Geologic Map of the National Parks in the National Capital Region, Washington, D.C., Virginia, Maryland, and West Virginia

By Scott Southworth and Danielle Denenny

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Contents

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Introduction

More than 51,000 acres within the National Capital Region are administered by the National Park Service (NPS). The land consists of parkways, trails, statues, monuments, memorials, historic sites, scenic areas, theatres, parks for performing arts, and Civil War battlefields. Although largely established for historical and cultural resources, each park is situated on a landscape that is influenced by the bedrock and surficial geology of the Central Appalachian mid-Atlantic region. Geologic mapping and field studies conducted for over 130 years by the U.S. Geological Survey (USGS), the Maryland Geological Survey (MGS), and Johns Hopkins University, are summarized to provide the earliest history of the parklands. The age, type, names, and the interpreted origin of the rocks, as well as the processes active in the formation of surficial deposits and the landscape are discussed for each park. The data and report are intended for management of natural resources and enhancement of educational and interpretative programs for visitors.

The diversity of the National Capital Region (NCR) parks is astounding in both the types of geology and variety of human culture. Examples include the Washington Monument and the National Mall, Antietam National Battlefield (NB) of the Civil War, Rock Creek Park (the first and largest urban park in the Nation), the scenic George Washington Memorial Parkway, historical parks such as Harpers Ferry and the C&O Canal National Historical Park (NHP), Catoctin Mountain Park, and Wolf Trap National Park for the Performing Arts (the first national park for the performing arts). Of all the parklands, Antietam NB, Catoctin Mountain Park, Monocacy NB, Manassas National Battlefield Park (NBP), Prince William Forest Park, Great Falls Park, George Washington Parkway, and Rock Creek Park are emphasized in this report due to their noteworthy geologic features. An introduction to each park is followed by a discussion of the geologic setting, bedrock, structure, surficial deposits, and landforms.

Most of the geologic maps presented here are confined to the NCR park boundaries. The single geologic map of Washington, D.C. (plate 1), however, envelopes the smaller parks that are designated as NCR East and NCR West by the NPS. The geology for this map is centered on the Potomac River in a manner similar to that of the C&O Canal NHP geologic map (Southworth and others, 2001).

Background

As part of a Memorandum of Understanding between USGS and NPS in 1994, geologic map data was provided to parks in the National Capital Region for application in a Geographic Information Systems (GIS). Geologic maps, a database, and reports were published for Harpers Ferry NHP, W. Va., Va., and Md. (Southworth and others, 2000a), Great Falls Park (Southworth and others, 2000b), and the Chesapeake and Ohio Canal NHP, Washington, D.C., Md., W. Va., and Va. (Southworth and others, 2001). From October 2001 to September 2004, the geology of the remaining parks in the NCR was investigated as part of the NPS Geologic Resource Division's Geologic Resources Inventory and Monitoring Pilot Project (http://www2.nature.nps.gov/geology/inventory/).

Previous Studies

The geology of the NCR has been studied for over 130 years, mainly by the USGS which is headquartered in the Washington, D.C. area. Early work by Darton and Keith (1901) was published as folios at 1:125,000 scale. Subsequent mapping of Washington, D.C., and adjacent Montgomery County was published at 1:62,500 scale by the Maryland Geological Survey (Cloos and Cooke, 1953). Geologic mapping by USGS and MGS in the region from the early 1970s to 2001 resulted in about eight published geologic maps at 1:24,000 scale. These 7.5-minute quadrangle geologic maps contained parklands, so they were revised and new data were collected for this study.

Many important advances in geology originated from studies in and around the NCR parklands. Such advances include recognition of young faults (Keith, 1894; Darton and Keith, 1901), recognition of reactivated faults (Fleming and Drake, 1998; Kunk and others, 2005), determining the crystallization age of rocks (Aleinikoff, and others, 2002); and metamorphism (Kunk and others, 2005). Bedrock and Coastal Plain units were named after local areas (type localities) where they are best exposed, and many are within or adjacent to parklands. Examples include the Antietam Formation, Potomac Formation, Chopawamsic Formation, Dalecarlia Intrusive Suite, Kensington Tonalite, Georgetown Intrusive Suite, Mather Gorge Formation, Bear Island Granodiorite, Bull Run Formation, Harpers Formation, Weverton Formation, and Catoctin Formation. Other rocks were named after familiar places within the NCR where they are best exposed, such as the Sykesville Formation, Laurel Formation, Frederick Formation, Araby Formation, and Ijamsville Phyllite.

The rocks in the central Appalachian region have geologic structures that trend northeast to southwest, and the resulting landforms show pronounced structural grain. This structural grain is the result of contractional and extensional tectonic processes that have been directed to the northwest and southeast for hundreds of millions of years. Foliation and beds mostly dip to the southeast, but dip to the northwest locally in the eastern Piedmont and the Culpeper basin. Areas within the Coastal Plain do not have this systematic alignment of landforms because they contain unconsolidated sediments that lack structural trends. The dominant surficial processes and erosional agents in this region are gravity and the Potomac River. Erosion by the Potomac River has produced extensive terraces, deposited significant gravel, and created a grand gorge with excellent bedrock exposures.

Methodology

Geologic field mapping and investigations were conducted from the fall of 2001 through the summer of 2004. Bedrock and surficial geologic units were compiled on 1:24,000 scale topographic base maps with 10-, 20-, and 40-ft contour intervals. Bedrock units and contacts from previously published maps were checked and revised where necessary. Geologic problems identified on the existing geologic maps were investigated and interpretations were revised. Surficial deposits were mapped along selected field traverses and by interpreting landforms on topographic maps.

Bedrock units from 1:24,000 scale maps were drafted with ink on mylar that was geographically registered to the latitude and longitude coordinates of the 7.5-minute quadrangles. These overlays were scanned and edited. The base map is a 30-m-resolution digital elevation model (DEM) derived from the USGS National Elevation Dataset. The DEM was processed to become a shaded-relief image that portrays the landscape as if illuminated by the sun and portrays the landforms in shades of gray that are free of cultural features.

Physiographic Setting

The parklands of the NCR occur in all of the major physiographic provinces (see insert on plate) of the central Appalachian region except the Appalachian Plateaus Province, which is within site of the western terminus of the C&O Canal (Southworth and others, 2001). The NCR parks in this report occur, from east to west, in the Coastal Plain, the Piedmont, and the Blue Ridge provinces in the Great Valley section of the Valley and Ridge province. The Blue Ridge province is characterized by a highland. The Great Valley to the west, and the Piedmont to the east of the Blue Ridge province are characterized by low, rolling hills punctuated by a steep gorge along the Potomac River. The Coastal Plain has the lowest topographic relief and altitude and is east of the Piedmont Province, and separated from it by the fall zone.

For this report, the parks are grouped by physiographic province as a means to compare those with similar and contrasting settings. The physiographic provinces are the same as the geologic provinces, because the physiography is a function of the bedrock and surficial deposits unique to each.

Geologic Setting and Chronology

The oldest dated rocks in the NCR parks are the volcanic rocks (~560 million years old (Ma)(Neoproterozoic) of the Catoctin Formation found in Catoctin Mountain Park, Md. (J.N. Aleinikoff, USGS, written commun., 2005). The lavas erupted from volcanic fissures during rifting of the ancient Laurentian continent. The lava was later overlain by quartz-rich sediments deposited by rivers and along beaches on the margin of the Laurentian continent around 542 Ma. The present-day highlands of the Blue Ridge province result from quartz-rich and erosion-resistant metamorphic rocks. The main structure of the Blue Ridge province is the Blue Ridge-South Mountain anticlinorium, whose eastern limb is the site of Catoctin Mountain Park.

The quartzite and clastic rocks of the Blue Ridge province were overlain by carbonate and clastic sedimentary rocks that were deposited on the continental margin of Laurentia as the Iapetus Ocean developed, about 530 to 475 Ma (Cambrian and Ordovician). These rocks underlie the Great Valley section of the Valley and Ridge province in Antietam NB and they also occur in Monocacy NB in the western Piedmont. The calcium carbonate rocks readily erode to lowlands in the humid temperate climates of the eastern United States. Sedimentary rocks rich in quartz are locally interbedded with the carbonate rocks, and form linear ridges with intervening swales.

In the Western Piedmont Province, the boundary between the Frederick Valley (west) and the Westminster terrane (east) occurs just east of Monocacy NB, along the Martic fault. The eastern margin of the ancient Iapetus Ocean consisted of shallow- marine carbonate rocks that merged east into deeper water deposits primarily comprised of fine-grained sediment deposited on the slope and rise of the Iapetus Ocean. The fine-grained sedimentary rock was subsequently metamorphosed to slate.

The eastern Piedmont province consists of an amalgamation of rocks that were deposited, deformed, metamorphosed, and intruded in different places, at different times, and under different conditions. The rocks were tectonically assembled onto the margin of the eastern U.S. (from about 480 to 280 Ma) as the various tectonic plates drifted from the southern to the northern hemisphere. Some of the oldest undated rocks are sediments that were deposited in ancient oceans. The mixed nature of sedimentary rocks and some igneous rocks suggests a complex setting such as a deep trench in oceanic crust. The turbidites of sedimentary rock at Great Falls Park support this setting, as do the mixtures of rock (diamictites), found in Turkey Run Park, Rock Creek Park, and Prince William Forest Park. These diamictities are cobbles of rock supported by a matrix of coarse-grained minerals. Both the turbidites and diamictites contain bodies of mafic rock that may be fragments of oceanic crust. Locally, the sedimentary rocks were partially melted during high-grade metamorphism to form migmatite. At depth in the crust, the metasedimentary rocks were intruded by a suite of mafic and felsic igneous rocks from about 478 Ma to 463 Ma (Aleinikoff and others, 2002). In Prince William Forest Park, there is a suite of volcanic, sedimentary, and plutonic rocks associated with an island arc that was active from the Middle Ordovician to the Early Silurian (461 Ma to 434 Ma) (Horton and others, 1998).

$^{40}Ar/^{39}Ar$ cooling ages of muscovite and hornblende in foliated metamorphic rocks, and fission-track ages of zircon and apatite, help define when the rocks were deformed, uplifted, cooled, and transported westward. In Great Falls Park there is evidence of deformation and metamorphism that dates to 480 Ma or older (Kunk and others, 2004, 2005). Two major fault zones are recognized between Great Falls Park and Rock Creek Park. The broad Stubblefield Falls-Plummers Island shear zone, which runs from the east end of Great Falls Park eastward to Turkey Run Park, was active in the Late Devonian (360 Ma) and Late Pennsylvanian (~300 Ma) (Kunk and others, 2004, 2005). To the east in Rock Creek Park, the Rock Creek shear zone straddles a fault that juxtaposed igneous and metsedimentary rocks. This 3-km-wide shear zone was active in the late Middle Ordovician (463±8 Ma), Late Mississippian to Early Pennsylvanian (320 to 310 Ma), and within the last several million years. The rocks of Prince William Forest Park were likely metamorphosed in the Mississippian (~321 Ma) (Sutter and others, 1985). Therefore, the bedrock in the eastern Piedmont was tectonically active between 480 Ma and 281 Ma.

The rocks of the Westminster terrane in the western Piedmont (see index on map plate) were metamorphosed in the Silurian (~430 Ma) (Kunk and others, 2004) and transported westward along the Martic fault (Southworth, 1996). The rocks of the Frederick Valley synclinorium (located in Monocacy NB) were probably folded at the same time as the folding of the Blue Ridge-South Mountain anticlinorium (Catoctin Mountain Park and Antietam NB) that occurred from Mississippian to Permian time (340 to 285 Ma). These rocks were inside the core of a mountain range that was comparable in relief to the present-day Rocky Mountains at the end of the Alleghanian orogeny (~320 to 281 Ma). Apatite fission-track ages of ~285 Ma (Kunk and others, 2004) suggest the time of emplacement of rocks above the North Mountain thrust sheet.

At the end of the Alleghanian orogeny (~220 to 200 Ma) the rocks of the Appalachian Mountains had been uplifted, eroded, and once deeply buried formations were now near the Earth's surface, while Mesozoic rocks were deposited on them just west of Great Falls Park. The Culpeper basin is situated in the western part of the Piedmont province. The fluvial (river) and lacustrine (lake) sedimentary deposits are similar to those in other basins that extend from Connecticut south to Georgia. The basins began forming during extensional tectonics as the Atlantic Ocean opened about 200 Ma. The soft, fine-grained, red sedimentary rocks were intruded by hard, black, igneous diabase that is found in Manassas NBP, which is located in the Culpeper basin. The hot, molten diabase metamorphosed the red siltstone to a gray hornfels at its contact. These rocks were down-faulted and rotated, with the homoclinal sections dipping west, and later eroded to become a lowland. A large normal fault immediately east of Catoctin Mountain Park forms the border fault to the Mesozoic Gettysburg basin, which is the northern extension of the Culpeper basin (see plate).

