The rocks in this part of the Culpeper basin (fig. 41) consist of a basal conglomerate overlain by and interbedded with sandstone and siltstone that were deposited by rivers and lakes. There are two basal conglomerate units. On the west is a variegated limestone conglomerate called the Tuscarora Creek Member of the Manassas Sandstone. The limestone clasts within the conglomerate were derived locally from the Cambrian Frederick Formation and the Cambrian and Ordovician Grove Formation. The basal conglomerate along the north and east margin of the basin is the Reston Member of the Manassas Sandstone (fig. 61). This conglomerate is composed of locally derived quartz and schist of the Potomac and Westminster terranes. Overlying the Reston Member basal conglomerate is red sandstone called the Poolesville Member of the Manassas Sandstone. The "Seneca Red Sandstone" quarried at Seneca was one of the most widely used building stones along the C&O Canal as well as the Smithsonian Institution Castle. The grain-size of the sandstone fines upward to a siltstone, and is then called the Balls Bluff Siltstone. Interbedded with the Balls Bluff Siltstone from near Whites Ferry to east of Furnace Mountain in Loudoun County, Va., is a variegated limestone conglomerate similar to the Tuscarora Creek Member of the Manassas Sandstone. The Leesburg Member of the Balls Bluff Siltstone, informally called "Potomac Marble" and "Calico Rocks", was quarried for the columns in Statuary Hall of Congress on Capital Hill. Historical maps show quarries near Whites Ferry (Frye and Jefferson, 1776) and east of Point of Rocks (Keith, 1894; Scheel, 1995). These conglomeratic rocks are interpreted to be ancient debris flow deposits on a large alluvial fan that extended eastward from a highland near present day Catoctin Mountain (Smoot, 1989). Therefore, the limestone conglomerate of the Tuscarora Creek Member and the Leesburg Member may be continuous in the subsurface. A significant amount of Cambrian limestone was exposed on and west of Catoctin Mountain in order to supply the abundant limestone clasts (Lindholm and others, 1979).

Near-vertical planar dikes and thick subhorizontal sills of Early Jurassic diabase intrude these sedimentary rocks. Outcrops are scarse so dike rocks commonly occur only as float of brown and gray cobbles and boulders. Locally the sedimentary rocks are altered by contact metamorphism when the molten diabase was intruded.

Within the Culpeper basin are some of the most extensive alluvial terraces of the Potomac River. East of MM 37 at Martinsburg, Md., and west of MM 41 in Loudoun County, Va., these deposits lie at 288 and 240 feet, respectively, above the Potomac River. Auger holes near Martinsburg reveal deposits more than 40 feet thick, whereas relief on the terrace in Loudoun County suggests a thickness of over 100 feet (Southworth, 1998).

Seneca to Edwards Ferry

MM 22.8 to MM 30.8

The eastern margin of the Culpeper basin coincides with the location of Dam 2, which was built where the shallow, broad bed of the Potomac River crosses the resistant metasedimentary rocks of the Mather Gorge Formation at Seneca Falls (fig. 60). Here are the remains of a rubble dam, constructed by placing local boulders on the bedrock ledges in the riverbed. The nature of the Potomac River changes dramatically here (fig. 61). Westward the river valley is broad with many elevated terraces, but to the east the Potomac has cut a gorge with abundant outcrop forming falls and islands. On the Virginia shore at Dam 2 is a skirting canal of George Washington's Patowmack Company called the "Seneca Bypass", "Seneca cut", "Seneca break", and "Washington cut", that was used prior to construction of the C&O Canal (Garrett and Garrett, 1987).

The Late Triassic age basal conglomerate of the Reston Member of the Manassas Sandstone is poorly exposed north of River Road and contains cobbles of vein quartz and schist derived from the underlying Mather Gorge Formation (fig. 62). The Seneca Creek Aqueduct (fig. 31), lock keepers house, and Seneca Stone Cutting Mill (fig. 25) are made of the red sandstone of the Poolesville Member of the Manassas Sandstone. Referred to as the "Seneca Red Sandstone", this rock was extensively quarried on the bluffs of the Potomac River west of the aqueduct. The quarries were opened in 1774 and operated until 1898 (Davies, 1999). The large impoundment of water between the towpath and bluffs was a holding basin for the barges that transported the stone. Along the bluffs from here to MM 24 are abandoned quarries for sandstone and at least one that prospected for copper.

Near MM 24, siltstone is more dominant than sandstone so the rocks are called the Balls Bluff Siltstone. Finer-grained siltstone is rather poorly exposed along the canal but can be seen at the type locality at the bluffs of Balls Bluff National Cemetary, Va., opposite MM 34.

From MM 24 to MM 30 the canal and towpath cross the broad flood plain of the McKee-Beshers Wildlife Management Area. The low-land required berms to be built above the canal to keep out flood water and overbank deposits of silt.

West of MM 30 is the only siltstone exposed until almost MM 38. Here near the Chisel Branch campsite the rock had to be drilled and blasted to construct the canal. The Goose Creek River Lock here connected the C&O Canal with the Goose Creek and Little River Navigation (Trout, 1991) that was used to transport goods as far away as Middleburg, Va.

Edwards Ferry to Monocacy Aqueduct
MM 30.8 to MM 42.2

Near MM 32 are the remains of the Broad Run Aqueduct, the only type of structure built of wood. West beyond MM 32.5 the canal and towpath cross the flood plain that locally has large blocks of quartzite transported by the Potomac River during floods. At Whites Ferry (MM 35.5) are the remains of a large bridge made of red sandstone that carried ferry users across the canal. From near MM 38 to west of Marble Quarry campsite (fig. 63), graded beds of limestone conglomerate (fig. 64) (Leesburg Member of the Balls Bluff Siltstone) are interbedded with siltstone and sandstone. These conglomerates are ancient distal debris flows that brought clasts of carbonate derived from north and west of Catoctin Mountain into a basin of muddy silt. An Early Jurassic diabase dike intrudes the conglomeratic rock. Clasts of limestone were metamorphosed into white marble that was quarried for agricultural lime. Native Americans lived on the islands and along the shore of this section of the Potomac and some of the best fish weirs (see fig. 10)(Guzy, 2000) are preserved here (Scheel, 1995).

From near MM 41 north to Monocacy River are good outcrops of siltstone interbedded with sandstone with drill holes and small quarries (fig. 64 C). Monocacy Aqueduct (fig. 32) is made of white quartzite quarried from the southern part of Sugarloaf Mountain and transported here by horse and wagon and light rail.

Monocacy Aqueduct to Point of Rocks
MM 42.5 to MM 48.2

From MM 42 to Rock Hall near MM 47.5, the canal and towpath cross a broad flood plain deposit on Triassic rocks that are, in part, down-faulted against older rocks of the Piedmont to the north (fig. 65). Limestone conglomerate of the Tuscarora Creek Member of the Manassas Sandstone outcrops on the flood plain of “Indian Flats” and looks identical to conglomerate of the Leesburg Member (Balls Bluff Siltstone) that occurs near MM 47. “Indian Flats” was undoubtably the site of a major village of Native Americans and upstream of MM 43 is a complex fish weir (fig. 10).

WESTMINSTER TERRANE

Phyllite, metalimestone, and greenstone of unknown age occur north of the confluence of the Potomac and Monocacy Rivers (fig. 65). These rocks are assigned to the Neoproterozoic(?) and Lower Cambrian (?) Ijamsville Phyllite, Silver Run Limestone, and Sams Creek Formation, respectively, and they were transported here along the Martic thrust fault. These rocks are interpreted to be deep water deposits of the Iapetus Ocean that were thrust westward onto metasiltstone of the Middle Cambrian Araby Formation. The Araby Formation and overlying Frederick Formation were deposited on the continental shelf and subsequently have been folded into the Frederick Valley synclinorium (Southworth, 1996,1998). The highly-folded phyllite (fig.

66) and metalimestone (fig. 67) are best exposed along the bluff of the Monocacy River, but there are rare outcrops within the flood plain at "Indian Flats". These rocks are truncated to the east along a Mesozoic normal fault that juxtaposes Upper Triassic sandstone against them. The terrace deposits at the north margin of “Indian Flats” flood plain contain blocks of quartzite as much as 3 meters long that were transported by the Potomac River during flood stage.

FREDERICK VALLEY SYNCLINORIUM

Early to Late Cambrian age metasedimentary rocks have been juxtaposed against older rocks of the east limb of the Blue Ridge-South Mountain anticlinorium along a Mesozoic normal fault that runs 22 miles from Furnace Mountain, Va., to Catoctin Furnace, Md. (fig. 65). These rocks constitute the Frederick Valley synclinorium that is interpreted to have formed along with the Blue Ridge-South Mountain anticlinorium during late Paleozoic deformation of the Alleghanian orogeny. The oldest rocks are quartz-rich metasiltstone of the Lower to Middle Cambrian Araby Formation that were deposited in a basin (Reinhardt, 1974). The type locality is northward near the Monocacy River at Araby Station. Overlying these rocks are limestone of the Upper Cambrian Frederick Formation that marks the development of the passive continental margin during Cambrian and Ordovician time. Mesozoic normal faults along the Potomac cause the bedrock in Virginia to be quite different from that of Maryland.

East of Catoctin Mountain in Virginia and Maryland are Early and Late Cambrian age rocks of the Antietam, Tomstown, and Frederick formations that underlie the Furnace Mountain area. The iron-and manganese-rich arkosic sandstone of the Antietam Formation was mined in the 1800's for manganese. With exception to dark gray graphitic phyllite (metamorphosed organic-rich mud) exposed in excavations (see fig. 73) , these rocks are the same as the rock sequence exposed on the western-most limb of the Blue Ridge- South Mountain anticlinorium west of Harpers Ferry, W.Va.

Highly cleaved tan and gray metasiltstone of the Araby Formation are exposed in the railroad cut opposite the broad flood plain from MM 42.6 to MM 44 (fig. 68). Gray limestone of the Frederick Formation occurs in several varieties. Thin-bedded limestone is exposed along New Design Road and along the creek that enters the Potomac River near Nolands Ferry (fig. 69A), limestone conglomeratic breccia is exposed near the Monocacy River (fig. 69B), and folded thin argillaceous limestone interbedded with shale is exposed in Virginia (fig. 69C). Similar limestone was used to build the water treatment facility along the towpath here. North of Nolands Ferry, the limestone is overlain by patches of limestone conglomerate (Triassic Tuscarora Creek Member of the Manassas Sandstone) as well as Quaternary age coarse alluvium. Noteworthy is the conical hill covered with rounded cobbles of quartzite and sandstone north of the intersection of Rt. 28 and New Design Road (fig. 70). The conical shape of the hill and deposit is interpreted to be the site of a former sinkhole in limestone that was filled with coarse alluvium. The resistant cobbles of quartz armored the otherwise soluble limestone and resulted in topographic inversion; that is, the depression became a hill.

From MM 42 to Rock Hall near MM 47.5 the canal was excavated in limestone conglomerate of the Leesburg Member of the Balls Bluff Siltstone (fig. 71A). This distinctive rock was quarried here for the columns of Statuary Hall in U.S. Congress on Capital Hill, Washington, D.C. (fig. 71B).

From about MM 47.5 to MM 48.2 the area is underlain by limestone of the Early Cambrian Tomstown Formation (fig. 72A) that is only exposed in Virginia. Extensive alluvial and colluvial deposits (fig. 72B) mantle the bedrock so only water well records and drill core (Hoy and Schumaker, 1956) reveal its presence in Maryland. “Big Spring”, or Kanawha Spring, discharges from the limestone near MM 47.5. Stratigraphically beneath the Tomstown Formation is dark carbonaceous and graphitic phyllite that produces a distinctive ashey soil where exposed in excavations (fig. 73A). Similar black shales are found locally within the limestone of the Frederick Formation (Southworth and Brezinski, in press). The graphitic phyllites were deposited on metasandstone of the Antietam Formation. These dirty metasandstones (fig. 73B) are only exposed in excavations along Furnace Mountain in Virginia. They are not composed of clean quartz like the metasandstone of the Antietam Formation found west of Harpers Ferry, but are more similar to the rocks of the Araby Formation. The change in facies of rocks of the Antietam Formation across the Blue Ridge province probably reflects a change from shallow marine to deep water slope when the rocks were deposited.

BLUE RIDGE PROVINCE

MM 48.2 to MM 63

Point of Rocks to Fort Duncan Bend

Access: Point of Rocks, Lander, Brunswick, Weverton, Sandy Hook, Harpers Ferry (W.Va), and Pleasantville

Introduction

Some of the oldest rocks in the Appalachians are exposed in the Blue Ridge Province. The main structure is a large overturned fold known as the Blue Ridge-South Mountain anticlinorium. This anticlinorium is defined by an eastern and two western flanks, that underlie Catoctin, South Mountain-Short Hill Mountain and Blue Ridge-Elk Ridge, respectively (fig. 74). The rocks were metamorphosed, folded, faulted, and transported westward in the late Paleozoic Alleghanian orogeny as the result of continental collision of North America and Africa.