More than 65 million years of erosion, from the Jurassic to Cretaceous Periods, reduced the Piedmont landscape to a plateau. The seas encroached and the material eroded from the western highlands of the Blue Ridge and Valley and Ridge provinces was deposited to the east, creating the blanket of unconsolidated sediments that become the Atlantic Coastal Plain province. The oldest of these Coastal Plain deposits is Early Cretaceous in age (~145 to 100 Ma) and the youngest is late Pliocene in age (~2.5 to 1.8 Ma). Both fluvial and transgressive-regressive marine deposition across the eastern Piedmont occurred during the Cretaceous (145-100 Ma?), early Paleocene (65-61 Ma), late Paleocene (58-55 Ma), early Eocene (55-48 Ma), Miocene (23-5 Ma?), and late Pliocene (2.5-1.8 Ma?). Many deposits were later removed by erosion or they were reworked to make a complex patchwork of landforms and deposits of various ages. Much of the high-level Coastal Plain and terrace deposits that are found east of Rock Creek Park likely existed to the west as well, but were eroded, leaving remnants like the Tenley Circle area in Washington, D.C. and the Tysons Corner area in Virginia. These gravel deposits originated from the erosion of the mountains west of Harpers Ferry, W. Va., as shown by clasts containing fossil worm burrows of Skolithos linearis. Analysis of fission- track data suggests that the Potomac River cut through the gap at Harpers Ferry about 15 Ma (Miocene) (Naeser and others, 2005). Prior to this, the Potomac River drainage was restricted to east of the Blue Ridge province. Quaternary fluvial deposits are near modern drainages and include alluvium, low and high terraces, and fluvial and estuarine deposits. Atlantic Coastal

Plain deposits of fluvial origin are at high elevations, some distance away from modern drainages.

During the last several million years, surface processes also helped shape the modern landscape. In the Great Valley and Frederick Valley, physiochemical weathering of carbonate-rich rocks has produced sinkholes and associated karst. In the highlands, accumulations of coarse boulders and cobbles of quartz-rich rocks mantle slopes and fill valleys. Some of these are periglacial deposits related to climatic conditions when the continental glacier was in central Pennsylvania, about ~11,000 years ago. The rivers and creeks continue to erode rock and deposit sediment to form terraces and alluvial deposits today.

Types of Rock

The three basic classes of rocks--sedimentary, igneous, and metamorphic--are all found in the NCR parklands. Sedimentary rocks deposited in shallow running water are found in Catoctin Mountain Park (quartzite) and Manassas NBP (siltstone). Sedimentary rocks deposited in deeper water include turbidites found in Great Falls Park, Va; slate near Monocacy NB and Prince William Forest Park; and diamictite in George Washington Memorial Parkway and Rock Creek Park. Sedimentary rocks that formed from the chemical precipitation of calcium-rich water and decomposition of shells are found in Antietam NB (limestone) and Monocacy NB (dolostone). Volcanic igneous rocks are found in Catoctin Mountain Park and Prince William Forest Park. The volcanic rocks in Catoctin Mountain Park were extrusive lava flows, whereas the diabase in Manassas NBP intruded the rocks when they were deeper in the crust. Plutonic igneous rocks are found in Rock Creek Park, Turkey Run Park, and Prince William Forest Park.

The sedimentary and volcanic rocks in the Blue Ridge province (Catoctin Mountain Park) and Piedmont province (Great Falls Park and Prince William Forest Park) were metamorphosed to various grades and at different times. Metasedimentary rocks at Great Falls Park were partially melted during the highest metamorphic conditions in the region and contain visible crystals of garnet, kyanite, and staurolite. Igneous rocks in Rock Creek Park and Turkey Run Park were metamorphosed to soapstone and talc schist. Shale and siltstone were metamorphosed to muscovite schist in Great Falls Park and Rock Creek Park.

Isotopic Ages of Rocks, Landforms, and Deposits

Relative ages of geologic units are interpreted by cross cutting and superposition relations, fossils, and lithologic correlations, whereas absolute ages are obtained by isotopic techniques. Zircons that grew during crystallization of igneous rocks have been recently analyzed by the U-Pb technique to establish many of the ages in this region. ^{14}C analyses of organic material and ^{10}Be analyses of quartz in bedrock help constrain the age of surficial deposits and landforms. The ages used here are adopted from Gradstein and others (2004).

The oldest rock in the region is metarhyolite of the Catoctin Formation. It had a Sensitive High-Resolution Ion Microprobe (SHRIMP) U-Pb zircon age of ~560 Ma (J. Aleinikoff, USGS, written commun., 2005). The sample was collected north of Catoctin Mountain Park in Pennsylvania, about 1 meter-beneath the base of the Chilhowee Group.

Igneous intrusive rocks in parks of the NCR in the Piedmont province have recently been dated by the SHRIMP U-Pb zircon technique (Horton and others, 1998; Aleinikoff and others, 2002). Metarhyolite of the Chopawamsic Formation has an age of 454±5 Ma (Late Ordovician); a metamorphosed lapilli tuff layer in the lower part of the Quantico Formation has an age of 451±6 Ma (Lower Ordovician); and metatonalite that intrudes rocks of the Chopawamsic Formation has an age of 434±6 Ma (Early Silurian) (Horton and others, 1998). Muscovite trondhjemite of the Dalecarlia Intrusive Suite has an age of 478±6 Ma (Early Ordovician); biotite-hornblende tonalite of the Georgetown Intrusive Suite has an age of 472±4 Ma (Early Ordovician); the Kensington Tonalite has an age of 463±8 Ma (Middle Ordovician); and the Lake Jackson pluton has an age of 461±7 Ma (Middle Ordovician) (Aleinikoff and others, 2002). Amphibole crystallized in diabase dikes and sills has a ^{40}Ar/^{39}Ar age of ~200 Ma (Late Triassic and Early Jurassic) (Kunk and others, 1992).

Several rocks cannot be dated but are older than the event that metamorphosed them. For example, the Bear Island Granodiorite has a muscovite ^{40}Ar/^{39}Ar cooling age of 422 Ma (Middle Silurian) (Becker and others, 1993). A lamprophyre dike has an argon biotite cooling age of about 360 Ma (Late Devonian) (Reed and others, 1980). Rocks of the Mather Gorge Formation contain bodies of amphibolite that have 480 Ma hornblende ^{40}Ar/^{39}Ar cooling ages (Kunk and others, 2004, 2005), so the amphibolite and the Mather Gorge Formation are older than 480 Ma.

Examples of crosscutting relations include the Sykesville Formation and Laurel Formation, both older than the rocks that intruded them (478±6 Ma and 472±4 Ma, respectively). The Lunga Reservoir Formation may contain clasts of Chopawamsic Formation, thus it may be older than 454±5 Ma. Xenoliths of phyllite in the Lake Jackson pluton suggest that the phyllite is older than 461±7 Ma.

Studies of cosmogenic ^{10}Be in quartz from bedrock terraces near Great Falls Park suggest that the high terraces were cut at about 200 thousand years ago (ka)(middle Pleistocene) and the incision of the Potomac River at Great Falls into Mather Gorge is 35 ka (late Pleistocene) (Bierman and others, 2004).

Fluvial and estuarine deposits excavated in LaFayette Park contained wood that is older than 50 ka (beyond the range of ^{14}C technique)(Ives and others, 1967; Knox, 1969). These deposits, estimated to be 450 ka, correlate with marine units in North Carolina (Fleming and others, 1994) and with the Chicamuxen Church Formation in Virginia (Davis and others, 2002). Low-level fluvial and estuarine deposits that correlate with the late Pleistocene Maryland Point Formation (Davis and others, 2002) contain wood chips that have a ^{14}C age of 20±0.5 ka (Fleming and others, 1994).

Fossils

Fossils--the remains, traces, tracks, or imprints of ancient plants and animals--are locally preserved in the Paleozoic and Mesozoic rocks in the region. The Triassic rocks of the Culpeper basin contain foot prints of dinosaurs as old as 210 Ma, but the rocks in the Valley and Ridge province and the Frederick Valley contain fossils that range from ~530 to ~472 Ma. The most common fossils are shells of creatures that inhabited ancient seas during the Paleozoic Era. The youngest Mesozoic rocks contain the remains of animals and plants that lived on land, as well as fish and amphibians that lived in lakes. Most fossils are of animals and plants that were quickly buried by sediment during storms. Once covered with sediment, the animal, plant or imprint remained undisturbed while the sediment became lithified, commonly over millions of years.

In the Blue Ridge province, the Harpers Formation of Cambrian age contains burrow trace fossils of *Skolithos linearis,* while the overlying rocks of the Antietam Formation of Cambrian age contain *Olenellus* (Walcott, 1891), the oldest trilobite fossil in the Central Appalachian Mountains region.

In the Great Valley section of the Valley and Ridge Province, the Lower Ordovician Conococheague Limestone contains some trilobites and conodonts, and abundant snails, brachiopods, echinoderms, bryozoans, and cephalopods.

In the Frederick Valley of the western Piedmont, the Cambrian Tomstown and Frederick Formations contain trilobites, algal colonies (stromatolites), and conodont microfossils. In the eastern Piedmont, slate of the Upper Ordovician Quantico Formation contains echinoderms, crinoids, and cephalopods (Pavlides and others, 1980). In the Culpeper basin in the western Piedmont, Upper Triassic rocks of the Culpeper Group yield phytosaur teeth, coelacanth fish, footprints of crocodiles, lizards, and carniverous dinosaurs, as well as plant impressions, pollen, spores, insect parts, conchostracans, ostracodes, and fish scales (Southworth and others, 2001).

An excellent review of the lithology and paleontology of the Coastal Plain deposits is provided by Ward and Powars (2004). The Early Cretaceous age of the Potomac Formation (130 to 112 Ma) is based on pollen (Doyle and Hickey, 1976) and well-preserved leaf and stem impressions of ferns, cycads, and gymnosperms. The early and middle Miocene age of the Calvert Formation (17 to 16 Ma) is based on shells, pebbles, and diatoms (Andrews, 1978). The early Paleocene age of the Brightseat Formation (65 to 62 Ma) is based on ostracodes, planktonic formanifera, and dinoflagellates. The late Paleocene age of the Aquia Formation (61 to 55 Ma) is based on molds and clasts of pelecypods and gastropods, as well as foraminifers, nannofossils, dynocysts, and mollusks (McCartan, 1989). The late Paleocene and early Eocene age of the Marlboro Clay is based on calcareous nannofossils (Gibson and Bybell, 1994). The early Eocene age of the Nanjemoy Formation is based on mollusk shells (McCartan, 1989).

Great Valley of the Valley and Ridge Province

Antietam National Battlefield and National Cemetery, Maryland

Introduction

Antietam National Battlefield (ANB) and National Cemetery (ANC) commemorate the end of Confederate General Robert E. Lee's first invasion into the North during the Civil War. The September 17, 1862 battle resulted in more than 4,000 men killed and 19,110 wounded and (or) listed as missing. Many more men died of wounds or disease in the days that followed. The carnage of the battle led to the Emancipation Proclamation by President Abraham Lincoln. Sharpsburg was turned into a hospital and burial ground extending for miles in all directions. ANC is one of 130 cemeteries of the National Cemetery System, which began during the Civil War. There are 4,776 Union remains buried here from the Battles of Antietam, South Mountain, and Monocacy; 38 percent of the buried are unknown.

Geologic Setting

ANB and ANC are located in the eastern part of the Great Valley section of the Valley and Ridge province, locally referred to as Hagerstown Valley. The bedrock consists of carbonate and clastic sedimentary rocks deposited on the continental margin of Laurentia in the Iapetus Ocean during Cambrian and Ordovician time. The rocks were buried for about 200 m.y., from the Silurian through the Permian Periods, when the rocks were folded and transported westward. This deformation was the result of the late Paleozoic Alleghanian orogeny (~285 Ma), when the African continent collided with North America. The folded rocks are part of the west limb of the Blue Ridge-South Mountain anticlinorium.

Bedrock

Tomstown Formation

The oldest rock in the park is the Dargan Member (Ꞓtd) of the Tomstown Formation, which consists of light-gray limestone interbedded with dolostone (Brezinski, 1992). A lower bioturbated dolostone alternates with intervals of laminated dolostone. In the upper part, bioturbated and oolitic dolostone is interbedded with laminated limestone and silty dolostone. These rocks are the first carbonate-platform deposits of the evolving passive margin. The vertical sequence of rocks suggests a change from shallow carbonate shelf to deep shelf to bank-edge carbonate sand shoal. These rocks are exposed in the extreme northeast corner of the park.

Waynesboro Formation

The Waynesboro Formation is subdivided into the three members: the Red Run Member (base), the Cavetown Member, and the Chewsville Member (top) (Brezinski, 1992). These members have distinctive physiographic expression. Sandstone of the Red Run (Ꞓwar) and Chewsville Members (Ꞓwac) underlie low hills with the intervening carbonate rock of the Cavetown Member (Ꞓwak) underlying a swale between the hills. The Red Run Member consists of interbedded light-brown calcareous sandstone and laminated, ribbony, sandy dolostone and light-green, silty, calcareous shale. The Cavetown Member typically is not well exposed. It consists of thick-bedded, massive limestone and bioturbated dolostone (lower); bioturbated dolomitic limestone and dolostone and thin calcareous sandstone and shale (middle); and thick-bedded, bioturbated dolostone with laminated, ribbony dolostone at the top (upper). The Chewsville Member is distinctive with its dusky red siltstone, sandstone, and shale. The siltstone generally has ripple marks and mudcracks; the sandstone is crossbedded and contains *Skolithos linearis* burrows. These rocks were deposited in a shallow subtidal to supratidal environment. Exposures occur along the valley of Antietam Creek on the east side of the park, and in roadcuts along Maryland Highway 34.

Elbrook Limestone

The Elbrook Limestone (Ꞓe) mostly consists of gray limestone interbedded with dolostone (Brezinski, 1992). The lower part of the formation consists of cyclic intervals of limestone, shale, and shaly dolostone. The middle part of the formation is largely thin-bedded, bioturbated limestone. The upper part of the formation is a thick sequence of medium-bedded algal limestone, dolostone, and dolomitic shale. These rocks are a shallowing-upward, peritidal marine deposit. The rocks are exposed between Sharpsburg and Antietam Creek, and underlying a hill in the western part of the park.

Conococheague Limestone

Conococheague Limestone (OꞒc) consists of light-gray limestone interbedded with dolostone and sandstone (Brezinski, 1992). The lower 328 feet of the formation consists of coarse-grained, calcareous sandstone, fine-grained limestone, and fine-grained dolostone of the Big Spring Station Member (Ꞓcbs). The Big Spring Station Member underlies the National Cemetery. Above the Big Spring Station Member, the Conococheague Limestone consists of conglomerates, algal bioherms, ribbon rock, and oolites, arranged in cycles. These rocks represent a shallowing-upward, peritidal marine deposit. The Conococheague Limestone underlies the higher grounds of the park, whereas the clastic rocks underlie low ridges.

Structure

The rocks are folded into a broad syncline and pair of anticlines that are secondary folds on the west limb of the Blue Ridge-South Mountain anticlinorium. The axis of the syncline corresponds with the high ground of the park north of Sharpsburg. The rocks mostly strike to the northeast, except in the hinge areas of the open folds. The rocks dip to the southeast and northwest. Cleavage associated with folding mostly dips to the southeast, axial planar to the folds, and is locally well developed or absent.

Surficial Deposits

Surficial deposits include alluvium (Qa) along modern drainages, one sinkhole (Qs) east of Burnside Bridge, and terrace deposits (Qt) along Antietam Creek.

Landforms

The high ground of the battlefield is on Conococheague Limestone in the core of a syncline that coincides with the local drainage divide between the Potomac River to the west and Antietam Creek to the east. The lower part of the Conococheague Limestone forms a swale between the Big Spring Station Member and more resistant strata. Strike belts of limestone, dolostone, and sandstone generally have trees and brush growing along them. This ridge and swale topography provided good cover for troops during the Civil War. The clastic rocks of the Waynesboro Formation underlie northeast-trending ridges with intervening swales, which in part control the location of Antietam Creek.

Blue Ridge Province

Catoctin Mountain Park, Maryland

Introduction

Human activity affected much of Catoctin Mountain Park. Between 1776 and 1903, the forests were clear-cut for timber and charcoal to fuel the iron industry at the Catoctin Furnace near Thurmont. The iron industry was established here because manganese iron ore was found in local rocks, limestone was locally available, and charcoal was a local product. In 1935, the Works Progress Administration and the Civilian Conservation Corps were employed in what was called the Catoctin Recreational Demonstration Area to rehabilitate the "sub-marginal" farmland for a recreational area. One recreational camp that was intended for Federal employees became the Presidential retreat of Camp David. In 1954, the area was divided into Cunningham Falls State Park and Catoctin Mountain Park as part of the Catoctin Project, a cooperative effort between State and Federal governments. This once-disturbed environment is now a second-growth mixed-hardwood forest ecosystem of 5,810 acres. It is part of a larger forested public lands complex that includes Cunningham Falls State Park, the Frederick and Thurmont Watersheds, and Gambrill State Park.

Geologic Setting

Catoctin Mountain Park is situated on the east limb of the Blue Ridge-South Mountain anticlinorium, immediately west of the boundary of the Blue Ridge and Piedmont provinces. The bedrock in the park is similar to that found in Harpers Ferry NHP, Shenandoah National Park, and parts of the Blue Ridge Parkway. The dominant rocks in the park are the Neoproterozoic volcanic rocks of the Catoctin Formation. These volcanic rocks are related to extensional continental rifting that occurred from about 575 to 560 Ma and resulted in the opening of the Iapetus Ocean. The volcanic rocks were overlain by quartz-rich sediments deposited by rivers on the margin of the Laurentian continent. These Lower Cambrian rocks are the Chilhowee Group, which consists of the Loudoun, Weverton, Harpers, and Antietam Formations. The rocks were buried for about 260 m.y. (from the Cambrian to the Permian Periods), metamorphosed in the Carboniferous, and deformed and uplifted during continental collision during the late Paleozoic Alleghanian orogeny to form the regional anticlinorium. A large normal fault immediately east of the park forms the border fault to the Mesozoic Gettysburg basin. Further uplift and erosion has produced extensive accumulations of coarse boulders and cobbles of the quartz-rich rocks that mantle the slopes and fill the valleys. At about 11,000 ka a cold climate, harsh landscape, and periglacial environment occurred due to the position of the continental glacier, which was located just 93 miles to the north in Pennsylvania.

Bedrock

Catoctin Formation

The oldest rocks in the park are the Neoproterozoic metavolcanic rocks of the Catoctin Formation, named after the rocks exposed on Catoctin Mountain in Maryland (Keith, 1894). From central Virginia to Pennsylvania, metamorphosed basalt (greenstone) is the dominant volcanic rock. In Maryland, however, quartz-rich volcanic rock (metarhyolite) is dominant. Catoctin Mountain Park has varieties of both metabasalt and metarhyolite (Fauth, 1977). The metabasalt consists of green, massive, and schistose, metamorphosed basalt flows containing vesicles (gas bubbles). Some vesicles are filled with secondary minerals and others are void. The metabasalt is rich in calcium and magnesium and weathers to an orange, clay-rich soil. Locally, the metabasalt contains light-green masses of quartz and epidote (epidosite) that formed during hydrothermal alteration. Metabasalt can be seen along Park Central Road and at Cunningham Falls.

Metarhyolite is a dark-bluish-black, fine-grained, foliated rock that weathers to light-gray slabs. Tan phyllite and quartz-sericite schist are locally intercalated with the metarhyolite. The cryptocrystalline metarhyolite was prized by native Americans who made tools and projectile points from it. Zircon from a sample of the same metarhyolite from approximately 9.3 miles north in Pennsylvania was dated by the U-Pb SHRIMP technique at ~560 Ma (John Aleinikoff, USGS, written commun., 2005). In addition, a metarhyolite dike that intruded gneiss dated at 1 Ga (billion years) along the Potomac River in Virginia yielded a 571±4 Ma U-Pb zircon age (Aleinikoff and others, 1995). Metarhyolite can be seen in the western part of the park on the hills and creek valley along Foxville-Deerfield Road.

Loudoun Formation

Rocks of the Lower Cambrian Loudoun Formation consist of conglomerate (Ꞓlc) and phyllite (Ꞓlp). The basal conglomerate is dark, variegated, and consists of quartz and red jasper. Most of the quartz is milky white but some is gray or dusky red. The discontinuous conglomerate probably represents local channel and fan deposits. Interbedded with the conglomerate is dark, variegated, tuffaceous, locally vesicular and amygdaloidal phyllite that also contains sand grains. The phyllite is probably a fine-grained volcaniclastic fluvial deposits derived from the weathered volcanic rocks of the Catoctin Formation. The rocks of the Loudoun Formation are transitional between the dominantly volcanic environment and fluvial environment at the boundary between the Neoproterozoic and Cambrian.

The conglomerate of the Loudoun Formation in contact with the Weverton Formation on the south bank of Big Hunting Creek. The phyllite of the Loudoun Formation can be seen along the slopes on the north side of Maryland Highway 77, east of the park's visitor center.

Weverton Formation

The Lower Cambrian Weverton Formation consists of three members (Brezinski, 1992): the Buzzard Knob Member, the Maryland Heights Member, and the Owens Creek Member. The basal Buzzard Knob Member (Ꞓwb) consists of light-gray metagraywacke, quartzite, meta-arkose, and metasiltstone and are transitional above conglomeratic rocks of the Loudoun Formation. The unit underlies the high ridge north of the visitor center and can be seen along the trails to Thurmont Vista. The Maryland Heights Member (Ꞓwm) consists of gray quartzite interbedded with metasiltstone. Rocks of the Maryland Heights Member underlie Chimney Rock and Wolf Rock and are accessible by trail. Dark-gray quartzite and pebble conglomerate of the Owens Creek Member (₵wo) is transitional above the Maryland Heights Member. These rocks are interpreted as alluvial-plain deposits. They are named after exposures along Owens Creek at the north margin of the park where they are well exposed; they are also exposed in the eastern region of the park.

Harpers Formation

Harpers Formation (₵h) consists of greenish-to-brownish-gray phyllite and metasiltstone interbedded with light-gray to brown, thin metasandstone. These rocks are transitional above the Owens Creek Member of the Weverton Formation and are found in the easternmost part of the park; they are also exposed along Big Hunting Creek. The environment of deposition was probably a delta and tidal flat.

Structure

The rocks that underlie Catoctin Mountain Park are situated on the east limb of the Blue Ridge-South Mountain anticlinorium. The axial surface of the larger fold is inclined moderately to the southeast and the fold plunges at a low angle to the northeast. The rocks are within second-order folds that verge northwest, up the east limb of the anticlinorium. The folds are disharmonic, which is due to the differential rock competency and bed thicknesses and reflected in the map pattern of the Maryland Heights Member of the Weverton Formation. The Catoctin Formation rocks are characterized by southeast-dipping cleavage that formed axial-planar to folds, although the folds are not readily recognized. This cleavage controls the inclined outcrop habit of the rocks, especially the metarhyolite, and the slab-like character of the colluvium clasts. The cryptocrystalline metarhyolite has laminations, which are flow structures that formed when the material was molten. Cross and longitudinal joints and fractures formed as the rocks were folded. Modern drainages preferentially flow parallel to these joints. Both Wolf Rock and Chimney Rock are rock cities (areas of large blocks that resemble buildings and struts) and tors (high, isolated pinnacles) that formed from weathering and gravitational spreading along these joints.

Surficial Deposits

Catoctin Mountain Park has slope deposits of colluvium so abundant and scattered, that they are too difficult to portray on the geologic map. Scree consisting of quartzite and conglomerate of the Weverton Formation and metarhyolite of the Catoctin Formation mantle all the slopes, with significant accumulations in hollows. These cobbles and boulders were transported by a combination of gravity and freeze-thaw processes, and locally they are probably active today (Godfrey, 1975). Modern streams have incised the slopes and have modified the boulder deposits and deposited alluvium (Qa). The presence of manmade dams constructed of stone and timber for trout fishing in Big Hunting Creek suggests that not much material is presently eroding and (or) being deposited. Low-level terrace deposits (Qt) of alluvium and reworked colluvium are concentrated where small creeks empty into the larger creeks. Examples are just west of the visitor center and along Owens Creek.

Landforms

The landscape of Catoctin Mountain Park is largely a function of the different types of bedrock. Nearly horizontal beds of Weverton Quartzite underlie the reclined folds on the east limb of the anticlinorium, and are expressed as prominent ridges and ledges in the east side of the park. Wolf Rock and Chimney Rock form peaks at ~1,401 ft and 1,419 ft altitude, respectively, on the crests of these ridges. Open longitudinal and cross joints form chasms that separate large house-sized blocks of bedrock (tors) that have separated from the main outcrop.

The zone along the contacts between the Catoctin Formation and the Chilhowee Group rocks, as well as between the metabasalt and metarhyolite of the Catoctin Formation, form linear valleys that parallel the northeast-trending bedding and foliation. Thurmont Vista provides a view east to the Piedmont lowland which is underlain by siltstone and limestone that are less resistant to erosion. The valleys of the Big Hunting Creek, Hunting Creek, and other unnamed tributaries mostly flow on bedrock but they are choked with blocks and boulders that accumulated from the side slopes. From the base of the ridges to the crests, the slopes everywhere are littered with similar boulders that are the result of gravity and freeze-thaw processes.

Western Piedmont Province

Monocacy National Battlefield, Maryland

Introduction

The Battle of Monocacy on July 8, 1864, marked the last campaign of the Confederate Army to carry the Civil War into the north and to capture Washington, D.C. Although the Confederates won the engagement, “the Battle that saved Washington” delayed their march on the Federal capital and allowed the capital to be reinforced. Monocacy National Battlefield (NB) encompasses 1,647 acres of farmland and forest along the Monocacy River. Although created in 1935 by an act of Congress, the land was purchased in the mid-1980s and the park opened in 1991.

Geologic Setting

Monocacy NB is situated in the western Piedmont Province along the boundary between the Frederick Valley to the west and the Westminster terrane to the east. The age of the Westminster terrane rocks has not been established. They are mostly fine-grained, unfossiliferous, sedimentary rocks that were deposited in deep, oceanic water. The rocks were metamorphosed under greenschist-facies conditions, and then folded, faulted, and transported westward along the Martic fault. The Cambrian rocks beneath and west of the Martic fault were deposited on the early margin of the Laurentian continent. These rocks were never buried deeply enough to be metamorphosed, but they were folded into the Frederick Valley synclinorium, which was probably synchronous with the folding of the Blue Ridge-South Mountain anticlinorium to the west.

Bedrock

Ijamsville Phyllite

The oldest geologic unit in the park is the Ijamsville Phyllite (₠Zi), which consists of blue, purple, and green phyllite, slate, and phyllonite that contains pods and stringers of folded white vein quartz. The fine-grained rocks are rich in hematite and probably were deposited in deep water in the Iapetus Ocean. The rocks are undated but interpreted as Neoproterozoic and Early Cambrian. These soft rocks were readily deformed, especially during movement along the Martic fault, so that the map unit is expressed as a broad shear zone (Southworth, 1996). The Ijamsville Phyllite is exposed in the extreme southeastern part of the park.