The rocks that underlie Catoctin Mountain on the east limb are resistant metamorphosed basalt (greenstone) of the Neoproterozoic Catoctin Formation (Zc) and quartzite of the Lower Cambrian Weverton Formation (Cw). Likewise, South Mountain and Blue Ridge-Elk Ridge to the west, are underlain by the same rocks, but the strata there are very folded and are overturned. Blue Ridge-Elk Ridge is almost a replica of South Mountain because a regional fault duplicates the strata and resultant ridges. The core of this anticlinorium contains 1.1 billion year old granitic rocks that were metamorphosed and deformed during the Mesoproterozoic Grenville orogeny

(Burton and Southworth 1996; Southworth and others, in press). The granitic rocks are gneissic, well layered, and varieties include biotite granite gneiss (Ygb), leucocratic metagranite (Yg), garnetiferous metagranite (Ygt), and hornblende monzonite gneiss (Yhg). The billion year old age of these rocks was determined by the uranium-lead (U-Pb) dating technique on zircon crystals that formed when the intrusive granite crystallized (Aleinikoff and others, 2000).

The first strata to be deposited on the granitic "basement" rocks were fluvial deposits that were lithified and metamorphosed to form the quartzite and metasandstone (Zsq), schist (Zss), phyllite (Zsp), and rare marble (Zsm) of the Neoproterozoic Swift Run Formation. The type locality of these rocks is Swift Run Gap in the Shenandoah National Park. The Catoctin Formation which overlies the Swift Run Formation is composed of greenstone or metamorphosed basaltic lava (Zc), light colored metarhyolite (Zcr), and some sedimentary phyllite (Zcs) and marble (Zcm) like that found within the underlying Swift Run Formation. These rocks are named after the greenstone that underlies Catoctin Mountain. The age of the volcanic rocks range from 571 My (a rhyolite dike exposed along the Potomac River opposite MM 52.5) to 565 My (greenstone dated from Shenandoah National Park area) (Badger and Sinha, 1988, Aleinikoff and others, 1995).

The granitic rocks within the core of the anticlinorium were intruded by many greenstone (metadiabase) dikes. These dikes are interpreted as fissures that fed basaltic lava through the granite to extrude on the surface as lava flows on top of clastic sediments that would later become rocks of the Swift Run Formation. The fissures and volcanic activity were the result of rifting of the continent referred to as Laurentia that resulted in the formation of the ancient Iapetus Ocean, approximately 600-545 My ago. Fossil soil, volcanic tuff, and silt and gravel were lithified to collectively make up the rocks of the Loudoun Formation. These rocks represent a dramatic change in the depositional environment.

Fluvial sand and gravel shed from the continent to an eastward shore were lithified to form light and dark quartzite of the Weverton Formation, whose type locality is Weverton Cliffs north of Lock 31. Silty rocks within the quartzite increase stratigraphically upward to form the Harpers Formation (Ch), whose type locality is along the Shenandoah River in Harpers Ferry National Historical Park. These dark fine-grained rocks that form the bold cliffs along the Potomac River at Harper Ferry, W.Va., are probably deltaic deposits (Southworth and Brezinski, 1996a). The siltstones are interbedded with thin beds of sandstone near the top of the formation where the dominant sandstone rocks are called the Antietam Formation (Ca). Named after exposures along Antietam Creek to the north, the tan metasandstone contains the trace fossil *Skolithus linearis*. In rocks of the Antietam Formation in Pennsylvania, *Ollenellus* trilobite is the first shelly fossil recognized in all of the rocks of the Blue Ridge province. Collectively, the Loudoun, Weverton, Harpers, and Antietam formations are part of the Chilhowee Group, named after Chilhowee Mountain, Tennessee, and the *Ollenellus* trilobite is the basis for the Early Cambrian age designation (Stose and Stose, 1944).

The western boundary of the Blue Ridge Province is generally considered to be the contact between the Antietam Formation (Ca) and the adjacent limestone of the Great Valley, which is the overlying Lower Cambrian Tomstown Formation (Ct). The eastern boundary of the province is the foot of the slope ("Piedmont") of Catoctin Mountain, west of the border fault of the Culpeper basin. The complex geologic history of the region is illustrated in fig. 4.

Point of Rocks to Brunswick

MM 48.2 to MM 55

Point of Rocks is a steep bluff of greenstone of the Catoctin Formation exposed where the Potomac River has cut a water gap through Catoctin Mountain (figs. 75 and 76). The Potomac River and flood plain widen as the less resistant rocks of the Piedmont are crossed (fig. 77). This "Point of Rocks" left little room for both a canal and railroad, so a tunnel was excavated through greenstone for the railroad. Just east of the bridge, folded rocks of the Harpers Formation were juxtaposed against Catoctin Formation along a normal fault about 200 million years ago. Greenstone crops out in the middle of the Potomac River and it is the dominant rock exposed from Point of Rocks to Lander (MM 51). At the railway tunnel, greenstone with gas vesicles (fig. 77 B) and intrusive vein quartz were folded and broken by faults (fig. 76 D and E).

The linear creek that drains into the Potomac immediately east of Lander flows along the contact between greenstone of the Catoctin Formation and granitic gneiss. Locally there are small pods of marble (fig. 78) in the greenstone. From here west to Brunswick and beyond to Weverton, the bedrock is granitic gneiss intruded by metadiabase dikes (fig. 79). These poorly exposed rocks can be seen just east of Catoctin Creek in the railroad cut. Quaternary age cobbles and boulders of sandstone and quartzite that litter the embankment here were deposited in an abandoned meander of the Potomac River. The Catoctin Creek Aqueduct collapsed in 1973 due to flood scour. Remains of the aqueduct, which was made of Ellicott City Granodiorite, are present beneath the footbridge. From here to Brunswick is a large railyard that takes advantage of the broad low terrace of the flood plain of the Potomac River.

Brunswick to Fort Duncan

MM 55 to MM 62.5

From Brunswick to Knoxville and beyond to Weverton, the canal and towpath are constructed on a broad low terrace of the Potomac River (fig. 80). Rocks of the Weverton Formation are located at the southern end of South Mountain where the Potomac River eroded through the western limb of the Blue Ridge-South Mountain anticlinorium. This ridge is underlain by folded and faulted quartzite and metasiltstone of the Weverton Formation that are mostly overturned to the west (fig. 81) (Southworth and Brezinski, 1996b). Coarse pebble conglomerate of the Loudoun Formation (fig. 82) is found at the base of the Weverton Formation north of the Potomac River but here only phyllite is exposed. The clasts in the conglomerate are mostly quartz but red jasper and greenstone were probably derived from erosion of the underlying Catoctin Formation. In the lower left part of the photograph along the Potomac are the stone remains of the Weverton Mills constructed in 1834 for manufacturing. The ledge of bedrock in the river and the mill ruins are quartzite. The sandy flood plain from here to Knoxville was the "Hobo jungle" of the depression era.

Just west of Lock 31 is the trace of the Short Hill-South Mountain fault that duplicates the west limb of the Blue Ridge-South Mountain anticlinorium by placing phyllitic metasiltstone of the Harpers Formation (Ch) on garnetiferous leucocratic (light-colored) granite (Ygt) to the west. Like most faults for this region it is poorly exposed. From drill core along Keep Tryst Road north of the canal, the fault was interpreted as an early Paleozoic normal fault that was folded and reactivated as a thrust in the late Paleozoic (Southworth and Brezinski, 1996a and 1996b). This fault is unique to the region in that there is no other evidence of a normal fault and extensional event between the Neoproterozoic (600-545 My) and Jurassic (about 200 My) Periods.

From here westward to Harpers Ferry, the rock sequence crossed from Lander to Weverton (granitic gneiss intruded by greenstone dikes, overlain by greenstone, quartzite, and metasiltstone) is repeated. Outcrops of gneiss and intrusive greenstone dikes are covered with soot along the adjacent railroad tracks to the north, but billion year old folded garnetiferous leucocratic granite can be seen in fresh exposures nearby (fig. 83). A rust-colored massive body of rock exposed near MM 59 is a diabase dike that was intruded when North America was rifting apart to create the Atlantic Ocean; a pyroxene crystal in the diabase here was dated at 200 My using the technique of analyzing the ratio of argon isotopes (Kunk and others, 1992). The flat uplands above the bluffs in Maryland and Virginia resemble river terraces but no deposits have been found. Chips of Ellicott City Granodiorite along the towpath near Lock 32 suggest that some of the dimension stone was transported here from Ellicott City as rough blocks and "dressed" at the site.

The Harpers Ferry area is a spectacular water gap, described by Thomas Jefferson as "worth the voyage across the Atlantic". Stereoscopic aerial photographs show the 3-dimensional perspective of the gorge created where the Potomac and Shenandoah Rivers converge to cross the Great Valley section into the Blue Ridge province (fig. 84).

Maryland Heights and Blue Ridge-Elk Ridge are composed of erosion resistant hard quartzite and metagraywacke of the Weverton Formation and on the bluffs are exposures of folded and faulted rocks and coarse colluvium (figs. 85 to 88). Figure 89 shows the western-most, southward-plunging, overturned anticline exposed during low-water conditions in the Potomac (see also in airphoto of fig. 84). Cross-bedded quartzite provides good criteria for identifying overturned, folded strata (fig. 90). Much of the canal across this section crosses quartzite that required excavation. Local lore holds that fires built on the bedrock were quenched and shattered with cold water hauled from the river. Much like Point of Rocks, a tunnel was required to accommodate both the canal and the B&O railroad. The west portal to the tunnel is along the near vertical contact of the Weverton Formation and stratigraphically overlying Harpers Formation. This point of land at the confluence of the Potomac and Shenandoah Rivers receives extensive erosion during the numerous floods that affect the area. Historical photographs (Hahn, 1995) show many structures of the canal that no longer exist at this location, and the working relationship that existed between the completed railroad and canal.

From here westward to Lock 35 the rocks are highly cleaved and folded metasiltstone of the Harpers Formation (fig. 91). The canal along here was locally excavated in cleaved metasiltstone and outcrops that served as berms retain the marks of drill holes (fig. 92A). Slabs of local colluvium were used to build walls around the outcrops. Near MM 61 is a good example of bedding and cleavage in outcrop along the berm of the canal (fig. 92B). Locally, the cleavage is itself folded by later folding or faulting, such as seen near Hoffmeister Road (fig. 93). The lumpy, swirly pattern in blocks of limestone in Locks 34-36 is interpreted to be bioturbation structures where marine organisms mixed the sediments while they were soft. The few blocks of white Keedysville marble in Locks 34 to 36, are from the base of the Tomstown Formation within the Bolivar Heights Member. Brezinski and others (1996) interpreted this marble to be recrystallized limestone along a regional fault that detached from the underlying sandstone of the Antietam Formation. Basically, all the overlying rocks of the Great Valley section were transported westward along this surface some unknown distance. The fault was early in the tectonic history of the region because it has been folded with the anticlinorium; here it is overturned and dips to the east. From here to Dam 3, stone berms built the canal and towpath above the flood plain.

Near the remains of Dam 3 and behind Lock 35 are good exposures of cleaved metasiltstone interbedded with metasandstone at the transitional contact of the Harpers and stratigraphically overlying Antietam Formation (fig. 94). Perpendicular to the metasandstone beds in the Antietam Formation are dark lines with raised centers that are the trace fossil *Skolithus linearis*. On top of the hill of the meander bend above Lock 36 is the strategic location of Fort Duncan. Built by Union forces in 1862 to defend Harpers Ferry, the outline of the forts ramparts are still preserved.

VALLEY AND RIDGE PROVINCE

GREAT VALLEY

MM 62.5 to MM 110

Fort Duncan to McCoys Ferry

Access: Pleasantville (Harpers Ferry and Hoffmaster Roads), Dargan Bend, Lock 37, Antietam, Lock 38, Snyders Landing, Taylors Landing, Dam 4, Charles Mill Road, Falling Waters Road, Williamsport, Dam 5, Two Locks, Four Locks, and McCoys Ferry

Introduction

The Great Valley (locally called the Shenandoah Valley in Virginia, Hagerstown Valley in Maryland, or Cumberland Valley in Pennsylvania) is the broad area of low relief between the mountainous regions of the Blue Ridge province (east) and Valley and Ridge province (west)(figs. 95 and 96). The Great Valley is underlain primarily by limestone and dolomite, so the valley has abundant caves and sinkholes (see fig. 15).

Structurally, the Great Valley is a large syncline called the Massanutten synclinorium, named after Massanutten Mountain in the core or center of the fold where the youngest rocks are found. The youngest rocks along the C&O Canal in this province belong to the Middle and Late Ordovician Martinsburg Formation and they consists primarily of shale with lesser amounts of sandstone. The eastern flank of the Massanutten synclinorium generally dips southeastward rather than westward toward the center of the syncline; the overturned fold is a limb of the Blue Ridge-South Mountain anticlinorium. Westward across the Great Valley the rocks become less intensely folded and faulted.

The western edge of the Great Valley is where the Cambrian and Ordovician carbonate rocks are thrust onto shale and sandstone of the Valley and Ridge proper, along the North Mountain fault. The rocks of the Great Valley, Blue Ridge, and Piedmont provinces have been transported tens of miles westward along this fault.