Araby Formation

The Lower and Middle Cambrian Araby Formation (₠ar) (Reinhardt, 1974, 1977) consist of light-brownish-gray, burrow-mottled, sandy metasiltstone and graphitic metashale. Bedding is obscured by cleavage. The metasiltstone and metashale are deepwater slope facies of a starved clastic basin (Reinhardt, 1974). The Araby Formation is conformably overlain by limestone and limestone breccia of the Rocky Springs Station Member of the Frederick Formation. In the northeast part of the Frederick Valley within the map area, metashale beds thicken near the top of the unit and are mapped as the Cash Smith Formation (not on the map). The Araby is exposed along the Monocacy River (where the river has cut into the ridges) in cuts along the railroad bed in the northeast part of the park, and in the road cuts in the southeast part of the park.

Frederick Formation

The Upper Cambrian Frederick Formation (Reinhardt, 1974, 1977; Brezinski, 2004) is a thick interval of thin- to medium-bedded limestone and dolostone with thin intervals of shale and sandstone. The Rocky Springs Station Member (₠fr) is characterized by intervals of polymictic limestone breccia that resulted when off-shelf submarine slide deposits accumulated at the toe of a paleo-slope (Reinhardt, 1974). An interval of gray to black shale (₠frs) locally is interbedded. A small borrow pit exposes the black shale along the trail to the Worthington House. The Adamstown Member (₠fa) consists of thinly bedded limestone with thin intervals of shale that were probably deposited as the basin became larger (Reinhardt, 1974). The Lime Kiln Member (₠fl) consists of thinly bedded limestone interbedded with algal limestone at the top of the formation. This upper member records depositional aggradation as the basin filled and became a shallow shelf (Reinhardt, 1974). The best exposures of the Frederick Formation are along the Monocacy River and within creek beds.

Structure

The rocks of the Ijamsville Phyllite above the Martic fault are structurally complex. Lower greenschist-facies (chlorite-paragonite zone) metamorphism and deformation occurred sporadically throughout the Paleozoic and resulted in folded vein quartz and multiple cleavages. The rocks of the Frederick Valley synclinorium beneath the Martic fault were deformed into folds inclined to the southeast; axial-planar cleavage is associated with one fold phase on the east limb of the synclinorium (Southworth, 1996). The quartz-rich rocks of the Araby Formation underlie ridges that define plunging anticlines.

The rocks of the Westminster terrane may have undergone metamorphism and deformation in the Silurian Period (Kunk and others, 2004), whereas formation of the Frederick Valley synclorium and Blue Ridge-South Mountain anticlinorium to the west probably happened in the Carboniferous Period during the Alleghanian orogeny (some 100 m.y. later).

Surficial Deposits

The predominant surficial deposits--fluvial terraces (Qt) and alluvium (Qa)--are found in the Monocacy River valley. Sand, gravel, and sandstone boulders on flat benches are terrace deposits as much as 50 ft above river level. The present flood plain is broad and susceptible to flooding during high rainfall. The river flows on bedrock and the alluvium locally as much as 20 ft thick. Within the flood plain are sinkholes (Qs) that formed as the result of dissolution of the underlying carbonate rocks. Fine colluvium consisting of the Araby Formation's metasiltstone chips and cobbles mantles the shallow bedrock on the lower slopes of ridges and hills.

Landforms

The landscape of Monocacy NB consists of the broad Monocacy River valley and the ridges underlain by the Araby Formation. The river is confined to the west side of the

Frederick Valley and tends to flow along the west base of the resistant ridges. These ridges, like Brooks Hill, are underlain by plunging anticlines of hard rock. Uplift and erosion has produced "valley and ridge" topography, with linear ridges and intervening valleys. To the west of the park, the landscape is a broad, open valley underlain by carbonate rocks that are susceptible to chemical erosion. To the east, the landscape is an elevated plateau underlain by fine-grained metamorphic rocks. Most of the battlefield is on the flat land which consists of terrace deposits overlying rocks of the Frederick Formation, just north of Interstate Highway 270.

Manassas National Battlefield Park, Virginia

Introduction

Manassas National Battlefield Park (NBP) was established in 1940 to preserve the land where two major Civil War battles occurred. The armies of the North and South clashed in 1861 and 1862 during the First and Second Battles of Manassas, respectively. The battlegrounds and associated monuments are within more than 5,000 acres of meadows and woodlands.

Geologic Setting

Manassas NBP is situated in the central Piedmont Province, near the eastern margin of the Mesozoic Culpeper basin. The east-flowing Bull Run forms the northern boundary of the park. Sedimentary rocks of fluvial (river) and lacustrine (lake) origin were intruded by igneous diabase at about 200 Ma (Kunk and others, 1992). The hot, molten diabase metamorphosed the red siltstone to gray hornfels near the contact. Subsequent uplift and erosion created low-level terrace deposits and extensive alluvium.

Bedrock

Groveton Member of the Bull Run Formation

The oldest rocks in Manassas NBP are gray-brown, and red siltstone and sandy shale of the Upper Triassic Groveton Member (TRbg) of the Bull Run Formation of the Chatham Group (Weems and Olson, 1997). The Groveton Member is predominately a thin-bedded, silty and sandy shale interbedded with clayey and sandy siltstone in cyclic sequences as much as 33 feet thick. Dark-gray lacustrine shale locally contains fish fossils. These stratified rocks are poorly exposed but weather to reddish or gray soil that contains abundant shale chips. Good exposures of the red shale occur along Bull Run. Several historic houses in the park and the Route 29 stone bridge at Bull Run were constructed of this red slablike rock as it makes good dimension stone.

Diabase

Linear, near-vertical dikes and near-horizontal sheets (sills) of diabase (Jd) intruded the sedimentary rocks at about 200 Ma. The occurance of diabase is characterized by a float of light-gray, subrounded cobbles and boulders commonly with a rusty weathering rind. Diabase underlies the ridge that trends northeast through Battery Heights to near Sudley Springs, where abundant float can be seen along Bull Run. Appropriately, diabase also underlies Stony Ridge in the western part of the park.

Thermally Metamorphosed Rocks

The siltstone was metamorphosed to hornfels (JTRtm) where it came into contact with the hot, molten diabase. Hornfels is light-grayish green, very finegrained, brittle rock with porphyroblasts of minerals that grew as the result of the heat. Siltstone and shale are altered to cordierite-spotted hornfels in the inner aureole, and epidote-chlorite hornfels characterizes the outer aureole. Sandstone is metamorphosed to tourmaline granofels and quartzite. Thin belts of hornfels are adjacent to narrow diabase dikes. The lowland between Stuarts Hill and Stony Ridge in the southwestern part of the park is underlain by hornfels.

Structure

The sedimentary rocks dip to the northwest. Down-to-the-east motion along a normal fault to the west of the park resulted in the rotation of the horizontal beds to the inclined attitude. The diabase in the western part of the park has two geometries. The easternmost body is a near-vertical dike that intrudes a near horizontal sill. Normal faults cut both of them. Fractures in the stratified rocks trend northeast and northwest and the drainage patterns parallel both sets.

Surficial Deposits

Terrace deposits (Qt) and broad alluvial deposits (Qa) underlie the valley along Bull Run and Youngs Branch. The creeks and streams in the region readily erode the soft red siltstone and shale, and the rocks are generally exposed in the beds and in the bluffs along the drainages. Thin soil is developed on the siltstone and shale and locally there is extensive sandy residuum developed on the diabase. The diabase and hornfels are hard, resistant rocks; they are also aquitards (confining beds), therefore ground water in fractures has facilitated their breakdown.

Landforms

The very prominent, northeast-trending grain of the topography is due to west-dipping siltstone beds that occur at shallow depths, and to several northeast-trending diabase dikes and faults. The area of diabase sills and hornfels in the west part of the park underlies swamp, as the rocks impede the flow of ground water.

Eastern Piedmont Province

Prince William Forest Park, Maryland

Introduction

Prince William Forest Park is the largest mixed-hardwood forest in the National Capital Region. The 15,000-acre park was established in 1936 and is located within the Quantico Creek watershed. It contains remnants of Joplin and Hickory Ridge, two small communities that existed prior to the park's establishment. The Civilian Conservation Corps (CCC) built the facilities, roads, and lakes during the 1930s, and the U.S. Army's Office of Strategic Services (OSS) used the land exclusively for training spies and radio operators between 1942 and 1945.

Geologic Setting

Prince William Forest Park straddles the Fall Zone, which is the boundary between the eastern Piedmont province and the Atlantic Coastal Plain province. The bedrock is a suite of volcanic, sedimentary, and plutonic rocks associated with a Middle Ordovician to Early Silurian island arc. The rocks were buried and metamorphosed in the late Paleozoic as the result of the Alleghanian orogeny, and then uplifted and beveled to a plateau. The bedrock is overlain by sediments of the Coastal Plain that are Cretaceous (~ 150 Ma) to Pleistocene (~10 Ma) in age. The forest and level ground seen along the scenic loop road show that the unconsolidated sediments of the Coastal Plain once extended far west of its present limit. Since the Pleistocene Epoch, rivers and creeks have created high-and low-level terraces, as they incised modern alluvium deposits.

Bedrock

Mafic and Ultramafic Rocks

The oldest rocks in the park are mafic and ultramafic rocks (ЄZum) that include epidote-hornblende gneiss and amphibolite. Pavlides (1980) interpreted these as Neoproterozoic and (or) Cambrian rocks deposited in the diamictite of the Lunga Reservoir Formation. The rocks are poorly exposed in the north-central part of the park.

Phyllite

Phyllite and metasiltstone (OЄp) were interpreted by Pavlides (1980) to be Ordovician and (or) Cambrian. These fine-grained rocks are poorly exposed in the extreme northwest part of the park.

Lake Jackson Pluton

Biotite and muscovite metatonalite of the Lake Jackson pluton (Olj) (Pavlides, 1980) is composed of albite, quartz, and perthite, with inclusions of phyllite (OЄp). The area underlain by the poorly exposed metatonalite has abundant boulders of metamorphic vein quartz that litter the surface. Metatonalite yielded a zircon U-Pb SHRIMP age of 461±7 Ma (Aleinikoff and others, 2002).

Chopawamsic Formation

The only rocks in the park that have been isotopically dated are part of the Ordovician Chopawamsic Formation (Oc) (Pavlides, 1980). These are metavolcanic and metasedimentary rocks derived from an island arc. The metavolcanic rocks include porphyritic volcanic flows, breccias, and tuffs that range in composition from rhyolite to andesite to basalt. The metavolcanic rocks are interbedded and interlayered with dark-gray slate, phyllite, schist, and metasandstone that were derived from weathering of volcanic rocks.

Coarse breccias and thin metabasalts interlayered with slate and metasiltstone (Ocg) are mapped separately. These metabasalts are exposed along Quantico Creek downstream of the Cabin Branch pyrite mine. Metarhyolite of the Chopawamsic Formation yielded a zircon U-Pb SHRIMP age of 454±5 Ma (Horton and others, 1998). Metabasalt of the Chopawamsic Formation from central Virginia is 470±1.4 Ma (Coler and others, 2000). The rocks of the Chopawamsic Formation are exposed along the North Valley Trail along Quantico Creek and South Fork Quantico Creek along the South Valley Trail.

Lunga Reservoir Formation

The dominant rock in the park is a sedimentary mélange that was named the Lunga Reservoir Formation (Olr) by Pavlides (1980). The diamictite resembles a granitic rock with xenoliths, as it contains a mixture of pebbles and cobbles of other rock types. The matrix is composed of rounded grains of quartz and plagioclase feldspar that eroded from a granitic rock. The pebbles and cobbles within the matrix consist of clear and milky white quartz, mica schist, calc-silicate rocks, and mafic and ultramafic rocks. The diamictite is a deep-water deposit of debris shed from the island arc during the Ordovician (Pavlides, 1980). Locally near the fault contact with the Chopawamsic Formation, the Lunga Reservoir Formation contains rock fragments that look similar to the Chopawamsic and may be derived from it. The Lunga Reservoir Formation is exposed along South Fork Quantico Creek.

Quantico Formation

In the eastern part of the park, dark-gray slate, metagraywacke, and tuffaceous metavolcanic rocks constitute the Quantico Formation (Oq) (Pavlides, 1980). The dark- gray slate is graphitic and sulfidic. Pyrite was mined from 1889 to 1919 at the Cabin Branch mine along the southwest side of Quantico Creek. The pyrite was mined for sulfur as an ingredient in gunpowder, especially during World War I. There is recent interest in reclamation of the mining area (Seal and others, 1998a,b).

A metamorphosed lapilli-tuff layer in the lower part of the formation yielded a zircon U-Pb SHRIMP age of 451±6 Ma (Horton and others, 1998). These rocks are exposed along Quantico Creek and its tributaries north of the visitor center and immediately east of the park. About 5.6 miles north of the park entrance, Pavlides and others (1980) found crinoids and a cephalopod in slate of the Quantico Formation.

Felsic Intrusive Rocks

Well-foliated biotite metatonalite and hornblende-quartz diorite (Oi) also intruded the rocks of the Chopawamsic Formation. Biotite metatonalite has a zircon U-Pb SHRIMP age of 434±6 Ma (Horton and others, 1998), which makes it one of the youngest dated rocks in the park. These rocks are exposed along Quantico Creek along the Quantico Falls Trail.