Fort Duncan to Antietam Creek
MM 62.5 to MM 69

The bedrock along the meander bends of the Potomac River is the Lower Cambrian Tomstown Formation (Ct) (fig. 96). Between MM 63 and MM 63.5 the outcrop of dark-gray dolomite is the type section of the Fort Duncan Member (Ctf). Some of the rocks here are assigned to the Bolivar Heights Member (Ctbh), whose type section is along the CSXT railroad tracks about l.5 km to the south. The red "terra rosa" soil exposed here characterizes residuum developed from weathered carbonate rock.

Between MM 63.5 and 65.2 shale and thin sandstone of the Harpers Formation (Ch) are exposed. By strict geologic definition these rocks are part of the Blue Ridge province, so along this stretch the boundary between the Blue Ridge and Great Valley provinces is crossed. The lime kiln at MM 65.2 burned high-calcium limestone from the Bolivar Heights Member of the Tomstown Formation (Ctbh) quarried from 1876-1910 just to the west (fig. 97). Near the northeastern part of the quarry is colluvium consisting of sandstone blocks of the Antietam Formation in a red brown mud and clay matrix deposited in a collapsed sinkhole. Blocks of the sandstone and fragments of the limestone contain dark nodular manganese that was discovered here during excavation of the canal and then was quarried and used to make steel (Hahn, 1985). Additional small quarries northward are within the Bolivar Heights Member because the overlying Fort Duncan Member was not suitable for the needs of the lime kiln operators.

Rip-rap fill for the towpath near MM 66 contains blocks of yellow jasper, a variety of quartz, found near the contact of Antietam and Tomstown formations that was prized by Native Americans for making tools.

Immediately south of Mountain Lock (Lock 37) rock of the Bolivar Heights Member was quarried to construct the Lock. The weathered surface of the cut stone has an interesting zig-zag pattern (see fig. 29). These structures are interpreted to be small dolomitized burrows within individual beds of limestone that are folded and aligned along penetrative cleavage. Outcrops of similar rock near MM 67.5 show the similar relationship of bedding, cleavage, and the distorted burrows (fig. 98).

Exposed on the bluff near MM 68 are collapse breccia and deposits of calcium carbonate-rich tufa. Just west of MM 68 is a tight fold within the upper part of the Bolivar Heights Member and bedding is obscured by foliation. This foliation, called cleavage, is well developed within the limestone of the Bolivar Heights Member (see figs. 29 and 98), but is absent within the dolomite of the overlying Fort Duncan Member. Westward are outcrops of massive, light gray dolomite of the Benevola Member (Ctb), and the type section of the medium-bedded dolomite and limestone of the Dargan Member (Ctd), the uppermost member of the Tomstown Formation.

From MM 68.2 northwestward, the flood plain widens and there are no outcrops of the Lower Cambrian Waynesboro Formation (fig. 100) that crosses here. The Waynesboro Formation is made up of three members (Brezinski, 1992): 1) the lower member is interbedded tan sandstone and dolomite named the Red Run Member (Cwar), 2) in the middle is the

Cavetown Member (Cwak) composed mainly of limestone and dolomite, and 3) the uppermost rock is the Chewsville Member (Cwac), comprised of interbedded red shale, sandstone and tan dolomite. Near MM 69 the canal crosses the contact of the Waynesboro Formation and overlying Elbrook Formation that is not exposed.

The Antietam Creek Aqueduct was built in 1834 of limestone and dolomite of the Cavetown Member of the Waynesboro Formation that was quarried about 0.75 miles to the southeast (Davies, 1989). The rock is very finely laminated and was deposited on an intertidal mud flat about 530 My ago. Each lamination is a single tidal cycle or storm event. Blocks along the top of the aqueduct have fossil mudcracks that also formed in a tidal flat environment.

Antietam Creek to Big Slackwater

MM 69 to MM 85.5

From here to Shepherdstown, the Potomac River flood plain is wide and obscures the interbedded thin limestone and shaly tan dolomite of the Middle to Upper Cambrian Elbrook Formation (Brezinski, 1996a) (fig. 101). Abundant algal stromatolites are common in the Elbrook (see fig.114), and good exposures are along the "river road" in West Virginia.

To the north and south the hills are covered by rounded Quaternary age gravel, cobbles and boulders of sandstone and conglomerate. These are river channel deposits left by the Potomac River as it cut down to the modern channel. There are also abundant sinkholes and caves developed in the limestone. Kilns and abandoned quarries of limestone are on both sides of the river near MM 71.5. The Botelers and Reynolds Cement Mill (fig. 102) operated from 1828 to 1834 in West Virginia, and the Potomac Cement Co. operated here from 1888 to 1903 (Davies, 1999).

For the next 13 miles nearly all the bedrock is interbedded gray limestone, tan dolomite and dolomitic limestone of the Upper Cambrian Conococheague Formation. These rocks are characterized by ribbon-like thin layers of gray limestone (0.25 to l.0 inches thick) interbedded with layers of tan dolomite or dolomitic limestone. They are exposed along impressive bluffs that show abundant drill holes and small caves. Near MM 72.6 is the “Shenandoah River Lock” which provided access to Shepherdstown, much like the Alexandria, Goose Creek, and Shenandoah River Locks did to commerce centers to the east.

East of MM 73 on the bluff is “Ferry Hill”, the headquarters of the C&O Canal NHP. On the top margin of the bluffs are large blocks and cobbles of round sandstone and quartzite deposited by the ancestral Potomac in the Pleistocene. These meander bends have extensive exposures on the north, or upstream side where erosion is most severe. In these areas the berms to the towpath are often lined with stone for protection. The south sides of the meanders are more gently sloping and terrace deposits are preserved.

Near MM 75.7 is a large overhang in limestone that is known as Killiansburg Cave, a Civil War shelter, illustrated in fig. 103. There is flowstone, or travertine in the cave, and lots of caves are found between here and MM 76.2 (Davies, 1999). Tufa deposits are in the tributaries near Snyders Landing. The large meander loop known as Terrapin Neck in West Virginia is the location of the new training center of the Department of Interior’s U.S. Fish and Wildlife Service. West of Mercersville the Potomac River cuts across the strike of bedrock in the Conococheague Formation. Between MM 83 and Dam 4 these rocks are tightly folded.

At MM 83.3 the Dam 4 cave, or “Bergen’s cave”, discharges spring water at canal level (fig. 16). In the bluffs at Dam 4, the near flat-lying uppermost limestone of the Conococheague Formation shows drill holes and a stuck drill rod (see fig. 23A). Canal boats used a part of the Potomac River here since the bluffs prevented construction of a canal, like the area to the west.

Big Slackwater to Williamsport

MM 85.5 to MM 99.5

Between Guard Lock 4 and Cedar Grove the towpath experiences severe erosion by floods. This is “the Big Slackwater” and there is no canal. The slow moving “slackwater” allowed canal boats to use the river where steep bluffs of bedrock prevented construction of a canal.

Limestone and dolomite of the Stonehenge and Conococheague formations along this section are well exposed (figs. 105 and 106). There are numerous small caves from MM 86.8 to MM 92 (Davies, 1999).

West of McMahons Mill (built in 1778) at the end of Charles Mill Road are 400 feet of medium-bedded limestone of the Stonehenge Limestone adjacent to a 120 foot wide interval of rock with paper-thin parallel laminations (fig. 107). The calcite and clay laminations in the rocks of the Stoufferstown Member of the Stonehenge Limestone are interpreted to be mylonitic foliation due to faulting.

West to Lock 41 is gray limestone interbedded with tan to brown dolomite of the Middle Ordovician Rockdale Run Formation (fig. 106). These lithologies are repeated in vertical succession from ribbony to sandy limestone to tan laminated dolomite. Although the relative thickness of individual limestone or dolomite beds varies through the succession, the sequence of limestone to dolomite is repeated through the formation. The lithologic cycles reflect a change in depositional environments from shallow subtidal (limestone) to supratidal (dolomite). The cyclicity seen within these rocks indicates that during this time sea level rose and fell with considerable frequency to produce the repeated sequence of lithologies. Original depositional features, such as chert, burrows, cross bedding, graded beds, and ripple marks (fig. 108) occur within the limestones and mudcracks are within the dolomites.

Upstream of Opequon Junction campsite are exposures of folded rocks of the Stonehenge and Rockdale Run formations. There are abundant small caves and dissolution features, like "Dellinger's cave" at MM 92.14 (Davies, 1999). This is the midway point of the 184.5-mile long canal. To the west the rocks belong to the Middle Ordovician Chambersburg Limestone. The stream valley between the two units overlies a thrust fault that placed the rocks of the Rockdale Run Formation above the younger rocks of the Chambersburg Limestone. Springs and tufa deposits are common in this area.

The Chamberburg Limestone is the youngest carbonate rock of the Great Valley and perhaps the most fossiliferous. It contains abundant brachiopods, bryozoans, trilobites, and near its base abundant remains of the echinoderm Echinospherites (fig. 20, *16*).

Westward the Chambersburg Limestone grades into shale of the overlying Martinsburg Formation west of MM 92.5. The Martinsburg Formation consists of gray to brown shale in its lower part and interbedded sandstone and shale in its upper part. This shaley interval marks the end of the depositional epoch that spans Early Cambrian to late Middle Ordovician time when only carbonate rocks were deposited. The environment on the shelf of the continent was similar to that east of Florida today. This stable environment resulted in the deposition of carbonate rock nearly 2 miles thick over a period of approximately 100 million years. Shale of the Martinsburg Formation marked the beginning of clastic-dominated (sandstone-siltstone-shale) deposition that continued through most of the middle and late Paleozoic, over a period of about 200 million years. The initiation of shale deposition also has been interpreted as representing the beginning of the Taconic orogeny, which occurred near the end of the Ordovician Period. This tectonic event formed a mountainous highland in the eastern Piedmont of Maryland that was the source of sand and clay in the Martinsburg Formation.

A small shale quarry marks the contact between the Chambersburg and Martinsburg formations. Scarce fossil remains of the trilobite Cryptolithus and fragments of graptolites occur here. These animals favored habitation within the deepwater environments where shale was deposited. The Martinsburg Formation is the youngest and only non-carbonate rock in the northern Shenandoah Valley and it forms the core of the trough of the Massanutten synclinorium. The axial region, or center, of the Massanutten synclinorium is crossed by the canal near MM 93.5, MM 96, and about MM 100. A dramatic change in land use and physiography in the area underlain by Martinsburg Formation is due to the contrast in materials that result from weathering.

From MM 95 to MM 96.5 are good exposures of shale in the lower part of the Martinsburg Formation. At the footbridge dolomite of the Rockdale Run Formation is thrust faulted above shale of the younger Martinsburg Formation, and rocks of the St. Paul Group and Chambersburg Limestone are missing.

At MM 97.1 piers for the old railroad trestle are made of Triassic red sandstone similar to the Triassic Manassas Sandstone quarried at Seneca, Md. These rocks were most likely quarried from the Gettysburg basin near Emmittsburg, Pa., and were transported here by railroad.

Limestone of the Stonehenge Limestone is exposed from MM 97 to MM 99 near Williamsport. Immediately east of the power plant, shale of the Martinsburg Formation is exposed beneath the same fault encountered near Lock 43 and the footbridge west of MM 97. This regional fault can be traced northward into Pennsylvania and southward into West Virginia. The steel drawbridge north of the power plant allowed coal trains to cross the canal to supply the plant.

Cushwa basin at the C&O Canal visitor center at Williamsport was a transfer station for canal cargo, principally coal from west of Cumberland (fig. 109). Like the basins at Seneca and Cumberland, these were large "parking lots" for canal boats and barges to load or unload cargo. High (1997) provides a great photograph (NPS) of a canal boat that crashed through the Conococheague Creek Aqueduct in 1920.

Williamsport to McCoys Ferry
MM 99.5 to MM 110

Over the next two miles the wide flood plain of the Potomac River is coincident with the outcrop belt of the Martinsburg Formation (fig. 110). Along the CSXT railroad tracks are dark gray incompetent silty shale of the lower member of the Martinsburg Formation that was folded and faulted more easily than the adjacent competent carbonate rocks. Approximately 2000 feet of shale grades upward into more sandy beds that mark the base of the upper member. The upper member of the Martinsburg Formation consists of gray, silty shale interbedded with gray to brown, fine to medium-grained sandstone. The sandstone beds are typically less than 1 foot thick (fig. 111A) in the lower part of the member and become increasingly thick up stratigraphic section so that they may be more than 20 feet thick near the top of the formation. The thin beds lower in the upper member exhibit basal scours and lineations suggesting that they were deposited in episodes of high-energy (fig. 111B). These sandstones are interpreted as distal deposits of deep water turbidity currents (McBride, 1962). The thicker sandstones, higher in the member, were deposited in shallower water, more proximal to the sand source, as the depositional basin was filling.

Near MM 102 is a small shale outcrop that marks the last of the eastern limb or flank of the Massanutten synclinorium. From this point westward to McCoys Ferry (MM 110) are the same bedrock formations that occur on the eastern flank of the fold. Rocks underlying the western limb of the synclinorium were not as severely deformed as those of the overturned eastern limb, therefore sedimentary structures and fossils are better preserved.

Westward from MM 102 to MM 103.2 are some of the best rock exposures along the Potomac River. This is a nearly continuous bedrock exposure starting near the base of the Martinsburg Formation and descending stratigraphically (westward) to the top of the Stonehenge Limestone (fig. 112).

Outcrops along here are wavy to nodular bedded, medium to dark gray, fossiliferous limestone of the Chambersburg Limestone (Oc) that is shaly at the base near the eastern wall of the quarry to the north. Westward the more gently dipping strata are part of the St. Paul Group (including the Row Park and New Market Limestones) that are being quarried. The St. Paul Group (Osp) consists mainly of thick-bedded, light-gray limestone with thin interbeds of tan dolomite. Underlying the St. Paul Group is an interval of gray, fractured dolomite of the Pinesburg Station Dolomite (Ops). These strata are exposed at the parking area at MM 103.2. Along the meander known as Millers Bend are scattered outcrops of folded rocks within the Conococheague and Stonehenge formations.

Beginning at Dam 5 (fig. 112) is a section of the upper Rockdale Run, Stonehenge, Conococheague, and the Elbrook formations. At Dam 5 and Lock 45 the rocks exposed are the Cambrian Conococheague Formation. Quaternary boulders and gravel litter a low river terrace. Approximately 1000 feet west of Lock 45 the rocks are highly cleaved due to a southeast-dipping thrust fault that places rocks of the Conococheague Formation on rocks of the Rockdale

Run Formation. Immediately west are the underlying rocks of the Stonehenge Limestone and a complete section is exposed from here (top) to the area between Locks 46 and 47 (base). From Lock 47 westward the Conococheague Formation is exposed relatively continuously to MM 108 where the upper strata of the underlying rocks of the Elbrook Formation occur in an anticline. Laminated limestone with mudcracks is exposed near MM 107.8 (fig. 113). Rocks of the Conococheague Formation are exposed all the way to Four Locks in a broad syncline (fig. 112).

At "Four Locks", canal boats were lifted to pass through the neck of a meander thereby obviating about 4.5 miles of canal construction. The elevated valley is an abandoned Pleistocene channel of a former tributary to the river. Shaly and algal limestones with stromatolites (fig. 114) exposed near the North Mountain campsite characterize the Elbrook Formation along the western limb of the Massanutten synclinorium (Brezinski, 1996a).

At MM 110 is an outcrop of very light gray to white quartzite of the Lower Silurian Tuscarora Quartzite (fig. 115). Intervening between the quartzite and the limestone of the Middle Cambrian Elbrook Formation is perhaps the most regionally significant thrust fault in the central Appalachian region. The North Mountain thrust fault has transported all of the rocks between here and Georgetown, D.C., westward over Silurian and Devonian age rocks.

For the next 74.5 miles to the western terminus of the canal at Cumberland the Potomac River transects the Valley and Ridge Province proper.

West of the North Mountain Fault

MM 110 to MM 184.5

McCoys Ferry to Cumberland

Access: McCoys Ferry, Fort Frederick State Park,
Big Pool, Little Pool, Hancock, Cohill,
Woodmont, Pearre, Little Orleans, Green Ridge/
Kasecamp Road, Twigg Hollow Road, Paw Paw Tunnel,
Keifers, Town Creek, Oldtown, Spring Gap, North
Branch, Wiley Ford, and Cumberland

Introduction

The Valley and Ridge Physiographic Province west of the Great Valley consists of Ordovician to Permian age sandstone, siltstone, shale, and limestone, that were folded into anticlinoria and synclinoria west of the North Mountain thrust fault during the Alleghanian orogeny (fig. 116). Silurian, Devonian, and Mississippian age rocks are exposed along the C&O Canal; Ordovician age rocks are exposed in the core of the Wills Mountain anticline west of Cumberland, and Pennsylvanian and Permian age rocks are exposed on the Plateau further to the west. Anticlinoria and synclinoria are major folds that are composed of smaller subsidiary anticlines and synclines. The limbs of the anticlinoria are underlain by resistant quartzite (Silurian Tuscarora) and sandstone (Devonian Oriskany) that make up ridges. These rocks exhibit bedforms such as ripple marks, cross beds, and worm burrows (*Skolithus linearis*) that indicate a beach environment that is similar to those found along the Atlantic Coast today. Most of the younger rocks are Devonian in age and consists of siltstone and shale that form mostly broad valleys with low ridges underlain by sandstone. The youngest rocks are the Mississippian Rockwell and Purslane formations that are preserved in the Sideling Hill syncline. These rocks underlie Sideling Hill, and are best exposed in the I-68 road cut at the landmark visitor center of the Maryland Geological Survey.

The oldest rocks within the map area are shale and sandstone of the Ordovician Juniata

Formation exposed in the core of the Wills Mountain anticline in the "Narrows" water gap northwest of Cumberland. Silurian and Lower Devonian rocks are exposed on North Mountain in the footwall of the North Mountain thrust fault and in anticlinoria (east to west) known as the Cacapon Mountain anticlinoria (between Tonoloway Ridge and Warm Springs Ridge), Irons Mountain anticline of the Patterson Creek anticlinoria, as well as Wills Mountain anticline (fig. 116). The mostly Middle and Upper Devonian siltstone and shale units are exposed (east to west) in the Meadow Branch synclinoria, Sideling Hill syncline, Whip Cove anticlinoria, Town Hill syncline, and the Evitts Creek syncline. Erosion on these rocks and their structures make up the classic namesake Valley and Ridge physiography.

The oldest rocks exposed along the C&O canal west of North Mountain are Silurian that range in age from about 443 to 418 My (Tucker and others, 1998). Shale and sandstone of the Rose Hill Formation (Srh) are exposed along the canal at Leopards Mill. These rocks are overlain by white Keefer Sandstone (Sk), which is overlain by shaly limestone of the McKenzie Formation (Sm), and in turn, is overlain by red shale and sandstone of the Bloomsburg Formation (Sb).

The Lower Silurian clastic rocks are overlain by Upper Silurian limestone and shale of the Wills Creek (Sw) and Tonoloway formations (Stw), and limestones of the Keyser Limestone and Helderberg Group (DSkh). The boundary between the Silurian and Devonian period is within the Keyser Limestone of the Helderberg Group. These rocks record a shallow marine sea that transgressed over and submerged much of the Appalachian basin during the Late Silurian.

Devonian rocks range in age from about 418 to 362 My and consist of the Oriskany Sandstone (Do), Needmore Shale and the Marcellus Formation (Dmn), and the Mahantango (Dm), Brallier and Sherr (Db), Foreknobs (Df), and Hampshire (Dh) Formations. The boundary between the Devonian and Mississippian periods is within the Rockwell Formation (MDr), the youngest rocks exposed along the C&O canal in the Valley and Ridge. Sideling Hill and Purslane Mountain are underlain by younger rocks (350 My) of the Mississippian Purslane Sandstone (Mp). The Oriskany Sandstone is interpreted as a beach sand deposited during the regression of the sea that deposited the underlying limestone of the Helderberg Group. Overlying the Oriskany Sandstone are shale, siltstone, and sandstone of the Needmore, Marcellus, and Mahantango formations that were deposited as turbidites as another Early Devonian sea transgressed over the region. During the Late Devonian, regional regression of the sea led to the development of a broad swampy lowland with deltas and rivers. Some of these rivers carried debris from a rising highland to the east that may have resulted from a tectonic event called the Acadian orogeny. Fragments of metamorphic rocks and granitic gneiss that constitute a diamicton, or bouldery deposit, at the Devonian-Mississippian boundary at the Sideling Hill cut along I-68, may be derived from rocks of the Blue Ridge and Piedmont that were exposed as the result of this orogeny.

All of the shale, siltstone, and sandstone of Devonian age that was deposited above the Oriskany Sandstone is a rather monotonous section of rock. The turbidite deposits are not laterally extensive and there are abundant facies changes both along and across strike that make defining unit contacts difficult. The transitional nature of these units and the inconsistent definition and mapping of them is seen in the many different versions of the published geology.

The Ordovician to Mississippian rocks were folded and faulted during the late Paleozoic Alleghanian orogeny when the North American tectonic plate collided with the African tectonic plate. The resultant forces folded the rocks and transported them westward above thrust faults that are in the subsurface (figs. 4 and 116).

McCoys Ferry to Licking Creek Aqueduct

MM 110 to MM 116

Along this section of the canal, the Potomac River has eroded a broad flood plain with sloping terraces along the north shore that overlie mostly shales and siltstones of Devonian age (fig. 117). Several anticlines underlain by the resistant Oriskany Sandstone form the mountains to the north. The folds plunge south toward the river valley. Abundant colluvium of sandstone mantles the ridge slopes. The combination of colluvium and alluvium on the lower slopes forms an extensive Quaternary deposit that conceals most bedrock. The bedrock is mostly shale, siltstone, and some sandstone of the Marcellus, Needmore, Mahantango, Brallier, Foreknobs, and Hampshire formations. The only bedrock exposed along the canal, however, is black shale of the Devonian Brallier Formation that was excavated near MM's 119 and 120. The rest of the canal along this section was excavated in alluvium.

Unique to the C&O Canal, Big Pool (MM 112.5 to MM 114) and Little Pool (MM 120.5 to 121.4), are areas where the engineers used the swamps of the broad flood plain to make the canal. Levees were constructed and water was impounded within the enclosed swampy lowland. Much of the towpath was raised to prevent repeated damage from floods. Large boulders of sandstone that remain along the lower terrace near MM 111 are evidence of ancient floods in the region. Similar boulders litter the uplands as much as 140 feet above the current river level, and were used as building stone for the construction of Fort Frederick in 1756, north of MM 112 (fig. 118). The swampy area near the campground at Fort Frederick is probably what the areas near Big Pool (fig. 119) and Little Pool looked like prior to canal construction.

Licking Creek Aqueduct to Round Top Cement Mill

MM 116 to MM 127.5

Fossilized mudcracks, similar to those shown in figure 113, occur on top of several limestone blocks at Licking Creek Aqueduct (~MM 116)(fig. 120A). Between the aqueduct and the I-70 overpass, limestone and chert of the Upper Silurian Helderberg Group (fig. 120B) are thrust on shale of the Devonian Mahantango Formation. From here to Tonoloway Creek Aqueduct (fig. 121) the canal was excavated in alluvium and the only rock exposed is shale of the Brallier Formation at MM 119 (fig. 122) and Foreknobs Formation at MM 120. Near MM 122, shale and siltstone of the Brallier and Foreknobs formations (fig. 123) in the Meadows Ground syncline is crossed. At the southeast abutment of the Tonoloway Creek Aqueduct (MM 123) is an outcrop of sandstone of the upper part of the Foreknobs Formation. This is a good example of the geomorphology of the flood plain. The modern flood plain is deposited on shallow bedrock that was leveled by the meandering river; the bedrock is later exposed by downcutting of the tributary Tonoloway Creek. To the immediate north is the NPS Hancock visitor center. Hancock is situated on the east limb of the Cacapon Mountain anticlinorium (fig. 121), a regional-fold that extends for over 45 miles from Virginia to Pennsylvania.

The east limb of the Cacapon Mountain anticlinorium is Warm Springs Ridge underlain by Oriskany Sandstone. This pure quartz sandstone is quarried commercially in West Virginia for making glass. The Oriskany Sandstone is also a major subsurface reservoir for natural gas throughout the central Appalachians. Natural warm water springs, such as Berkeley Springs to the south, are situated where radiogenically-heated groundwater rises within the sandstone and discharges at the surface. Stratigraphically above the Oriskany Sandstone is dark fissile shale of the Marcellus and Needmore formations that contain nodules of limestone (fig. 124).

The Potomac River has eroded through and deposited alluvium on the Oriskany Sandstone and older rocks from Little Tonoloway Creek west to MM 127. Southeast of MM 126 are white cliffs of Oriskany Sandstone at “Lovers Leap”. North of the canal near MM 127 (west of White Rock campsite), the creek flows across broadly folded beds of white sandstone. But these “white rocks” are Silurian Keefer Sandstone.

At about MM 127.5 are the remains of the Round Top Cement Mill (fig. 38) and some of the best outcrops of folded and faulted rock in this region. As summarized by Glaser (1987), the studies of these folds, cleavage, and faults here and along the abandoned railroad cut above the canal by Cloos (1951, 1958, 1964) and Geiser (1970, 1974) have advanced our understanding of the mechanisms of structural geology. The anticline called the “Devils Eye Brow” (figs. 125 and 127) and adjacent folds (fig. 128), are in red sandstone, siltstone, and shale of the Silurian Bloomsburg Formation. Calcareous shale and limestone has weathered away to form a cave-like recessed area in the hinge area of the “Devils Eye Brow” anticline (fig. 127). Limestone, with high calcium content, of the overlying Silurian Wills Creek Formation was mined (fig. 129) and processed for cement beginning in 1837.

Round Top Cement Mill to Sideling Hill Aqueduct

MM 127.5 to about MM 137

From here to MM 133 the Potomac River meanders through some complexly folded rocks in the core and along the northwest limb of the Cacapon Mountain anticlinorium (fig. 129). The nearly flat-lying rocks excavated along the canal northeast of Leopards Mill indicate that this is the axial region or crest of the main anticline. The oldest rocks, Early Silurian Tuscarora Quartzite, are exposed opposite the river near Sir Johns Run. Along the road and creek northwest of MM 130, are outcrops of sandstone and shale of the Rose Hill Formation (fig. 130) and Keefer Sandstone; elsewhere Quaternary colluvium and alluvium underlie the gentle slope and cover bedrock. Near MM 131.8 are drill holes in bedrock from excavation of the canal.