Structure

The bedrock in Prince William Forest Park has a well-developed foliation that is nearly vertical in orientation. The metamorphism and deformation associated with the development of the foliation is younger than the 434 Ma foliated felsic intrusive rocks. Data from an $^{40}Ar/^{39}Ar$ traverse along the Rappahannock River about 9.3 miles to the south by Sutter and others (1985) suggest that cooling from metamorphism of the region ranged from 321 to 307 Ma (Late Mississippian to Early Pennsylvanian) as part of the Alleghanian orogeny. The trace of the fault between the Chopawamsic Formation and the Lunga Reservoir Formation suggests that the fault is folded, so it may predate the Alleghanian metamorphism and deformation event.

Atlantic Coastal Plain Deposits

Unconsolidated sediments more than 130 feet thick comprise the Atlantic Coastal Plain deposits that overlie the bedrock units in the eastern part of the park (Mixon and others, 1972). These sediments are arranged in a complex pattern of cut and fill so that the distribution of materials is not continuous.

The Potomac Formation (Kp) contains the oldest sediments, which consist of quartz- and feldspar- sand and pebbles that grade into silty sand, clayey silt, and silty clay. The clay contains rare stems of plants that were replaced with silica and coal. The Potomac Formation was deposited in channels, bars, and flood plains by rivers that flowed eastward. The sediment tapers to a feathered edge to the west.

Lower and Upper Cretaceous deposits are overlain by sand and gravel of Miocene upland terrace deposits (Ttu). Sandy gravel and gravelly quartz sand contain large pebbles and cobbles of vein quartz and quartzite. The lower part is sandy with clayey silt and was deposited in marine waters.

Early Pleistocene upper-level fluvial and estuarine deposits (Qfe) overlie the Miocene sand and gravel. They consist of boulder and gravel beds at the base overlain by feldspathic quartz sand containing local thin clay beds.

Low-level fluvial and estuarine deposits (Qte) consist of sand, sand interbedded with thin silt, and clay beds that locally contain wood fragments. Sandy clay beds contain scattered pebbles and cobbles, and limonite-filled root zones capped by sand.

Surficial Deposits

Since the Pleistocene, rivers and creeks have incised into bedrock to make strath terraces consisting of sand and gravel deposits in the eastern part of the park. There are high-level (QTt) and low-level (Qt) terraces that relate to different episodes of downcutting that probably relate to changes in climate and (or) tectonic uplift. Modern creeks continue to incise bedrock, and alluvium (Qa) continues to be deposited in modern creeks, especially during flood events.

Landforms

Much of Prince William Forest Park retains the upland plain characteristic associated with the previous extensive Coastal Plain that once blanketed the entire region. There are remnants of these Coastal Plain deposits in the central part of the park along the loop road. Incision by drainages in the last several million years has exposed bedrock in the creek bottoms. The Fall Zone in the park is at least 3.1 miles wide. The fall line proper is east of the park. Some small falls are located mostly in the eastern part of the park.

Parks along the Potomac River Corridor, Virginia and Maryland

Introduction

National Capital Region parks along the Potomac River corridor include those parks administered by the George Washington Memorial Parkway (GWMP) and the NCR Parks-East. Because of the noncontiguous nature of these parklands, a geologic strip map was made to cover the Potomac River corridor from Great Falls Park to Mount Vernon Estate and Gardens in Virginia, Washington, D.C., and Piscataway Park, Md. (see plate). The geology of Great Falls Park, GWMP, and Turkey Run Park are emphasized.

Great Falls Park, Virginia

Introduction

George Washington helped establish the Patowmack Canal Company in 1785 to enable transportation around the Great Falls of the Potomac River. The goal was to link the eastern seaboard with land being settled in the Ohio Valley. The canal was completed in 1802; for 26 years, boats loaded with cargos of grain, flour, pig iron, tobacco, meat, cast-iron stoves, and more were lifted and (or) lowered around Great Falls through the town of Matildaville. In the early 1900s, the area became an amusement park that included overlook decks, an observation tower, a dance pavilion, a light show, a wooden carousel, a Lovers Lane along the Patowmack Canal ruins, and an inn (Dickey's Inn) for lodging and dinners. The amusement park closed and Potomac Edison Power Company (PEPCO) purchased the land to construct a hydroelectric dam. Fairfax County Park Authority leased the land from PEPCO. National Park Service acquired the 800 acres in 1966 and constructed a visitor center, 15 miles of trails, and stabilized the locks of the Patowmack Canal.

Geologic Setting

Great Falls Park is located in the eastern central part of the Piedmont province along the Potomac River. The sedimentary and igneous rocks were metamorphosed and deformed several times during the Paleozoic Era (Kunk and others, 2004, 2005). Erosion by the Potomac River over the past 35,000 years (Bierman and others, 2004) formed bedrock strath terraces as the river cut laterally and downward. Great Falls is the largest waterfall of the Potomac River as it drops about 80 ft over a distance of about 1,000 ft. Great Falls is not located on what is usually referred to as the "Fall Line," which is the boundary between the Piedmont and Coastal Plain provinces. Instead, Great Falls Park is within a 20-mile-wide Fall Zone that extends from Theodore Roosevelt Island west to Seneca Falls. To appreciate the erosive power of the river, compare the landscape of Great Falls Park with that of Wolf Trap Park, which shares the same bedrock.

Bedrock

Introduction

The rocks in Great Falls Park consist of (1) kyanite-staurolite-garnet-muscovite schist interbedded with thin metagraywacke (ЄZms), (2) metagraywacke interbedded with schist (ЄZmg), and (3) migmatitic metagraywacke (ЄZmmg). Migmatitic metagraywacke contains bodies of amphibolite (ЄZa) and granodiorite (Ob). Several lamprophyre dikes (Dl) intruded the metagraywacke near the southern overlook. Collectively, the rocks constitute the Bear Island domain (Kunk and others, 2004, 2005), which is a distinct metamorphic and structural unit.

Ultramafic Rocks and Amphibolite

Some of the oldest rocks exposed in Great Falls Park are bodies of amphibolite (ЄZa) found within rocks of the Mather Gorge Formation. Bodies of dark-greenish-black amphibolite are found within migmatitic rocks of the Mather Gorge Formation from Cow Hoof Rock east to Difficult Run. These rocks are either intrusive dikes and sills, or blocks of volcanic rock deposited within the enclosing turbidites. The amphibolite rocks are undated, but $^{40}Ar/^{39}Ar$ amphibole metamorphic cooling ages suggest that the rocks can be no younger than 480 Ma (Kunk and others, 2004, 2005). Ultramafic rocks (ЄZu) occur west of the entrance to the park. These dark, massive rocks are interpreted to be oceanic crust that was emplaced either as thrust sheets or blocks eroded from submarine cliffs. To the north in Maryland are similar ultramafic rocks (serpentinite) which underlie serpentine barrens that host unusual flora.

Mather Gorge Formation

Metamorphosed sedimentary rocks of the Mather Gorge Formation include schist interbedded with thin metagraywacke (ЄZms) and meta-arenite and metagraywacke interbedded with schist (ЄZmg). These rocks originally were impure sandstones and shales deposited as turbidites in a submarine fan. These coarse- and fine-grained rocks were deposited in a complex depositional setting that was further complicated by metamorphism and deformation. The metagraywacke contains graded beds, soft-sediment slump folds, and clastic dikes. Metagraywacke is best exposed at the falls where the water drops about 80 ft over the resistant, near-vertical beds. The dominant rocks in Great Falls Park are schists that are well exposed along the river trail and in the bluffs of Mather Gorge. The lustrous muscovite-rich schist was intruded by thin quartz veins. Both the schist and quartz veins have been more complexly deformed and folded than the more resistant metagraywacke.

The metagraywacke and schist were metamorphosed to staurolite-kyanite grade during the Ordovician when they partially melted to form migmatite. Migmatite is confined to a narrow belt between the boat landing and Difficult Run. The partially melted schist and gneiss has a soupy appearance of swirly layers of white vein quartz and light-gray granite.

Bear Island Granodiorite

The metamorphism and partial melting or migmatization described above was accompanied by the intrusion of granodiorite. These light-gray igneous intrusive rocks are called the Bear Island Granodiorite (Ob) and are named for Bear Island, where they are best exposed.

Lamprophyre

The youngest dated rocks are lamprophyre dikes (D1) that intrude the metagraywacke and schist along the bluffs near "fisherman's landing." Biotite from one of these dikes has a $^{40}Ar/^{39}Ar$ cooling age of 360 Ma, suggesting emplacement prior to Devonian cooling. The dikes are not foliated and the fractures that they intruded are open and straight. Remarkably, this suggests that the complexly deformed rocks in the gorge have not been deformed much since the Devonian.

Structure

The complex rocks in Great Falls Park were metamorphosed and structurally deformed in several episodes during the Paleozoic. The dominant foliation dips steeply southeast and is locally vertical. At the falls, the Potomac River follows the bedding and foliation of the massive metagraywacke of the Mather Gorge Formation. The river flows southeast along the linear Mather Gorge, suggesting faulting, although there is only evidence of minor faults and fracture control parallel to it.

The near-vertical rocks are coplanar to steep folds with vertical axes that locally were refolded with semihorizontal axial surfaces. Drake (1989) named these structures the Captain Hickory and Potomac fold phases, respectively. The most structurally complex rocks are the partially melted migmatitic rocks exposed along Difficult Run. The Bear Island Granodiorite and associated pegmatites display variable amounts of deformation. Some granodiorite and pegmatite bodies are foliated and folded and others are not, which suggests that there are different generations of leucocratic intrusions or discrete domains of structural deformation.

Surficial Deposits

The dominant surficial deposits in the park are the bedrock strath terraces where the parking lots, picnic areas, and visitor center are located. Rock pinnacles with potholes crop out on the surface. The potholes formed as water and gravel eroded along and into cracks. Overbank deposits during modern flood events probably filled the irregular carved bedrock surface to produce the flat strath. Boulders and cobbles of rocks that are exotic to the Great Falls area were carried downstream by the Potomac River. Boulders on Glade Hill are high-level terrace deposits. These boulders were derived from Jurassic diabase, Triassic sandstone, Paleozoic quartzite and conglomerate, and Mesoproterozoic granite, all of which originated from the area near and west of Harpers Ferry, W. Va. Extensive alluvial deposits of cobbles and sand may be seen along Difficult Run, especially along a broad meander near Virginia Highway Route 193. Local concentrations of colluvium may be seen in steep valleys or in hollows on slopes. These rocky deposits are the result of gravity, freeze-thaw processes, and debris flows related to high-rainfall events.

Landforms

Great Falls Park is obviously best known for the grand waterfall, but several other landforms are noteworthy. The entrance road to the park is on classic Piedmont upland, a thick residuum containing few rock outcrops. The residuum is exposed in deep roadcuts. The parking lots, picnic areas, and visitor center are built on a flat terrace in which the Patowmack Canal is dug into. To the southeast of the visitor center entrance is a feature known as Glade Hill, a tear-shaped hill that sits about 75 ft above the terrace. Boulders exposed on the southwest side of the top of Glade Hill were deposited in the bed of the former Potomac River. The Potomac River cut down into the bedrock, thus creating an island (Glade Hill), and the flat terrace now occupied by the picnic area was the bed of the river. The river then migrated northeast and incised downward, and created Mather Gorge. Analysis of cosmogenic ^{10}Be in quartz of exposed bedrock surfaces on the terrace and at the river level at the base of the falls suggests that the Potomac River began to cut the falls 30,000 years ago (Bierman and others, 2004).

George Washington Memorial Parkway, Virginia

Introduction

George Washington Memorial Parkway (GWMP) preserves the natural scenery along the Potomac River from George Washington's home in Mount Vernon, past the Nation's Capital which he founded, to Interstate Route 495 east of Great Falls Park, where he helped develop the Patowmack Canal. The first section of the parkway was completed in 1932 to commemorate the bicentennial of his birth. The 7,374-acre parkway protects the view of the Potomac River and the route to scenic, historic, and recreational sites. Other parklands that are administered by or accessed by the GWMP are Arlington House, Robert E. Lee Memorial, Arlington National Cemetery, Clara Barton National Historic Site, Clara Barton Parkway, Claude Moore Colonial Farm, Fort Marcy, Glen Echo Park, Great Falls Park, Lyndon Baines Johnson Memorial Grove on the Potomac, Mount Vernon Estates and Gardens, Mount Vernon Trail, Potomac Heritage National Scenic Trail, Theodore Roosevelt Island, Turkey Run Park, U.S. Marine Corps War Memorial, and Netherlands Carillon.

Geologic Setting

The GWMP transects the eastern Piedmont province (from Interstate Highway 495 at exit 14, just south of the American Legion Bridge) and the Coastal Plain province (from near Theodore Roosevelt Island south to Mount Vernon Estate and Gardens). The parkway follows the edge of the Piedmont uplands overlooking the Potomac River gorge. The only outcrops along the parkway are the cliffs of rock exposed where it descends into the river valley near Spout Run. The bedrock consists of metamorphosed sedimentary rocks of the Sykesville Formation that were locally intruded by Ordovician mafic and felsic igneous plutonic rocks. These rocks were metamorphosed and deformed in several tectonic episodes during the Paleozoic. Following uplift, the rocks were eroded to a beveled plateau, and were overlain by Cretaceous and Tertiary deposits of the Atlantic Coastal Plain. Subsequent erosion by the Potomac River produced fluvial terrace deposits during the Quaternary. There are remnant gravel deposits of probable Coastal Plain affinity as far west as Turkey Run Park and Tysons Corner corroborate that the Coastal Plain once blanketed much of the Piedmont.