The Potomac River cuts across strike from near MM 133 to the Sideling Hill syncline near MM 137 (fig. 131). From MM 133 west to Dam 6 and Tonoloway Ridge are folded Silurian and Devonian rocks on the northwest limb of the Cacapon Mountain anticlinorium (fig. 132). Near MM 133 is an anticline of tan Keefer Sandstone (fig. 133A). There are drill holes oriented perpendicular to the beds and tube-like lines of trace fossil Skolithus linearis (fig. 133B). Also present here are thrust faults that truncate beds of sandstone (fig. 133C). The intricately folded rocks along this section of the C&O Canal (fig. 134) are best exposed to the south along the Cacapon River at Fluted Rocks, W.Va. Here the folds are secondary to the larger fold that underlies Cacapon Mountain to the east where white quartzite of the Tuscarora Quartzite is exposed. The folds at "fluted rocks" show how contrasting rock types, such as sandstone and shale, respond differently to deformation. Differences in the geometry of the folds (Lessing, 1988)(fig. 135) reflect this competency contrast. In the Potomac River near MM 133.5, Davies (1999) noted a fish weir made by Native Americans.

Resistant cherty fossiliferous limestone of the Helderberg Group (fig. 136) overlain by Oriskany Sandstone underlie Tonoloway Ridge west of MM 134. The Oriskany Sandstone was quarried locally for silica-rich sand and dimension stone. And like Dam 3 at Harpers Ferry, feeder Dam 6 was built above resistant sandstone ledges and shallow falls. Outcrops of sandstone with fossil brachiopod molds (fig. 137) form the base to the dam abutment. The original dam was a timber crib filled with sandstone rubble and then covered with wooden planks, but only rubble remains (fig. 36). Opposite Dam 6 are impressive fluvial terraces of both the Potomac and Cacapon Rivers.

Stratigraphically above the Oriskany Sandstone are shale, siltstone, and sandstone turbidite deposits of the Needmore and Marcellus formations (fig. 138). Westward from here, the siltstone and sandstone is folded (fig. 139) (Cloos, 1947). The axial region of the Sideling Hill syncline is crossed at the Sideling Hill Aqueduct. This syncline is best exposed along the I-68 road cut (fig. 140). The east end of the aqueduct is made up of sandstone taken from the adjacent outcrop of the basal part of the Rockwell Formation (fig. 141). These are the youngest rocks seen along the C&O Canal west of Point of Rocks. The best exposures of the Devonian and Mississippian rock are along the abandoned railroad just north of the canal.

Sideling Hill Aqueduct to Paw Paw Tunnel

MM 137 to MM 156

The large fold structure of this region is called the Broadtop synclinorium and it occurs between the Cacapon Mountain anticlinorium (MM 133) and the Broadtop anticlinorium (MM 167 at Oldtown) (fig. 113). The Broadtop synclinorium is comprised of numerous secondary folds like the Sideling Hill syncline, Whip Cove anticline, and several unnamed folds. The Potomac River meanders across the rocks of the Broadtop synclinorium to form the incised meanders of the “Paw Paw bends” (fig. 116). A composite geologic sketch shows parts of the structure (figs. 142 and 143). From MM 137 to MM 138 are east-dipping rocks of the Devonian Hampshire Formation on the west limb of the Sideling Hill syncline. West of Indigo Neck campsite are the underlying rocks of the Foreknobs Formation. From about MM 140 west to the old railroad bridge are folded rocks of the Late Devonian age Brallier and Sherr formations that comprise an anticlinorium. A detailed sketch of these folds and a photograph and tracing of a tight anticline exposed west of MM 143 is also shown in fig. 142. Like the "Devils Eye Brow" anticline at Round Top, the hinge of this anticline forms a "cave", or overhang. In this region, the shale bedrock and thin soil forms a unique ecosystem called "shale barrens". Plants like cactus prefer the stratum and relatively dry climate. Westward there are large folds of rock exposed along the cliffs at MM's 145, 152 and 154.

Beyond Lock 62 is perhaps the most famous man-made structure associated with the C&O Canal, the Paw Paw Tunnel. The approach to the tunnel follows the route of a former tributary through 3 lift locks that have fraction designations. Building the tunnel was a solution to bypass the construction of a canal along bedrock cliffs on 4 meanders of the Potomac River. So in order to retain the lock numbering system to the west, fraction numbers were required for the additional locks that had not been planned for. South of Lock 65 near MM 155, the bedrock was excavated at an oblique angle to folded shale and sandstone beds. A cross section of the anticline is exposed at the north portal to the tunnel (fig. 37). The towpath cuts across the axis of the fold, but it mostly follows the northwest limb of the anticline and the beds dip toward it (fig. 144A). Steel rock bolts prevent bedrock landslides along bedding planes onto the towpath. On the opposite wall of the canal the rocks dip ***into*** the slope. These rocks break along joints and fall into the canal. These slope failures suggest that the 12 year construction of the 3,118 foot tunnel was both a major accomplishment and hazardous. Exposed along the towpath are ancient mud cracks that are accentuated by cleavage that refracts through them (fig. 144B). The shale beds have fossil burrows and tracks (fig. 144C) made by Devonian age organisms that crawled in the mud before it was lithified. Slickensides of vein quartz parallel to beds formed as the beds flexured and slipped during folding (fig. 144D).

Paw Paw Tunnel to Old Town

MM 156 to MM 167

West of the exit of the Paw Paw Tunnel, the area is underlain by the same Devonian shale, siltstone, and sandstone seen from here to near Woodmont (MM 135) (fig. 145). Abandoned incised meanders and gravel deposits are present from the ancestral Potomac River, Little Cacapon River, and tributaries at Purslane Run (MM 157.3) and Reckley Flat (around MM 159) (figs.12 and 146) (see the discussion in the section on **Abandoned Entrenched Meanders)**. Folds on the west-dipping, east limb of the Town Hill syncline are seen at MM 159.5 before the axial region (center) is crossed about MM 161. From here to Lock 68 (Crabtrees Lock), the Devonian rocks dip east on the west limb of the Town Hill syncline.

The Potomac River as such begins at the confluence of the South Branch Potomac River and the North Branch Potomac River west of MM 164.5. Like the Cacapon (MM 133.5) and Little Cacapon (MM 159) Rivers, there are impressive incised meanders near the confluence of these major tributaries and the Potomac River. Near MM 161.5 the canal and towpath cross the axial region of the Town Hill syncline. Red fissile shale and thin sandstone (fig. 147) and cross bedded sandstone deposited as channels are rocks of the Devonian Hampshire Formation.

West at MM 165 the Potomac River has cut through an anticline of the Devonian Oriskany Sandstone and parts of the northwest-dipping flank were drilled and blasted to create the canal (fig. 148). Note the pine trees and mountain laurel that prefer to grow on the thin sandy soil. From this position the canal diverges from the Potomac River west to Oldtown, an early settlement and river crossing for the 5 Nation Great Warrior Path.

Oldtown to Spring Gap

MM 167 to MM 173.5

West of Oldtown the Potomac River cuts across the strike of Devonian rocks that form an unnamed syncline to rocks of the Patterson Creek anticlinorium (fig. 149). The canal at Oldtown was excavated in shale in an abandoned valley of Mill Run because there are bluffs of shale along the Potomac River that prevented construction of a canal and towpath. North of MM 168, the canal ***and towpath*** were excavated (fig. 40B, **Engineering** section) through fissile shale of the Devonian Marcellus and Needmore formations to rejoin the bank of the Potomac River. From here west to Spring Gap the area is characterized by shale barrens and a broad flood plain developed on an anticline and syncline. There are good outcrops of folded shale of the Brallier Formation on the limb of the syncline near MM 172 (fig. 150). Anticlines underlain by resistant Oriskany Sandstone that are crossed near Spring Gap are part of the Patterson Creek anticlinorium.

Spring Gap to Cumberland
MM 173.5 to MM 184.5

North of MM 174 are alluvial terrace deposits left when the Potomac River flowed almost a hundred feet higher in elevation than at present (fig. 151). Oriskany Sandstone and the underlying limestone of the Helderberg Group are exposed again at MM 175. From the west flank of the westernmost anticline the Potomac River meanders across the Devonian shale and siltstone of the broad Evitts Creek-Bedford syncline.

For the next 3 miles the canal crosses a large meander of the Potomac River known as Mexico Farms. The surface of the meander contains large rounded boulders of sandstone deposited by a former Pleistocene river level. To the south above the Potomac River is an elevated incised meander called Death Valley. And to the north the municipal Airport and Cumberland are built on similar elevated terraces. North of MM 180 are excellent cuts that reveal Quaternary alluvial deposits on bedrock that are hundreds of feet above the current river level (see fig. 11). From MM 181 to the visitor center at Cumberland the canal follows a meander bend and the only bedrock exposed is shale of the Brallier and Sherr formations near MM 184.

Historical photographs are all that remains to show what this region looked like when the canal was in operation (fig. 152) because much has been removed and filled in. To many, this outpost on the western frontier was where the C&O Canal ***started,*** with coal-filled canal boats on their journey east to supply the national capital region with heating fuel.

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FIGURES

Figure 1. Index map of the C&O Canal, geologic provinces, and the Potomac River basin.

Figure 2. Historical map showing the Patowmack Company's skirting canals and locks, iron and manganese prospects and furnaces, limestone quarries, mills, kilns, foundries and armory associated with early commerce along the Potomac River. Inset on lower left shows the U.S. canal system in 1850 (NPS, 1991). Inset on upper right shows the canals and Potomac River near Washington, D.C., in 1771 as shown by Pierre L'Enfant (Hall, 1991). The C&O Canal in Georgetown, D.C., Alexandria Aqueduct, and Alexandria Canal shown were built by 1843.

Figure 3. Tectonic map of the study area.

Figure 4. Diagrammatic sketches showing the geologic history of the Potomac River valley over the past 1 billion years. A) intrusions of granitic gneiss, metamorphism, and deformation related to the Grenvillian orogeny lasted 60 Million years from 1.1 billion to 950 million years ago. These rocks are found in the Blue Ridge province. B) Continental rifting and volcanic activity in the Grenville terrane (current Blue Ridge province), and turbidites deposited in deep water basin to the east (current Piedmont province), lasted about 200 Million years, from about 770 to 575 Million years ago. C) The margin of the continent became stable with carbonate rocks deposited in quiet water (rocks of the current Great Valley and Frederick Valley). To the east (current Piedmont province), thrust sheets of the turbidite deposits create a sedimentary mélange. Shelly fossils appear about 545 Million years ago. D) Deep water rocks were deposited into a basin east of the shelf margin for about 65 Million years (current western part of the Piedmont province). E) The stable shelf floundered as the Taconic orogeny (480-460 Million years ago) elevated the rocks to the east and provided a source for the clastic material that make up the shale of the Martinsburg Formation (current center of the Great Valley). Rocks in the Piedmont province were intruded by plutonic rocks (near Georgetown) and transported westward along the

Pleasant Grove and Martic thrust faults. F) A thick sequence of sedimentary rocks were deposited in a deepening Appalachian basin for 120 Million years. Most of these rocks are now found in the Valley and Ridge province. About 370 Million years ago igneous rocks were intruded in rocks near Great Falls. G) About 240 Million years ago, the continental tectonic plates of North America and Africa collided, resulting in the Alleghanian orogeny. Many of the folds and faults in rocks west of the Piedmont province are related to this event. H) About 20 Million years later, continental rifting began and lasted for about 20 Million years (220 to 200 Million years ago). Thick sequences of sedimentary rock were deposited in fault-bounded basins, there was volcanic activity, and the end result was the creation of the Atlantic Ocean. The Culpeper and Gettysburg basins in the western Piedmont are the result of this event. I) For the last 200 Million years, the landscape has eroded and rivers have carried the sediment eastward to deposit the thick strata of the Atlantic Coastal Plain. J) Further erosion has removed much of these extensive Coastal Plain deposits and further sculptured the bedrock to create the modern landscape. Some patches of Coastal Plain deposits remain near the Fall Zone of the Potomac River.

Figure 5. Alluvium and alluvial terraces of the Potomac River. The alluvium underlies the modern flood plain.

Figure 6. Stacked schematic cross sections of the Potomac River valley at Cumberland and Georgetown, showing the change in terrace morphology, topographic elevation, and surficial deposits along its course. Evidence that the Potomac River migrated across the valley is best preserved at Cumberland, Paw Paw bends, Williamsport, and near Seneca, where terrace gravels are preserved on shale bedrock. The modern flood plain is also greatest at Cumberland and Seneca.

Figure 7. Recent alluvium along the Potomac River near Monocacy River consists of gravel, sand and silt, as much as 20 feet thick.

Figure 8. Illustration showing large water-filled potholes and channels on Bear Island, near Great Falls and Widewater. Interpreted from 5 foot contour topographic map of NPS.

Figure 9. A) Potholes in migmatite of the Mather Gorge Formation along the bluff of Mather Gorge. Sixteen foot canoe for scale; arrows point to close up of the pothole shown in B) (photo by Dave Usher, USGS).