Bedrock

Sykesville Formation

The Sykesville Formation (Ꞓs) (Hopson, 1964) is a sedimentary mélange consisting of a gray matrix of quartz and feldspar that contains distinctive round and tear-shaped cobbles of white and clear quartz. There are also larger boulders of dark-gray phyllonite, light-gray migmatite and metagraywacke, and greenish-black mafic and ultramafic rocks; metagabbro; and light-gray metafelsite and plagiogranite. The diamictite is massive gneiss that extends from Theodore Roosevelt Island west to the Turkey Run Park area, but it is sheared from Turkey Run Park west to the American Legion Bridge. Near the contact with the Mather Gorge Formation along the Plummers Island fault near the American Legion Bridge, the Sykesville Formation locally contains 50 percent or more cobbles of phyllonite and schist that Drake (1989) and Muller and others (1989) thought were derived from the Mather Gorge Formation. Kunk and others (2004, 2005) alternatively suggest that the Sykesville and Mather Gorge Formations were at different crustal depths and geographically separate until the Devonian; therefore, the clasts in the diamictite probably could not have come from the rocks of the Mather Gorge Formation. The massive gneiss exposed along the bluff of the Potomac below Chain Bridge was quarried for building stone in the late 1800s (Darton and Keith, 1901).

Intrusive Rocks

Rocks that intrude the Sykesville Formation include the Georgetown Intrusive Suite, Dalecarlia Intrusive Suite, Clarendon Granite, Bear Island Granodiorite, pegmatite, and vein quartz.

Georgetown Intrusive Suite

The Georgetown Intrusive Suite consists of tonalite with biotite (Ogb), tonalite with biotite and hornblende (Ogh), and ultramafic rocks and soapstone (Ogus), all of which intrude rocks of the Sykesville Formation. The igneous rocks contain many xenoliths of ultramafic, mafic, and metasedimentary rocks. Superficially, especially in Turkey Run Park, it is difficult to distinguish between the meta-igneous rocks and the diamictite of the Sykesville Formation (from which they were partially derived). The mafic rocks were altered during metamorphism. Biotite-hornblende tonalite has a U-Pb zircon SHRIMP age of 472±4 Ma (Aleinikoff and others, 2002). On the bluffs northeast of the GWMP headquarters at Turkey Run Park, dark-greenish-gray, foliated pyroxenite and serpentinite (Ogu), and talc schist and soapstone (Ogus) were quarried (Keith and Darton, 1901).

Dalecarlia Intrusive Suite

Muscovite trondhjemite (Odt) of the Dalecarlia Intrusive Suite (Drake and Fleming, 1994) intruded the diamictite of the Sykesville Formation along the Potomac River near Little Falls and along Pimmit Run. The muscovite trondhjemite is light gray to white, and fine grained with a sugary texture. Associated biotite monzogranite of the Dalecarlia Suite has a zircon U-Pb SHRIMP age of 478±6 Ma (Aleinikoff and others, 2002).

Clarendon Granite

The Clarendon Granite (Oc) is a leucocratic, foliated biotite-muscovite monzogranite that intrudes diamictite of the Sykesville Formation along Turkey Run in Turkey Run Park and Claude Moore Colonial Farm.

Bear Island Granodiorite

The Bear Island Granodiorite (Ob) (Cloos and Cooke, 1953) is a leucocratic muscovite-biotite granodiorite composed of quartz, albite, and microcline. The granodiorite and related pegmatite form small- to moderate-sized sheets, sills, and dikes within diamictite of the Sykesville Formation east of Turkey Run Park.

Pegmatite

Pegmatite (Op) is light gray and composed of coarse grains of muscovite, microperthitic microcline, albite, and quartz. It is nonfoliated and crosscuts schistosity and foliation in the Sykesville Formation along the bluffs of the Potomac River between Donaldson Run and Windy Run.

Vein Quartz

Veins, lenses, and irregular bodies of white and clear, massive, jointed, and locally foliated vein quartz (Pzq) of several different ages intruded all of the rocks along the gorge. Loose boulders of quartz commonly litter the Piedmont province because the silica is very resistant to weathering.

Structure

The bedrock structure along the GWMP corridor is complex. The rocks are on the east limb of the Potomac composite fan of Drake (1989), and the main foliation strikes northerly and dips steeply to the west. There are abundant joints and fractures along the bluffs and the river obviously utilized a set of northwest-striking joints to incise the current channel. The intersection of fractures facilitated quarry operations of the massive rock along the bluffs, east of Chain Bridge. Water seeps, freeze-thaw processes, and gravity contribute to rock falls near intersecting joints in excavations along the parkway.

Atlantic Coastal Plain Deposits

The crystalline rocks of the Piedmont are unconformably overlain by sediment derived from erosion of the mountains to the west. The oldest deposit is the Early Cretaceous Potomac Formation (Kp), which consists of unconsolidated coarse sand composed of feldspar and quartz grains, quartz gravel, montmorillonite and illite, clayey sand, and sandy silt with lignite. A clay-dominated lithofacies (Kpc) (Fleming and others, 1994) contains leaf and stem impressions and rare silicified tree trunks. Upland terrace deposits are on top of the Potomac Formation. Low, intermediate, and high terraces that are remnants of previously more extensive deposits. Low terraces consisting of alluvium and estuarine deposits of sand, silt, gravel, and peat (Qte) underlie much of the broad flood plain adjacent to the Potomac River.

The GWMP crosses the Piedmont province and rocks of the Sykesville Formation near Key Bridge and Rosslyn, Va. From here south to Alexandria, the parkway is situated on the low terrace alluvium and estuarine deposits (Qte) that consist of sand, silt, gravel, and peat. Near Theodore Roosevelt Island and Columbia Island, the parkway is built on extensive artificial fill. Near Four Mile Run, there are a series of dissected upland, low-level terrace deposits (QTt) on either side of the parkway. South of Hunting Creek and Alexandria, the parkway follows a broad alluvial plain that includes the Dyke March Wildlife Preserve and Belle Haven Park and Marina. Near the Alexandria Avenue Bridge, the parkway climbs onto upland low-level terrace deposits, then drops in altitude onto the lowland terrace alluvium and estuarine deposits (Qte). After crossing Little Hunting Creek, the parkway climbs in altitude onto the Potomac Formation (Kp). A thin sequence of the clay-dominated lithofacies of the Potomac Formation (Kpc) occurs here; it is overlain by the upland, low-level terrace deposit (QTt). At an altitude of about 140 ft, these terraces provide the view of the Potomac River that George Washington sought.

Surficial Deposits

Alluvium of unconsolidated clay, silt, sand, gravel, and cobbles underlying flood plains (Qa) are incised into the older alluvium and estuarine deposits (Qte). Colluvium occurs locally on the bluffs along the GWMP and consists of gravel, cobbles, and boulders which were derived from the coarse terrace deposits above them. Extensive fill and disturbed ground (dgf) were required to construct much of the parkway and infrastructures along the Potomac River.

Landforms

The GWMP follows the Piedmont upland from Interstate Highway 495 south to near Spout Run, where it descends onto the low plain of the Coastal Plain province. The last bedrock exposures are seen near Theodore Roosevelt Island. From here south to Mount Vernon Estate and Gardens, the parkway follows alluvial and estuarine flood plains. Near Mount Vernon the parkway climbs in altitude onto terrace deposits of the dissected Coastal Plain upland where George Washington built Mount Vernon, in part, because of the view.

Turkey Run Park, Potomac Heritage National Scenic Trail, and Claude Moore Colonial Farm, Virginia

Turkey Run Park consists of about 700 acres of forested land along the Potomac River, from the American Legion Bridge east to near Virginia Highway 123. The George Washington Memorial Parkway and the Potomac Heritage National Scenic Trail cross it, and Claude Moore Colonial Park is within it. Complex rocks underlie Turkey Run Park and the Potomac Heritage National Scenic Trail provides good access to excellent outcrops. The Potomac Heritage National Scenic Trail along the Potomac River is part of a network of trails that eventually link to the Allegheny Highlands at Pittsburgh, Pa. The trail is 10 mi-long and runs from the American Legion Bridge east to Theodore Roosevelt Island, where it joins the 17 mi-long Mount Vernon Trail.

The rocks in Turkey Run Park are complex. East of the American Legion Bridge, the dominant bedrock is diamictite of the Sykesville Formation, which is locally intruded by igneous rocks. The Sykesville Formation (Ꞓs) (Hopson, 1964) is a sedimentary mélange consisting of gray matrix of quartz and feldspar that contains distinctive round and tear-shaped cobbles of white and clear quartz. It also contains boulders of dark-gray phyllonite, light-gray migmatite and metagraywacke, and greenish-black mafic and ultramafic rocks, and metagabbro, and light-gray metafelsite and plagiogranite. Near the contact with the Mather Gorge Formation along the Plummers Island fault beneath The American Legion Bridge, the Sykesville Formation locally contains 50 percent or more cobbles of phyllonite and schist which Drake (1989) and Muller and others (1989) thought were derived from the Mather Gorge Formation. Kunk and others (2004, 2005) suggest the rocks of the Sykesville Formation and the Mather Gorge Formation were at different crustal depths and geographically separated until the Devonian. From the American Legion Bridge east for about .6 miles, the diamictite is strongly sheared into a tectonite (Ꞓst) and is part of the Late Pennsylvanian (Alleghanian orogeny) Plummers Island shear zone (Kunk and others, 2004, 2005). Here, the diamictite contains bodies of sheared amphibolite (ꞒZa) and weakly foliated biotite tonalite (Ogb).

Rocks that intruded the Sykesville Formation include the Georgetown Intrusive Suite, Dalecarlia Intrusive Suite, Clarendon Granite, Bear Island Granodiorite, pegmatite, and vein quartz. Tonalite with biotite (Ogb) tonalite biotite and hornblende (Ogh), and ultramafic rocks and soapstone of the Georgetown Intrusive Suite (Ogus) (Fleming and others, 1994) are dark-gray, medium- to coarse- grained rocks that have a relict igneous flow foliation as well as a metamorphic and structural foliation. The granular rock contains many xenoliths of ultramafic, mafic, and metasedimentary rocks. Superficially, these rocks are difficult to distinguish from the diamictite of the Sykesville Formation, which they were partially derived from. Biotite-hornblende tonalite has a SHRIMP U-Pb age of 472 ± 4 Ma (Aleinikoff and others, 2002). The remains of a building stone quarry in soapstone and pyroxenite (Ogu) that was active in the late 1880s (Darton and Keith, 1901) is located along the bluff northeast of GWMP headquarters. Float of talc schist and soapstone (Ogus) occurs along the river where the stone was probably loaded onto barges. Soapstone is also found to the east, just south of the gaging station. Both the soapstone and the foliated talc schist were originally pyroxenite that was altered during metamorphism and deformation.

Muscovite trondhjemite (Odt) of the Dalecarlia Intrusive Suite (Drake and Fleming, 1994) crops out east of where the Potomac Heritage National Scenic Trail climbs from the flood plain up to the parkway. The muscovite trondhjemite is light gray to white and finegrained with a sugary texture. Associated biotite monzogranite of the Dalecarlia Suite has a zircon U-Pb SHRIMP age of 478±6 Ma (Aleinikoff and others, 2002). Clarendon Granite (Oc) is a leucocratic, foliated biotite-muscovite monzogranite exposed along Turkey Run near Claude Moore Colonial Farm. Bear Island Granodiorite (Ob) (Cloos and Cooke, 1953) is a leucocratic muscovite-biotite granodiorite composed of quartz, albite, and microcline. The granodiorite and related pegmatite forms small- to moderate-sized sheets, sills, and dikes in diamictite of the Sykesville Formation around Turkey Run Park. The pegmatite is light gray and composed of coarse grains of muscovite, microperthitic microcline, albite, and quartz. Veins, lenses, and irregular white and clear bodies of massive, foliated and jointed vein quartz (Pzq) of several different ages intruded all of the rocks along of the gorge.

Dead Run has cut a dramatic bedrock gorge as it falls about 130 ft over a distance of about 1,000 ft to the Potomac River. Abundant blocky colluvium may be found on the bluffs of the river. In addition, rounded gravel composed of quartz and quartzite has washed downslope from the remnants of upland terrace deposits.

The Claude Moore Colonial Farm is a living history site that demonstrates the life of a poor family living on a small farm prior to the American Revolutionary War. The farm includes 12 acres planted with corn, tobacco, wheat, flax, rye, barley, and includes a kitchen garden and an orchard. The park is underlain by soil and regolith derived from diamictite of the Sykesville Formation (Ꞓs) that is intruded by biotite-hornblende tonalite of the Georgetown Intrusive Suite (Ogh) and biotite-muscovite monzogranite of the Clarendon Granite (Oc). These rocks are only exposed in Turkey Run to the northwest.

Wolf Trap National Park for the Performing Arts, Virginia

Wolf Trap National Park for the Performing Arts is underlain by bedrock similar to that of Great Falls Park. This park was a gift from Catherine Filene Shouse that Congress accepted in 1966. The 168 acres of forest and meadow was the first national park for the performing arts. This area was popular for trapping wolves for bounty in the early 1700s.

Metagraywacke (ꞒZmg) and schist (ꞒZms) of the Mather Gorge Formation are exposed along Wolf Trap Creek. Large blocks of light-gray massive muscovite-biotite granite (Og) were excavated along a sewer and water line along the creek. Abundant vein quartz (Pzq) intruded the metasedimentary rocks and large blocks of quartz are found near the creek. The structure of the rocks is complex. Foliation dips steeply to the southeast or is vertical. Wolf Trap Creek has eroded a broad valley that is underlain by alluvium (Qa). Fine colluvium (Qc) of variable thickness fills the broad hollows in the meadows. There is a lot of disturbed ground (dgf), including cut and fill from construction of the parking areas and roads.

Theodore Roosevelt Island, Virginia

Diamictite of the Sykesville Formation (Ꞓs) is exposed along the northern perimeter of the 91-acre Theodore Roosevelt Island. This is one of the easternmost exposures of bedrock in the Piedmont province. The tear-shaped island formed as the river migrated across its flood plain and incised the underlying bedrock. The morphology and genesis of the island is analogous to Glade Hill in Great Falls Park, Va., where erosion of the river created the island. The top of Theodore Roosevelt Island was farmed in the 18th century. Gravel and cobbles were not recognized on top of it during this study. The eastern side of the island is a swamp underlain by fill material.

Arlington House, Robert E. Lee Memorial, Arlington National Cemetery, U.S. Marine Corps War Memorial, and Netherlands Carillon, Virginia

Arlington House was the home of Robert E. Lee and his family for 30 years. George Washington Parke Custis, Lee's father-in-law, built the house between 1802 and 1818 to be his home as well as a memorial to George Washington, his step-grandfather. It was here that Robert E. Lee made his decision to resign from the U.S. Army and wrote his resignation letter. Arlington House and its associated slave quarters and gardens are now preserved as a memorial to Robert E. Lee, who used his influence after the Civil War to help heal the Nation.

Arlington House and the Robert E. Lee Memorial sit on the bluff of a Tertiary upland terrace deposit at about 210 ft above sea level. The terrace deposit unconformably overlies the sand-dominated lithofacies of the Cretaceous Potomac Formation. Arlington National Cemetery is developed on several units. The highest ground is underlain by an upland terrace deposit, which is incised by lower terraces. The lower area consists of terraces, alluvium, and estuarine deposits. The U.S. Marine Corps War Memorial and the Netherlands Carillon are situated on a low-level terrace deposit that is incised into Potomac Formation.

Lyndon Baines Johnson Memorial Grove and Lady Bird Johnson Park, Virginia

The Lyndon Baines Johnson Memorial Grove is located in Lady Bird Johnson Park. This low ground along the Potomac River is a combination of disturbed ground and fill (dgf) on a terrace of alluvium and estuarine deposits.

Mount Vernon Estates and Gardens, Va., Fort Washington Park, Md., Piscataway Park, Md., National Colonial Farm, Md., Marshall Hall, Md.

Mount Vernon Estates and Gardens in Virginia, the home of George Washington, is built on a series of terrace deposits above the Cretaceous Potomac Formation. The view of the Maryland shore of the Potomac River from Mount Vernon was preserved in 1952 to retain the scenery as it was during George Washington's day. On the Maryland shore, Piscataway Park extends 6 mi from Piscataway Creek to Marshall Hall on the Potomac River. Marshall Hall was built starting in 1730 by Thomas Marshall, a friend of George Washington, and was part of a tobacco plantation.

The oldest geologic unit exposed along this stretch of bluffs on the Potomac River is the Tertiary Aquia Formation (Ta). The Aquia Formation consists of olive to black, micaceous, glauconitic, extensively burrowed quartz sand with silty clay and sandy silt layers. The sediments contain molds and clasts of pelecypods and gastropods, and locally abundant ilmenite. The Aquia Formation is overlain by the Marlboro Clay (Tm), which consists of a distinctive layer of gray clay and yellow silty clay with lenses of silt. The thickness of the clay ranges from 0 to 40 ft, but typically it is 10 to 20 ft thick. The Marlboro is locally overlain by the Nanjemoy Formation (Tn), which is a dark-grayish-green, glauconitic quartz sand and silty clay containing fossiliferous beds with abundant mollusk shells. The Nanjemoy Formation is overlain by the Calvert Formation (Tc), which consists of grayish-olive quartz sand and sandy clay, with brown layers of phosphatic grains, shells, pebbles, and diatoms. The Yorktown Formation and Bacons Castle Formation (shown undivided as unit Tyb) overlie the Calvert Formation. The late Pliocene terrace contains deposits of red and tan sand and gravel with cobbles in the lower part and silt at the top. This unit is correlated with the Brandywine Formation of Glaser (1978). Locally draped along the bluff are colluvial deposits (Qc). At least one fluvial terrace (Qt) has been incised into the Aquia Formation. Adjacent to the Potomac River, alluvium (Qa) incised the Pleistocene fluvial and estuarine deposits (Qte). Much of Marshall Hall is situated on these broad alluvial-plain deposits.

Fort Washington Park guarded the Potomac River approach to our Nation's Capital. The fort was in existence during George Washington's time, as he mentioned that location in his writings, and is one of the few coastal fortifications in its original form. Over 200 years of military use has left the 341-acre park with diverse structures. Fort Washington is built on a late Pliocene terrace of Yorktown Formation and Bacons Castle Formation (Tyb), about 100 ft above the river. At Fort Washington, the oldest geologic unit is the Potomac Formation (Kp), which consists of alluvial deposits of massive, mottled, silty clay with minor sand and thin beds of tan, clayey sand. The Potomac Formation is overlain by the Monmouth Formation (Km), which consists of a basal gravel of vein-quartz pebbles overlain by sand, clayey sand, and silty sand. The Monmouth is overlain by the Aquia Formation (Ta), which in turn is overlain by the Calvert Formation, and the undivided Yorktown and Bacons Castle Formations; the latter four units are identical in composition to their occurrances along the Virginia side of the Potomac. At Fort Washington, the Yorktown and Bacons Castle are exposed in the bluffs along the river. Alluvium lies along the Potomac River and the channels of its tributaries.

Parks in the District of Columbia

Introduction

The National Capital Region (NCR) parks in the District of Columbia consist of Rock Creek Park and many diverse parks on more than 9,000 acres that are administered by the NCR Parks-Central and NCR Parks-East. These parks include statues, historic sites and buildings, recreation areas, parkways, archeological sites, tidal and nontidal wetlands, meadows, and forests. They also serve as the settings for government buildings and the museums of the Smithsonian Institution (U.S. Geological Survey, 1999). The parklands include the African-American Civil War Memorial, Anacostia Park and Kenilworth Aquatic Gardens, Baltimore-Washington Parkway, Battleground National Cemetery, Capitol Hill Parks, Constitution Gardens, Ford's Theatre National Historic Site, Fort Circle Parks, Fort Washington Park, Franklin Delano Roosevelt Memorial, Frederick Douglass National Historic Site, George Mason Memorial, George Washington Memorial Park, Greenbelt Park, John Ericsson National Memorial, Korean War Veterans Memorial, Lincoln Memorial, Mary McLeod Bethune Council House National Historic Site, National Mall, National World War II Memorial, Old Post Office Tower, Oxon Cove Park and Oxon Hill Farm, Pennsylvania Avenue National Historic Site, Piscataway Park, President's Park (White House), Sewall-Belmont House National Historic Site, Suitland Parkway, Thomas Jefferson Memorial, U.S. Navy Memorial, Vietnam Veterans Memorial, and the Washington Monument.

Rock Creek Park, D.C.

Introduction

Rock Creek Park was established in 1890 as the first and largest urban park administered by the National Park Service. Within or adjacent to Rock Creek Park are the Carter Barron Ampitheatre, Meridian Hill Park, Montrose Park, Rock Creek and Potomac Parkway, Dumbarton Oaks Park, Fort Totten Park, Fort Stevens Park, Fort DeRussy, and Fort Reno Park of the Civil War Defenses of Washington, Battleground Cemetery, Soapstone Valley Park, Pinehurst Parkway, Normanstone Parkway, Old Stone House, Pierce Mill, Palisades Park-Battery Kemble Park, Glover Archibold Park, Whitehaven Park, Melvin Hazen Park, Klingle Valley Park, and Piney Branch Parkway.

Geologic Setting

Rock Creek Park straddles the boundary between the eastern Piedmont province and the Coastal Plain province to its east. Rock Creek flows south to join the Potomac River opposite Theodore Roosevelt Island. Rock Creek is a one of the largest tributaries of the lower Potomac River located in the Piedmont. Meanders of Rock Creek are incised along bedrock fractures that strike northwest and northeast. The National Zoological Park is developed on a terrace above one of these meanders.

The bedrock consists of sedimentary rocks that were deposited in deep water and igneous rocks that intruded them. The sedimentary rocks were buried, metamorphosed, and deformed, and then intruded by mafic and felsic igneous plutonic rocks during the Ordovician Period. A near-vertical fault that trends north to south, named the Rock Creek shear zone by Fleming and Drake (1998), is located immediately west of Rock Creek. This fault was active during the intrusion of the igneous plutonic rocks, and it was reactivated during the Pennsylvanian (Kunk and others, 2004, 2005). The rocks were further uplifted during the late Paleozoic during the Alleghanian orogeny, and then were eroded to a plateau.

Surficial deposits that were eroded from the mountains to the west and by transgression of marine deposits to the east constitute the Atlantic Coastal Plain. Incision by the ancestral Rock Creek and Potomac River eroded away all but isolated patches of the Coastal Plain sediments, principally those west of the park. The remaining sediments underlie the flat ground at Ward Circle, Tenley Circle, and Wisconsin Avenue. Further incision by Rock Creek formed a series of fluvial terraces along its length that step down to the modern flood plain. Contractional tectonic stress resulted in northwest-trending faults that thrust the crystalline rocks over surficial deposits, making Rock Creek Park one of the few known areas in eastern North America that are currently tectonically active.

Bedrock

Metavolcanic and Meta-igneous Rocks

The oldest rocks exposed in Rock Creek Park are metamorphosed, mafic and ultramafic volcanic and igneous rocks that occur as bodies within the diamictite of the Laurel Formation (Ꞓl). These are intruded by Ordovician plutonic rocks. The ultramafic rocks are metagabbro and metapyroxenite (ꞒZg) that have been further altered to soapstone, talc schist, serpentinite, or amphibolite (ꞒZu). Soapstone, talc schist, and actinolite (ꞒZt) are greenish-gray and fine- to coarse-grained; the schist is foliated. They are found near Connecticut Avenue at the head of Soapstone Branch, where Native Americans quarried them to make implements. Although many quarries and outcrops have been filled in and buildings constructed on them, there are abundant cobbles of greasy-textured soapstone and talc schist in the lower flood plain of Soapstone Branch. The soapstone and talc schist were likely derived from the mafic rocks by hydrothermal alteration during metamorphism and deformation. Amphibolite (ꞒZa) is dark green and black, medium to coarse grained, foliated and composed of hornblende, plagioclase, and epidote. Elongate bodies of amphibolite extend from Broad Branch south to the National Zoo. Dark-greenish-black metagabbro and metapyroxenite (ꞒZg) composed mostly of pyroxene occur at the southeastern end of the National Zoo.

Laurel Formation

The Laurel Formation (Ꞓl) is a sedimentary mélange that is similar to the diamictite of the Sykesville Formation. Rocks of the Laurel Formation have a matrix of quartz and feldspar that support fragments, elongate cobbles, and bodies of meta-arenite and muscovite-biotite schist. Unlike the Sykesville Formation, the Laurel Formation locally consists of more than 50 percent meta-arenite clasts. This unique rock is exposed in the drainage at Klingle Park. Some exposures of Laurel Formation show pegmatites and leucosomes indicative of partial melting and migmatization.

Sykesville Formation

The Sykesville Formation (Ꞓs) (Hopson, 1964) is a sedimentary mélange consisting of a gray matrix of quartz and feldspar that supports distinctive rounded and elliptical white and clear quartz cobbles, and blocks of dark gray phyllonite, light gray migmatite and metagraywacke, and dark greenish black mafic, ultramafic, and metagabbro rocks, and light gray metafelsite and plagiogranite. The Sykesville Formation occurs at the mouth of Rock Creek Park and as a large northerly trending xenolith within the Kensington Tonalite in Woodley Park. The contact of the Laurel and Sykesville Formations along Rock Creek is interpreted to be the Rock Creek fault that has been overprinted by the Rock Creek shear zone. The body of Laurel Formation in Woodley Park is probably a xenolith within metatonalite.

Georgetown Intrusive Suite

The Georgetown Intrusive Suite intrudes rocks of the Sykesville Formation and Laurel Formation in and around Rock Creek Park. These rocks occur in bodies that are structurally aligned in a northerly direction along foliation within the Rock Creek shear zone. In this park, the suite is composed of gabbro and three varieties of tonalite (Fleming and others, 1994). Garnetiferous biotite-hornblende tonalite (Ogr) is a dark-gray, coarse-grained well-foliated to gneissic rock that typically contains less than 25 percent biotite and hornblende and abundant mafic inclusions. It occurs as an elongate body striking north to south along the Rock Creek fault. Biotite tonalite (Ogb) is a dark-gray, medium- to coarse-grained, massive to well-foliated tonalite that contains from 20 to 40 percent biotite and numerous inclusions of gabbro, amphibolite, biotite-hornblende tonalite, and metasedimentary rocks, as well as layers of biotite-hornblende tonalite. It is exposed near the mouth of Piney Branch. Quartz gabbro (Ogg) is a dark-gray, medium- to coarse-grained quartz-augite-hornblende gabbro that contains thin cumulate layers of pyroxenite. A body of quartz gabbro is aligned in a northerly direction from Klingle Park to Pierce Mill. Biotite-hornblende tonalite (Ogh) is a light-gray, medium- to coarse-grained tonalite that contains xenoliths of mafic and ultramafic rocks. There are at least three bodies of this rock along Rock Creek near the National Zoo. It has a U-Pb zircon SHRIMP age of 472 ± 4 Ma (Aleinikoff and others, 2002).