Figure 10. Aerial photograph of fish weirs constructed by Native Americans. The weirs are alluvial boulders piled about 3 feet high on the bed of the Potomac River.

Figure 11. A) Quaternary fluvial terrace deposit of the Potomac River in the Valley and Ridge province near Cumberland, Md., near MM 180. The large boulders of sandstone are 1 meter across. B) A large boulder of quartzite (Cambrian Weverton Formation of the Blue Ridge?) was deposited on a terrace about 65 feet above and 1 mile away from the Potomac River.

Figure 12. Planimetric sketches (A-C) and surficial map (D) illustrating the evolution of the abandoned incised meanders of the Potomac and Little Cacapon Rivers near Paw Paw, W.Va. (centered on MM 157), that probably occurred within the past 1,000,000 years.

Figure 13. Schematic illustration of the Great Falls of the Potomac River showing the evolution of the abandoned channel of Widewater and the island of Glade Hill, Va., from before the Ice Age to the present channel incised into Mather Gorge (modified after Reed and others, 1980).

Figure 14. Rounded boulder (5 feet diameter) of diabase deposited by the Potomac River on top of Glade Hill, approximately 135 feet above the present river level. (photo by Dave Usher, USGS).

Figure 15. Map showing the distribution of caves and sinkholes, and carbonate rock susceptible to the development of karst landforms along the C&O Canal.

Figure 16. Looking in A) and out of B) the "Dam 4 cave". The cave and emergent spring are in limestone of the Conococheague Formation near MM 83.5.

Figure 17. Fossils from the rocks of the Frederick Valley, western Piedmont Province.
1-5 are trilobites and 6-9 are conodonts. 1.- Olenellus, from the Araby Formation. 2.- Plethometopus, Grove Formation. 3.- Rasettia, Grove Formation. 4.- Westonaspis, Frederick Formation. 5.-Acmarachis, lower Frederick Formation. 6.- Proconodontus, Frederick Formation. 7.- Clavohamulus, Grove Formation. 8.- Cordylodus, Grove Formation. 9.- Rossodus, Grove

Formation. Repetski, USGS, unpublished data.

Figure 18. Dinosaur tracks in the Balls Bluff Siltstone exposed in the Culpeper Crush Stone Quarry, Va., are of the three-toed kayentapus, a carniverous dinosaur.

Figure 19. Brachiopod shell fragments from A) the Silurian McKenzie Formation, and internal molds of brachiopods in the Devonian B) Oriskany Sandstone and C) Foreknobs Formation.

Figure 20. Key index fossils that are present in the rocks found along the C & O Canal of the Valley and Ridge Province. 1.-Glossopleura. 2.-Elrathina. 3.-Modocia. 4.-Genevievella. 5.-Crepicephalus. 6.-Ptychaspis. 7.-Calvinella. 8.-Pseudosaratogia. 9.-Bellephontia. 10.-Homagnostus. 11.-Finkelburgia (from Sando, 1957). 12.-Diphelasma (from Sando, 1957). 13.-Ophileta. 14.-Diparelasma (from Sando, 1957). 15.-Calliops. 16.-Echinospherites. 17.-Rhinidictya. 18.-Strophomena. 19.-Hebertella. 20.-Orthorhyncula. 21.-Diplograptus. 22.-Rafinesquina. 23.-Byssonychia. 24.-Schuchertella. 25.-Uncnulus. 26.- Atrypa. 27.-Hormatoma. 28.-Hormatoma?. 29.- Cyathophyllum. 30.-Dolichopterus. 31.-Gypidula. 32.-Stropheodonta. 33.- Camarotoechia. 34.- Calymene. 35.- Leperditia. 36.-Leptaena. 37.-Favosites. 38.-Schuchertella. 39.-Meristella. 40.-Stropheodonta. 41.-Tentaculites. 42.-Spirifer. 43.-Cypricardinia. 44.-Loxonema 45.-Polypora. 46.-Cyclonema. 47.-Palaeoneilo. 48.-Spirifer. 49.-Cyclonema? 50.-Pterinea. 51.-Productella. 52-Mucrospirifer. 53.-Loxonema? 54.-Leptodesma. 55.-Dalmanella. 56.-Rugosochonetes. 57.-Macropotamorhyncus.

Figure 21. -Key guide-conodonts to the strata of the Valley and Ridge Province. 1.- Phakelodus. 2.- Westergaardodina. 3.- Proconodontus. 4.- Cambrooistodus. 5.- Hirsutodontus. 6.-Cordylodus. 7.- Loxodus. 8.,9- Rossodus. 10.- Scolopodus. 11.- Eucharodus. 12.- Oepikodus. 13.- Diaphorodus. 14.- Tropodus. 15.- Colaptoconus. 16.- Histodella. 17.- Cahabagnathus. 18.-Leptochirognathus. 19.- Appalachignathus. 20.- Amorphognathus. 21.- Plectodina. 22.-Phragmodus. 23.- Panderodus. 24, 25.- Oulodus. 26, 27.- Ozarkodina. 28, 29.- Icriodus. 30, 34, 37.- Polygnathus. 31.- Mesognathus. 32, 35.- Ancyrodella. 33.- Palmatolepis. 36.- Delotaxis. John Repetski, USGS, unpublished data.

Figure 22. Map showing locks, aqueducts, and the dominant building stone used (see table 1),

known quarries, areas that the canal, towpath, and tunnel were excavated (drilled and blasted) through bedrock (black), and areas where the canal was excavated (dug) in alluvium (dotted). The Potomac River was used from near MM 86 to MM 88 (Big Slackwater), and near Dam 5, so no canal was constructed there.

Figure 23. Evidence of excavated bedrock includes A) drill holes and drill rod stuck in limestone in cliffs about 50 feet above Slackwater (MM 84), and B) drill holes in metagraywacke over 50 feet above the canal at Blockhouse Point (MM 21). C) Historical photograph (NPS) shows that bedrock excavated for the Western Maryland Railroad (on left) was used to fill the towpath of the C&O Canal east of Oldtown.

Figure 24. A) Blocks of Cretaceous Potomac Formation, "Aquia Sandstone" in Lock 6, show B) cross bedding and rounded clasts of quartz (penny for scale). C) Mules pulled canal boats by rope that made grooves in the friable sandstone.

Figure 25. A) "Seneca Red Sandstone", (Triassic Poolesville Member of the Manassas Sandstone) was drilled and quarried for dimension stone as seen along the bluffs west of Seneca, and B) the dressed blocks can be seen in the ruins of the Seneca Stone Cutting Mill.

Figure 26. A) East end of Lock 24 (Riley' Lock) showing smooth (wire saw) and rough cut (hammer dressed) red sandstone. B) close-up of rough-cut "Seneca Red Sandstone" shows beds of finer-grained siltstone within sandstone with granular texture of quartz sand and white feldspar grains.

Figure 27. A) Blocks of Ordovician Ellicott City Granodiorite in Lock 28. B) The non-foliated igneous rock has a crystalline texture of amphibole (dark) and feldspar (light) crystals.

Figure 28. A) Blocks of quartzite of the Lower Cambrian Weverton Formation of Lock 31. B) Some of the rocks are vitreous orthoquartzite and C) some are granular quartzite.

Figure 29. A) Blocks of limestone of the Lower Cambrian Bolivar Heights Member of the Tomstown Formation at Lock 37 (Mountain Lock). B) enlargement shows beds (vertical) and burrows accentuated by cleavage (horizontal). C) Elsewhere in the Valley and Ridge, thin-bedded, laminated limestone was a popular dimension stone.

Figure 30. Lock 60 was wood-lined to help water seal the rough-cut sandstone locally quarried from the Devonian rock (NPS).

Figure 31. A) Historical photograph of Seneca Creek Aqueduct (NPS), which is composed of B) smooth cut Manassas Sandstone.

Figure 32 .A) Historical photograph of Monocacy River Aqueduct (NPS). B) Smooth-cut blocks of Sugarloaf Mountain Quartzite that make up the aqueduct are comprised of C) round grains of quartz sand.

Figure 33. To prevent erosion, stone berms were constructed between the towpath and the Potomac River at A) Mary's Wall (MM 14), B) near Blockhouse Point (MM 19), and C) at Devils Eyebrow, west of Hancock (MM 127.5) (photo by C.D. Walcott, USGS).

Figure 34. Modern erosion in the canal near Lock 34 has exposed the clay liner (above the rock hammer) that was placed above rubble fill (below the rock hammer) to hold water. This clay was probably taken from the residuum of the carbonate rocks of the Tomstown Formation near Fort Duncan to the immediate west.

Figure 35. Historical photograph (looking south) of the timber crib filled with stone that was Dam 3 north of Harpers Ferry, W.Va. (NPS).

Figure 36. A) The wood-planked, stone-filled crib of Dam 6 north of Cacapon, W.Va. (Hahn, 1985), B) was breached in the 1936 flood. In the upper right background are west-dipping beds of Oriskany Sandstone that provided rubble for the fill.

Figure 37. Historical photographs (NPS) of the Paw Paw Tunnel: A) South portal (looking north) and B) north portal (looking south). From the south, the tunnel is on the southeast limb of an anticline of shale and thin sandstone of the Devonian Brallier Formation, whose crest is exposed above the upper right stonework of the north portal (B). C) The 3,118 foot long tunnel is lined with brick (NPS).

Figure 38. Historical photographs (NPS) showing A) the area of the Round Top Cement Company west of Hancock, where limestone was quarried, mined, and processed, and B) close-up of the plant (Hahn, 1985).

Figure 39. Historical photograph showing construction required to build the towpath and canal at Widewater (NPS). The canal occupied an abandoned channel of the river whose outlet valleys required fill to hold water and bridge the towpath.

Figure 40. A) The towpath was adjacent to the Potomac River at “Big Slackwater” (MM 88) and canal boats used the river. No canal was constructed because of the cliffs of limestone. B) Both the towpath and canal west of Old Town (MM 168) were excavated through thin-bedded fissile shale of Devonian age.

Figure 41. A) Tectonic map and B) Geologic cross section of the Piedmont province.

Figure 42. Geologic map from Georgetown (MM 0) to near Glen Echo Park (about MM 7).

Figure 43. National Historical Marker where the canal intersects Rock Creek. Dark and light rock fragments, called olistoliths, occur in metagraywacke of the Cambrian Sykesville Formation from which the marker is made.

Figure 44. The canal was excavated through igneous rocks of the Ordovician Georgetown Intrusive Suite near Key Bridge. The suite includes both light and dark colored rocks; A) is a light (leucocratic) granitoid, B) is a close up showing quartz and plagioclase crystals, C) is dark (melanocratic) gabbro, and D) is a close up showing the crystalline texture of amphibole and plagioclase crystals.

Figure 45. A) Alluvial cobbles of sandstone derived from terrace deposits near MM 7.5 litter the canal and B) some have cross bedded laminations. The cobbles probably were derived from sandstone of lower Paleozoic age found west of Harpers Ferry, W.Va., that were carried by the Potomac River to this site.

Figure 46. Geologic map from around Glen Echo Park (MM 7) to Swains Lock (MM 17).

Figure 47. Sedimentary mélange of the Neoproterozoic Sykesville Formation has clasts, or olistoliths, of older rocks derived from the Mather Gorge Formation. Pocket knife (A) and lens cap (B) for scale.

Figure 48. Sheared mélange of the Sykesville Formation has elongated fragments of quartzite and quartz in a matrix of quartz and feldspar above a bed of white quartzite near MM 11.5. Knife

and keys for scale.

Figure 49. A) Stereoscopic aerial photographs, B) sketch, and C) oblique aerial photograph of the Great Falls of the Potomac River.

Figure 50. A) Phyllonite of the Neoproterozoic Mather Gorge Formation (CZmp) and folded vein quartz (binoculars for scale), are B) intruded by undeformed Ordovician Bear Island Granodiorite (Ob) near MM 12.5..

Figure 51. A and B) Formerly melted metagraywacke and schist of the Mather Gorge Formation, called migmatite, shows rootless, ductile folds. Pocket knives for scale.

Figure 52. A) Photograph and B) sketch of migmatite of the Mather Gorge Formation (CZmm) that contains blocks of dark-colored amphibolite (Cza) intruded by light Bear Island Granodiorite (Ob) on an island in Mather Gorge (photo by Dave Usher, USGS).

Figure 53. A) Dark amphibolite intruded by white pegmatite. B) the amphibolite is comprised of crystals of hornblende (dark) and plagioclase feldspar (light); the light veins of pegmatite and quartz intrude it. Pocket knife for scale.

Figure 54. Vein quartz that intruded rocks near Widewater, is milky white and fractured. Similar vein quartz was mined for gold to the immediate north.

Figure 55. A) Illustration of the underground gold mine north of Great Falls Tavern (Reed and Reed, 1970). B) Close-up of gold (Au) in vein quartz (Reed and Reed, 1970).

Figure 56. A) Devonian lamprophyre dikes intruded metagraywacke of the Mather Gorge Formation along a prominent fracture system (parallel to arrows) on Bear Island south of Lock 16 (photo by Dave Usher, USGS; Reed and others, 1980).

Figure 57. A) Metagraywacke and schist of the Mather Gorge Formation was recumbently folded (F1), folded upright (F2), and then intruded by pegmatite and granodiorite (Ob) (Reed and others, 1980; Drake,1989)(photo by Dave Usher, USGS). Ruler for scale, left of center.

Figure 58. Geologic map from Swains Lock (MM 17) to Seneca (MM 22.8).

Figure 59. A) Bluffs of folded metagraywacke Formation are common from Great Falls Tavern to

Blockhouse Point. At Blockhouse Point, isoclinal folds of quartzite (B and C) show the style of deformation.

Figure 60. Geologic map from Seneca (MM 22.8) to Edwards Ferry (MM 30).

Figure 61. Stereoscopic aerial photographs and sketch shows the change in the morphology of the Potomac River valley in the Piedmont across the boundary between the Culpeper basin (west) and Potomac terrane (east). The Potomac terrane is dissected and the Culpeper basin has a broad flood plain. The tonal change in the river is Seneca Falls and the rubble remains of Dam 2.

Figure 62. The conglomerate that forms the base of the Culpeper basin, called the Reston Member of the Manassas Sandstone, has A) rounded cobbles of vein quartz and metamorphic rocks in B) a matrix of arkosic sandstone.

Figure 63. Geologic map from Edwards Ferry (MM 30) to Monocacy Aqueduct (MM 42.2).

Figure 64. A) Opposite "Marble Quarry campsite" there are bluffs of limestone conglomerate interbedded with red siltstone of the Upper Triassic Leesburg Member of the Balls Bluff Siltstone. An Early Jurassic diabase dike intruded and locally metamorphosed the limestone clasts to marble. B) Some of the conglomerate was excavated to create the floor of the canal. C) From here west to Monocacy Bottom, bluffs of siltstone help explain the formal name of the unit, Balls Bluff Siltstone.

Figure 65. Geologic map from Monocacy Aqueduct (MM 42.2) to Point of Rocks (MM 48.2).

Figure 66. Photograph and sketch of sheared phyllite and folded white vein quartz of the Neoproterozoic(?) and Lower Cambrian (?) Ijamsville Phyllite that lies above the Martic thrust fault along the Monocacy River north of Indian Flats.

Figure 67. Photograph and sketch of tightly-folded, thin-bedded limestone within the Ijamsville Phyllite along the Monocacy River. Hand-lens for scale.

Figure 68. Metasiltstone of the Middle Cambrian Araby Formation is foliated with near vertical cleavage along the CSXT railroad north of MM 43. Pocket knife for scale (top center).

Figure 69. There are different varieties of limestone of the Upper Cambrian Frederick Formation. A) Laminated limestone is exposed in Tuscarora Creek north of Nolands Ferry (Pocket knife for

scale, top center), B) platy limestone conglomerate near the Monocacy River, and C) folded thin limestone interbedded with shale is south of the Potomac River.

Figure 70. A) Conical hill north of Nolands Ferry and Rt. 28 represents topographic inversion. B) Cobbles of sandstone and quartzite were deposited in a sinkhole in limestone. The surrounding limestone has since been eroded while the resistant gravel armored the hill.

Figure 71. A) Near MM 47 the canal was excavated in limestone conglomerate of the Leesburg Member of the Balls Bluff Siltstone. To the immediate east, these rocks were quarried for B) the ornamental columns of Statuary Hall (photo by NPS).

Figure 72. Folded beds of limestone and marble of the Tomstown Formation only crop out south of the Potomac River in Loudoun County, Va., because B) colluvium of sandstone and vein quartz cover the bedrock in Maryland.

Figure 73. These two rock units are not exposed along the canal and river, but are within the map area. A) Dark gray to black carbonaceous phyllite forms ashey soil. B) arkosic metasandstone of the Antietam Formation was quarried for manganese in the 1700's along Furnace Mountain just south of the river. In Pennsylvania, this unit contains trilobites and are the oldest fossil bearing rocks known in this region.

Figure 74. A) Tectonic map and B) schematic geologic cross section of the Blue Ridge province, showing locations of detailed geologic sketches.

Figure 75. Geologic map from Point of Rocks (MM 48.2) to Brunswick (MM 55).

Figure 76. A) Historical photograph (NPS) and B) 1996 photograph of Point of Rocks, where cliffs of rocks of the Neoproterozoic Catoctin Formation form the north side of the water gap of Catoctin Mountain. The rocks include C) greenstone with tiny holes, called vesicles, that formed by the release of gas bubbles when the basalt flowed on the surface about 570 million years ago, and D) folded greenstone schist and phyllite with E) folded vein quartz. If these rocks were folded in the late Paleozoic Alleghanian orogeny, when was the vein quartz intruded?

Figure 77. Stereoscopic aerial photographs and sketch centered on Point of Rocks, the north side of the water gap in Catoctin Mountain.

Figure 78. Locally beneath the greenstone of the Catoctin Formation and above the granitic gneiss are A) schist and metasandstone of the Swift Run Formation. Along the creek at Lander, and east of Short Hill Mountain to the west, are B) pods of marble that were probably deposits of shallow water limestone.

Figure 79. The core of the anticlinorium in this area consists of light granitic gneiss intruded by numerous dark metadiabase dikes that probably fed the basalt flows of the Catoctin Formation (photo by Bill Burton, USGS).

Figure 80. Geologic map from Brunswick (MM 55) to Harpers Ferry area (MM 62.5).

Figure 81. A) Photograph and B) sketch of Weverton Cliffs at the southern end of South Mountain, showing quartzite beds of the Lower Cambrian Weverton Formation. Cwb, Cwm, and Cwo are the Buzzard Knob, Maryland Heights, and Owens Creek Members of the Weverton Formation, respectively. Ch is Harpers Formation. In the left foreground of the photograph are the stone ruins of the Weverton mills.

Figure 82. Stratigraphically above phyllite and greenstone of the Catoctin Formation are local deposits of a polymictic conglomerate (Loudoun Formation) that may represent alluvial fan and channel deposits at the onset of the deposition of the quartz rich sediments of the Weverton Formation.

Figure 83. A) Bluffs of Mesoproterozoic granitic gneiss are shown in this historical photograph (NPS) along the B&O railroad and C&O Canal west of Weverton. These rocks are now covered with soot but B) fresh garnetiferous leucocratic granite is exposed in the roadcut of southbound Route 340, north of Potomac River. Uranium-lead dating of zircon crystals show that this granite formed over 1 billion years ago and was then metamorphosed and folded during the Grenville orogeny. Shiny graphite and almandine garnet in this rock suggests that an older suite of metasedimentary rocks was melted to form the granite.

Figure 84. Stereoscopic aerial photographs and sketch centered on Harpers Ferry, W.Va, showing the Potomac River gorge and water gap.

Figure 85. Sketch of the bluffs of Blue Ridge-Elk Ridge north of the C&O Canal showing folded

quartzite beds within the Weverton Formation that comprise the overturned west limb of the Blue Ridge-South Mountain anticlinorium. See figure 81 for unit symbols. The 2 large folds on the east side (Cwb) are shown in fig. 86.

Figure 86. Overturned pairs of anticlines and synclines of quartzite of the Buzzards Knob Member of the Weverton Formation.

Figure 87. Historical photographs showing the easternmost overturned anticline of quartzite (A) and close up showing the massive beds of quartzite of the Buzzards Knob Member of the Weverton Formation near the crest (photo by G.W. Stose, USGS).

Figure 88. Historical photographs of the westernmost overturned anticline of quartzite of the Buzzard Knob Member of the Weverton Formation (A) and close up B) of nearly flat-lying beds of quartzite at the crest of the fold that become vertical and are then overturned, dipping to the southeast (photo by G.W. Stose, USGS).

Figure 89. The westernmost overturned anticline shown in fig. 88 plunges southward toward the Potomac River and can be seen in low water conditions from Loudoun Heights, Va., as well as from an airplane (see figure 84).

Figure 90. Cross-bedded quartzite of the Weverton Formation at Maryland Heights, are defined by layers of dark heavy minerals in light quartz sand. The truncation of the beds is used to determine whether the rocks are A) upright or B) overturned. Mechanical pencil is for scale.

Figure 91. Geologic sketch of the bluffs from about MM 61, to the Great Valley west of Lock 36 (MM 62.5). Rocks of the Harpers Formation have penetrative cleavage, folds that are defined by bedding, and folded cleavage by deformation near thrust faults. The rocks of the Antietam and Tomstown formations are oriented vertical and steeply-dipping (overturned) to the southeast.

Figure 92. Folded and cleaved metasiltstone of the Harpers Formation was drilled and blasted to excavate the canal near MM 61. A) Pervasive slaty cleavage dips at a low angle to the southeast and beds and drill hole scars are nearly vertical, but nearby B) bedding dips to the northwest. The stone wall of colluvium that abuts the outcrop is the berm of the canal.

Figure 93. Cleavage in metasiltstone of the Harpers Formation is itself folded as the result of

motion along a thrust fault, west of Hoffmeister Road. Spaced crenulation cleavage dips to the northwest. Pocket knife in center for scale.

Figure 94. A) The transition from metasiltstone of the Harpers Formation upward into metasandstone of the Antietam Formation is near Dam 3, where 2-3 inch thick clean metasandstone is interbedded with darker metasiltstone. B) Dark lines perpendicular to the laminated bedding in the Antietam Formation are the trace fossil *Skolithus linearis*. *Skolithus* are tubular ancient worm burrows in sand that were infilled with finer-grained silt in shallow water.

Figure 95. A) Tectonic map and B) schematic geologic cross section of the Shenandoah Valley, Great Valley of the Valley and Ridge province, showing locations of detailed geologic sketches.

Figure 96. Geologic map from Fort Duncan (MM 62.5) to Antietam Creek (MM 69).

Figure 97. Geologic sketch from MM 65.2 westward, across the overturned thrust fault contact (Keedysville detachment) of metasandstone of the Antietam Formation (Ca) with limestone of the Bolivar Heights Member of the Tomstown Formation (Ctbh), and another thrust fault cutting an upright anticline of the Bolivar Heights, Fort Duncan (Ctf) and Benevola (Ctb) members of the Tomstown Formation. Both thrust faults are marked by mylonite, marble, and cleavage. The lime kiln was for limestone mined locally. Manganese discovered during excavation of the canal was also mined near the overturned contact, near the sinkhole that is filled with colluvium.

Figure 98. Limestone of the Bolivar Heights Member of the Tomstown Formation near MM 68. A) Pervasive cleavage dips at a low angle and beds dip steeply to the northwest. B) close up shows that fossil burrows (originally oriented perpendicular to beds) are disrupted and realigned by pervasive cleavage oriented near horizontal.

Figure 99. A) Collapse breccia of limestone cemented by calcium carbonate, B) tufa deposits, and C) small caves are common in the bluffs of the Great Valley.

Figure 100. A) Shale, sandstone, and dolomite of the Chewsville Member of the Waynesboro Formation and B) limestone and dolomite of the Cavetown Member of the Waynesboro Formation that are beneath alluvium along this section of the canal.

Figure 101. Geologic map from Antietam Creek (MM 69) to Big Slackwater (MM 85.5).

Figure 102. Historical photograph (NPS) showing Botelers quarries of near vertical limestone (in West Virginia opposite MM 71.6) and Botelers/Reynolds Dam (on right) for mill race for the cement mill (left background). Prior to Round Top this supplied the cement for the canal masonry.

Figure 103. Historical sketch of Killiansburg cave (Hahn, 1985) near MM 75.7 suggests that the cave is situated in the hinge of an anticline of Conococheague Limestone, but it actually is developed in east-dipping beds.

Figure 104. Historical photograph (NPS) north of Dam 4 shows where canal boats entered the Potomac River since cliffs of limestone prevented construction of a canal, like "Big Slackwater" to the west.

Figure 105. Geologic map from Big Slackwater (MM 85.5) to Williamsport (MM 99.5).

Figure 106. Geologic sketch from McMahons Mill near MM 88 westward to Lock 41 depicting Ordovician age rocks of the Stonehenge Limestone (Os), Stoufferstown Member (Oss) of the Stonehenge Limestone thrust on limestone of the Rockdale Run Formation (Orr) that are folded into a syncline beneath the fault. There are several limestone quarries and caves in the bluffs.

Figure 107. Mylonitic limestone within the Stoufferstown Member of the Stonehenge Limestone was produced as the rocks were thrust westward above rocks of the Rockdale Run Formation. The mylonitic foliation is defined by clay seams and recrystallized limestone (parallel to the rock hammer handle). The mylonitic foliation is kinked by later folds .

Figure 108. A) Dark chert and limestone of the Rockdale Run Formation along the bluffs near MM 88.5. Note the stylolites that are parallel to beds. B) Ancient ripple marks (3 inch spacing) in shaly limestone exposed on the bluff near MM 88.5 indicates that the rocks were deposited in a shallow tidal water environment.

Figure 109. Historical photograph of Cushwas basin at Williamsport showing coal being loaded into horse drawn wagons. The coal was transported down the canal from Cumberland (NPS).

Figure 110. Geologic map from Williamsport (MM 99.5) to McCoys Ferry (MM 110).

Figure 111. A) Thin bedded sandstone and shale of the Martinsburg Formation are turbidites

deposited in a deepening basin at the onset of the Taconic orogeny. These are the first clastic rocks deposited after almost 100 Million years of deposition of carbonate strata on the continental shelf. B) Flute casts at the base of a sandstone bed in the Martinsburg Formation was formed by sand filling a trough scoured by turbulent water, that flowed parallel to the direction of the mechanical pencil.

Figure 112. A) Geologic sketch from Pinesburg Station (MM 102) west to Millers Bend (MM 103), illustrates the folded Ordovician bedrock of the west limb of the Massanutten syncline, from the shale of the Martinsburg Formation (Om) (east) down-section to the Stonehenge Limestone (Os) (west). Intervening limestone rocks are Rockdale Run Formation (Orr), Pinesburg Station Dolomite (Ops), St. Paul Group, undifferentiated (Osp), New Market Limestone (Onm), and Chambersburg Limestone (Oc). B) Geologic sketch from Dam 5 westward to near Four Locks. Just west of Dam 5 the Conococheague Formation (Occ) is thrust on Rockdale Run Formation (Orr). From there the rocks form a broad anticline cored by Elbrook Formation (Ce); the axis of the anticline is at MM 108. West of Charles Mill the Conococheague Formation is folded to form a broad syncline. The other bedrock units are Big Springs Station Member of the Conococheague Formation (Ccb), Stonehenge Limestone (Os), and Stoufferstown Member of the Stonehenge Limestone (Oss). There are several caves and limestone quarries along this section.

Figure 113. A). Cross section of laminated limestone of the Conococheague Formation with mudcracks near MM 107.8. B) View of mudcracks on the top of a bed of limestone. The polygonal shape (4 inches across) is very similar to present-day mudcracks that form in the silty deposits after the Potomac River floods.

Figure 114. Fossil algal "heads", or stromatolites, in limestone of the Cambrian Elbrook Formation east of McCoys Ferry, near MM 109.5.

Figure 115. A) Silurian Tuscarora Sandstone at McCoys Ferry is highly fractured along the North Mountain thrust fault. Rocks to the east were transported westward structurally above the B) fractured and brecciated sandstone. To the south, this resistant sandstone underlies North

Mountain.

Figure 116. A) Side-looking airborne radar image of the Valley and Ridge province illustrates the namesake physiography. Erosion resistant rocks on the limbs of anticlines and synclines underlie hills, ridges, and mountains. Easily eroded shale and limestone are in the valleys. B) The major folds are named after the corresponding ridges and mountains. C) Schematic geologic cross section of the Valley and Ridge province, shows the locations of detailed geologic sketches.

Figure 117. Geologic map of the Valley and Ridge province from McCoys Ferry (MM 110) to Licking Creek Aqueduct (MM 116).

Figure 118. A) Fort Frederick was built in 1756 (photograph by NPS), of B) colluvial and alluvial boulders of sandstone that were gathered from the fields.

Figure 119. Historical photograph (NPS) of workers and mules scraping the floor of Big Pool After it was drained to remove silt (NPS).

Figure 120. Between A) the Licking Creek Aqueduct and I-70 is a thrust fault (not exposed) that places B) limestone of the Helderberg Group and Shriver Chert on shale of the Mahantango Formation.

Figure 121. Geologic map from Licking Creek Aqueduct (MM 116) to Round Top Cement Mill (MM 127.5) west of Hancock.

Figure 122. Thin-bedded sandstone and shale of the Devonian Brallier Formation east of the access trail to Little Pool (~MM 120.2) resemble turbidites of the Ordovician Martinsburg Formation near Williamsport (see fig. 111).

Figure 123. A) Fissile red shale interbedded with thin sandstone and B) thin bedded red sandstone are characteristic of rocks of the Devonian Foreknobs that are best exposed south of the Potomac River on the limbs of the Meadows Ground syncline. The sandstone beds become more massive and thicker upsection into the Hampshire Formation in the core of the syncline. Down section, the thick red shale transitions to C) thin-bedded sandstone and shale of the Devonian Brallier Formation last seen near MM 120.2 (see fig. 122).

Figure 124. A) Fissile black shale of the Marcellus Formation dips east on the limb of the Cacapon Mountain anticlinorium, and displays west dipping cleavage. Locally these rocks contain B) concretions of limestone that were deposited above the Oriskany Sandstone.

Figure 125. A) Historical photograph (see cover) (C. D. Walcott, USGS) and B) sketch of the Devils Eye Brow and ruins of the Round Top Cement Mill west of Hancock (modified after Davies, 1989).

Figure 126. Historical photograph (C.D. Walcott, USGS) of the Devils Eye Brow, an anticline of rocks of the Silurian Bloomsburg Formation. The “cave” in the core of the anticline behind the sitting man was formed from the weathering of limy shale and limestone.

Figure 127. A) Lime kilns of the Round Top Cement Mill are situated above an anticline west of Devils Eye Brow, and the intervening syncline B) is shown in a historical photograph (C. D. Walcott, USGS). Note the cleavage nearly perpendicular to the folded beds.

Figure 128. Historical photograph (C.D. Walcott, USGS), looking down the axis of an anticline where limestone in the core of the fold was mined on Round Top.

Figure 129. Geologic map from Round Top Cement Mill (MM 127.5), to Little Orleans (MM 141).

Figure 130. The oldest rocks exposed along the canal in the Valley and Ridge are shale of the Silurian Rosehill Formation that were drilled and excavated near Leopards Mill, MM 130.

Figure 131. Historical photograph (NPS) from the overlook on Cacapon Mountain, W.Va., looking west toward Sideling Hil. Note the fresh rock exposed along the canal and railroad excavations in the lower right (illustrated in fig. 132). The nearly flat open pasture amid forests are old terraces of the ancestral Potomac River. Similar terraces south of the Potomac River (left), are younger in age and lower in elevation.

Figure 132. Geologic sketch from east of MM 133 west to Dam 6 and Tonoloway Ridge, shows the folded and faulted Silurian and Devonian rocks on the west limb of the Cacapon Mountain anticlinorium. Locations of detailed photos and sketches are shown.

Figure 133. A) An anticline of Keefer Sandstone is exposed along the canal east of MM 133 (see

fig. 132). Compare the style of folding seen here with the chevron-style folds shown in fig. 135. The thrust fault on the eastern limb of fold is shown in C); Outcrop about 15 feet high.
B) Perpendicular to sandstone beds are *skolithus*, trace fossil worm burrows, that are similar to those seen in the Antietam Formation near Harpers Ferry (fig. 94B). Quarter for scale. C) A thrust fault formed during flexural slip folding of the beds. Sandstone beds are fractured and truncated beneath the fault, which is in the more ductile and cleaved shale.

Figure 134. Geologic sketch (after Cloos, 1951) of folded and faulted rocks of the Silurian Wills Creek Formation east of MM 134. Outcrop is about 15 feet high.

Figure 135. A) Geologic sketch of folded and faulted strata at Fluted Rocks, along Cacapon River, West Virginia (modified after Lessing, 1988). Silurian rocks of the Rose Hill Formation, Keefer Sandstone, and McKenzie Formation are folded into anticlines and synclines. B and C) are historical photographs (G.W. Stose, USGS) showing the intricately folded and faulted rocks.

Figure 136. A) Chert in limestone of the Helderberg Group and B) coral fossils are abundant in the uppermost Silurian and lowermost Devonian rocks.

Figure 137. A) Devonian Oriskany Sandstone that underlies Tonoloway Ridge at Dam 6 has abundant molds of brachiopod shells. B) These molds are cross sections of brachiopod shells that were deposited on a sandy beach.

Figure 138. The first shale deposited as part of the thick deposit of Devonian clastic rock
Are thin sandstone and shale of the Needmore Formation exposed above the Oriskany Sandstone immediately west of Tonoloway Ridge.

Figure 139. Historical photograph (USGS), and sketch of folded and faulted shale and sandstone of the Devonian Brallier Formation exposed above the canal along the railroad at MM 135 near Woodmont Station. Chevron folds are in sandstone beds about 3 inches thick.

Figure 140. A) Photograph and B) sketch of Mississippian rocks of the Sideling Hill syncline exposed in the I-68 road cut through Sideling Hill. The black seams are the first beds of coal deposited in the region.

Figure 141. Gravel of vein quartz in sandstone of the Mississippian Rockwell Formation exposed

along the Sideling Hill Aqueduct may be derived from rocks of the Piedmont province exposed and eroded by tectonic activity associated with the Acadian orogeny.

Figure 142. A) Composite geologic sketch from MM 137 west to MM 138, from Lock 57 west to the west portal of Indigo Tunnel, and from MM 143 west to the old railroad bridge (MM 143.5), illustrating the folded strata on the west limb of the Sideling Hill syncline. B) detail sketch of the anticlinorium of Brallier and Scherr formations. C) Photograph and sketch of a tight, upright anticline in thin sandstone and shale of the Brallier and Scherr formations west of MM 143.

Figure 143. Geologic map from Little Orleans (MM 141) to Paw Paw Tunnel (MM 156).

Figure 144. A) Photograph taken from above the north portal of the Paw Paw tunnel. The towpath and canal transect an anticline (see fig. 36) so that bedrock of the west limb dips into the towpath and canal. The bedrock on the dip slope required bolts to prevent gravity slides along bedding. B) Beds of shale along the towpath north of the Paw Paw tunnel have mudcracks that are accentuated by cleavage, C) burrows and trails made by organisms before the mud was lithified to rock, and D) quartz slickensides and slicken lines along fault surfaces that are parallel to bedding.

Figure 145. Geologic map from Paw Paw Tunnel (MM 156) to Old Town (MM 167).

Figure 146. A) The terrace at Reckley Flat is underlain B) by fluvial silt, sand, and gravel of sandstone above shale bedrock.

Figure 147. A) Red fissile shale and thin sandstone beds grade up section into B) thicker beds of cross bedded sandstone of the Devonian Hampshire Formation, exposed east of Town Creek on the limb of the Town Creek syncline.

Figure 148. Oriskany Sandstone on the west limb of the Broadtop anticline was locally excavated to construct the canal and towpath east of Old Town near MM 143. Pine trees and mountain laurel prefer the thin sandy soil found on the sandstone.

Figure 149. Geologic map from Old Town (MM 167), to Spring Gap (MM 173.5).

Figure 150. A) Geologic sketch (after Davies, 1999) showing folded shale of the Devonian Foreknobs Formation near MM 172. Distance between canal and Railroad is about 20 feet.

B) Photograph of recessed area of anticline illustrated on left side of sketch.

Figure 151. Geologic map from Spring Gap (MM 173.5), to Cumberland (MM 184.5).

Figure 152. Historical photograph showing the canal and wharf area at Cumberland where boats would be loaded with coal for transport eastward (Hahn, 1976).

TABLES

Table 1. Locks and aqueducts, the type of building stone used, and the map unit of the building stone.

SOURCES OF DATA FOR 7.5-MINUTE QUADRANGLES

(quadrangles listed from east to west)

Washington West: Fleming and others (1994); Southworth (unpub. data)

Falls Church: Drake and Froelich (1997); Southworth (unpub. data)

Rockville: Drake (unpub. data); Southworth (unpub. data)

Vienna: Drake and Lee (1989); Southworth (unpub. data)

Seneca: Drake and others (1999); Southworth (unpub. data)

Sterling: Lee (1979); Southworth (unpub. data)

Leesburg: Lee (1979); Southworth (unpub. data)

Poolesville: Southworth (1998)

Waterford: Burton and others (1995); Southworth (unpub. data)

Buckeystown: Southworth and Brezinski (in press)

Point of Rocks: Burton and others (1995); Burton and Southworth (1996); Brezinski and Southworth (unpub. data)

Harpers Ferry: Southworth and Brezinski (1996b)

Charles Town: Nickelsen (1956); Brezinski, Orndorff, and Southworth, (unpub. data)

Keedysville: Dean and others (1987); Brezinski (1992); Brezinski and Southworth (unpub. data)

Shepherdstown: Dean and others (1987); Brezinski, Orndorff, and Southworth (unpub. data)

Williamsport: Dean and others (1987); Brezinski, Orndorff, and Southworth (unpub. data)

Hedgesville: Dean and others (1987); Glaser (unpub.data); Brezinski, Orndorff, and Southworth (unpub. data)

Big Pool: Lessing and others (1995); Glaser (unpub. data); Brezinski and Southworth (unpub. data)

Cherry Run: Dean and others (1995); Glaser (unpub. data); Southworth (unpub. data)

Hancock: Dean and others (1995); Glaser (unpub. data); Brezinski, Dickinson, and Southworth (unpub. data)

Bellegrove: Glaser (1994a); Lessing and others (1997); Brezinski and Southworth (unpub. data)

Great Cacapon: Lessing and others (1997); Southworth (unpub. data)

Artemas: Kulander and others (1997); Glaser and Southworth (unpub. data)

Paw Paw: Glaser (1994d); Kulander and others (1997); Brezinski, Dickinson, and Southworth (unpub. data)

Oldtown: Glaser (1994c); Kulander and others (1997); Southworth (unpub. data)

Patterson Creek: DeWitt and Colton(1964); Southworth (unpub. data)

Evitts Creek: DeWitt and Colton(1964); Southworth (unpub. data)

Cresaptown: Glaser (1994b); Southworth (unpub. data)

Cumberland: Glaser and Brezinski (1994); Southworth (unpub. data)