Kensington Tonalite

The Kensington Tonalite (Ok) (Cloos and Cooke, 1953; Fleming and others, 1994) intruded rocks of the Sykesville Formation and Georgetown Intrusive Suite in the Rock Creek shear zone. Within this 1.8-mile-wide shear zone, it consists of foliated mylonitic granodiorite gneiss that contains augen and coarse porphyroblasts of microcline. The tonalite is light gray, coarsegrained, and well foliated, with muscovite and biotite and locally garnet. It has a SHRIMP U-Pb zircon age of 463±8 Ma (Aleinikoff and others, 2002).

Light-colored Granite

Small dikes, sheets, and irregular bodies of fine- to coarse-grained, well-foliated muscovite monzogranite and granodiorite (Ogl) occur near National Zoo and north of Military Road on the east side of Rock Creek. This intrusive rock contains as much as 3 percent biotite and hornblende and is probably related to rocks of the Georgetown Intrusive Suite and Kensington Tonalite.

Quartz Bodies

White, massive, and fractured vein quartz (Pzq) intruded the Kensington Tonalite near the Rock Creek shear zone in the northern part of the park. Float of similar vein quartz throughout the area suggests that it is common.

Structure

The rocks in Rock Creek Park are foliated and dip steeply to the west, with metasedimentary and meta-igneous rocks strongly aligned north to south along the Rock Creek fault and shear zone. Kensington Tonalite intruded rocks of the Laurel Formation along the Rock Creek fault. The Rock Creek shear zone later juxtaposed rocks of the Laurel Formation against rocks of the Sykesville Formation, Georgetown Intrusive Suite, and Kensington Tonalite. The rocks were sheared for about .93 mi on either side of the fault, creating a dominant tectonic feature in the Piedmont of eastern North America (Fleming and Drake, 1998).

The shear zone has an exposed length of 15.5 mi and width of up to 1.9 mi, and a very complex history, as follows:

(1) Rocks of the Sykesville and Laurel Formations were juxtaposed along an early Rock Creek fault (Fleming and Drake, 1998).

(2) Biotite-hornblende tonalite of the Georgetown Intrusive Suite dated at 472±4 Ma by Aleinikoff and others (2002) intruded the fault and the rocks on either side of it.

(3) Mylonitic foliation was formed by sinistral shearing under middle-amphibolite metamorphic conditions during emplacement of the Kensington Tonalite at 463±8 Ma (late Middle Ordovician) (Aleinikoff and others, 2002), followed by ductile sinistral faulting with top-to-the-northwest motion.

(4) $^{40}Ar/^{39}Ar$ hornblende-cooling ages of middle Early Devonian (~400 Ma) across the fault suggest that the Rock Creek shear zone has had little vertical offset since then.

(5) Ultramylonitic foliation with quartz ribbons and oblique shear bands formed during dextral shearing under greenschist-facies metamorphic conditions in the Late Mississippian and Early Pennsylvanian (320 to 310 Ma) (Kunk and others, 2004).

(6) Oblique, west-side-up, dextral faults were active with the ductile to brittle transition during uplift in the Early Permian (281±13 Ma) (Kunk and others, 2004, 2005).

(7) Early Jurassic to Early Cretaceous (197±21 Ma) apatite fission-track cooling ages reflect the time of uplift (Kunk and others, 2004, 2005).

(8) A system of post-Cretaceous, north-northwest-directed thrust faults in crystalline rocks cut the Coastal Plain strata as late as the Quaternary (less than 1.8 Ma). The distribution of Cretaceous and Tertiary deposits as well as the Quaternary terraces suggest that the west side of the Rock Creek shear zone has been uplifted, incised, and eroded more than the area to the east.

Atlantic Coastal Plain Deposits and Landforms

The oldest Coastal Plain deposits are the Potomac Formation (Kp). Both the sand-dominated facies (Kps) and the clay-dominated facies (Kpc) of the Potomac Formation are found on the east side of Rock Creek Park. The Calvert Formation (Tc) occurs only on the west side of Rock Creek Park in Cleveland Park. There are at least four terrace levels along Rock Creek that may be related to the ancestral Potomac River. The oldest upper-level terrace (Ttu) occurs on a flat bench at an altitude of about 360 ft above sea level, west of Rock Creek Park near Walter Reed Army Medical Center. There are at least three lower-level terraces (Tt) in the area. The next highest terrace underlies the area of the Carter Barron Ampitheatre. An intermediate-level terrace underlies the broad area opposite the National Zoo, and a low-level terrace is incised into the intermediate terrace south of the zoo. These terraces probably range from middle Miocene (~13.5 Ma) to late Pliocene (2.5 to 1.8 Ma) based on pollen and stratigraphic correlation (McCartan, 1989). Colluvium (Qc) derived from Tertiary deposits on the uplands forms drapes of cobbles on the slopes near Woodley Park. Although interpreted to be Tertiary in age by Fleming and others (1994), the colluvium has probably been accumulating since then as well.

Rock Creek Park is centered on the Rock Creek Valley, which has as much as 150 ft of relief from the channel to the terraces on the upper plateau. The creek flows on bedrock with few falls, yet regionally it marks the Fall Line. On either side of the valley is a plateau of the Coastal Plain. The east side of the valley is the Coastal Plain proper. The west side of the valley has dissected Coastal Plain deposits locally preserved at Tenley Circle, Fort Reno, American University, and Washington Cathedral.

A study of topographic change by Chirico (2004) compared 1:4,800 scale maps made by the U.S. Coast and Geodetic Survey in 1888 with current topographic data made in the late 1990s in order to determine areas where land has changed. The cumulative effect of cut-and-fill activities throughout the city's past 100-year history has drastically modified the landscape. Two important factors when considering urban land use and ecology are whether the flatlying landforms are natural or manmade and the character of the subsurface materials.

Surficial Deposits

There are at least three levels of terrace deposits along Rock Creek that are Tertiary to Holocene in age. The upper-level terrace deposits (QTt) consist of sand, gravel, and boulders that underlie flat benches that were cut into bedrock. Early Pleistocene upper-level fluvial and estuarine deposits (Qfe) consist of swamps that overlie bedrock and Tertiary sediments near the mouth of Rock Creek Park. These deposits are in a basin that forms the lowlands of Washington, D.C. They are bounded on the north by an arcuate berm that is incised into bedrock and the Potomac Formation. The berm has the morphology of a fluvial meander perhaps cut by the ancestral Potomac River. Low-level terraces (Qt) form flat benches along Rock Creek and have sand, gravel, and boulders scattered on their surfaces. An unsorted mixture of fine and coarse debris (Qd) fills hillslope depressions. The debris is material that was deposited by gravity, water, and debris-flow processes. Colluvium (Qc) on the berm of the terraces consists of an unsorted mixture of pebbles in clayey sand or sandy clay, which was transported mostly by gravity. Alluvium (Qa) consists of unconsolidated clay, silt, sand, gravel, and cobbles, and underlies flood plains of Rock Creek (Smith, 1976). A few areas of disturbed ground and artificial fill (dgf) are shown on the map.

Other Parks Around Rock Creek Park

- Carter Barron Ampitheatre is situated on a terrace just east of a bluff overlooking Rock Creek. Diamictite of the Laurel Formation (Ꞓl) is unconformably overlain by the Cretaceous Potomac Formation (Kp) and upper-level terrace deposits (Tt).

- Meridian Hill Park is situated on a terrace (Tt) above the Cretaceous Potomac Formation (Kp).

- Montrose Park is situated on a low-level terrace (Tt) above biotite-hornblende tonalite of the Georgetown Intrusive Suite (Ogh).

- Dumbarton Oaks Park is underlain by biotite-hornblende tonalite (Ogh) and biotite tonalite (Ogb) of the Georgetown Intrusive Suite; several low terraces (Tt) and (T3) are also found there.

- Soapstone Valley Park covers an area from Broad Branch westward across the Kensington Tonalite (Ok) to soapstone (ꞒZt) at Connecticut Avenue.

- The Palisades Park and Battery Kemble Park are underlain by diamictite of the Sykesville Formation (Ꞓs), which is intruded by biotite-hornblende tonalite (Ogh) of the Georgetown Intrusive Suite. Ultramafic rocks (€Zu) may be found in Battery Kemble Park beneath a debris-fan deposit (Qd).

- Glover Archibold Park is underlain by different varieties of the Georgetown Intrusive Suite. A few bodies of metagraywacke occur as xenoliths (€sg).
- Whitehaven Park crosses rocks of the Georgetown Intrusive Suite that are overlain by terraces (Tt).
- Melvin Hazel Park crosses the Kensington Tonalite (Ok) between the Rock Creek fault and the ultramafic rocks (€Zu) near Connecticut Avenue.
- Klingle Valley Park is underlain by diamictite of the Laurel Formation (€l) and associated mafic rocks (€Zg), and by the Kensington Tonalite (Ok) across the Rock Creek shear zone. The tonalite has large xenoliths of Georgetown Intrusive Suite and Sykesville Formation (€s).
- Rock Creek and Potomac Parkway transects the Laurel Formation (€l) and associated ultramafic rocks (€Zu), Sykeville Formation (€s), Kensington Tonalite (Ok), and biotite-hornblende tonalite (Ogh) of the Georgetown Intrusive Suite. The parkway also crosses alluvium (Qa), debris-fan deposits (Qd), and low-level terraces (Qt).
- The Pinehurst Parkway crosses the Kensington Tonalite (Ok).
- The Normanstone Parkway is built on Kensington Tonalite (Ok), and three different varieties of the Georgetown Intrusive Suite.
- The Piney Branch Parkway crosses rocks of the Laurel Formation (€l) and the biotite tonalite (Ogb) of the Georgetown Intrusive Suite that intrudes it.

The National Mall

Part of the National Mall is situated on early Pleistocene fluvial and estuarine deposits (Qfe) that also underlie the high ground of Capitol Hill. Low-level terrace alluvium and estuarine deposits (Qte) are incised into the fluvial and estuarine deposits and they underlie the Mall east of the Washington Monument. West of the Washington Monument is extensive disturbed ground and artificial fill (dgf). Earthen material was used to fill the former valley of Tiber Creek and reclaim a swamp into much of the land of the National Mall. The remaining National Mall is situated on unconsolidated sediments of fluvial and marine origin from Early Cretaceous (145-100 Ma) to Pliocene (~2 Ma) age. Landforms and deposits formed by the ancestral Potomac and Anacostia Rivers have incised into these older sediments, forming a patchwork of sediments of various ages and origins by cut and fill, and recycling. Many of the unit contacts are marked by unconformities, with as much as 34 m.y. of geologic history missing from the record. In addition, there are younger deposits of alluvial terraces, colluvium, and landslides. The flatlying units of sandy material interbedded with clay help to localize the ground water, which contributes to slope instability.

There are as many as 12 map units that are either fluvial or marine deposits. The sequence, from oldest to youngest, is as follows: the Potomac Formation (Early Cretaceous, fluvial), the Severn Formation (Late Cretaceous, marine), the Monmouth Formation (Late Cretaceous, marine), the Brightseat Formation (early Paleocene, marine), Aquia Formation (late Paleocene, fluvial and marine), Marlboro Clay (late Paleocene and early Eocene, marine), Nanjemoy Formation (early Eocene, marine), Calvert Formation (middle Miocene, marine), the Yorktown Formation (Pliocene, fluvial) and Bacons Castle Formation (late Pliocene, fluvial), early Pleistocene upper-level fluvial and estuarine deposits (Qfe), and late Pleistocene low-level terrace alluvium and estuarine deposits (Qte). Upland deposits (Miocene and Pliocene, fluvial), upper-level terraces (Tertiary and Pleistocene, fluvial), and low-level terraces (Pleistocene and Holocene, fluvial) are incised into these older deposits.

For this map, the units designated by McCartan in Davis and others (2002) are used, with some terminology of Froelich and Hack (1975), Hack (1977), and Glaser (1978).

Anacostia Park

Anacostia Park is one of Washington, D.C.'s largest recreation areas with more than 1,200 acres that also includes Kenilworth Park and Aquatic Gardens and the Kenilworth Marsh. All three are mostly developed on the alluvium (Qa) on the flood plain of the Anacostia River. Much of this area is disturbed ground and artificial fill (dgf). Bluffs of the Potomac Formation are located north and west of Langston Golf Course in the western part of the park. There are remnants of upper-level terrace deposits overlying the Potomac Formation.

Capitol Hill Parks

All of the Capitol Hill Parks are on a terrace underlain by early Pleistocene upper-level fluvial and estuarine deposits (Qfe). These parks include Lincoln Park, Folger Park, Stanton Park, and Marion Park; Maryland Avenue Triangles; Pennsylvania Avenue Medians; Seward Square and Triangles, Potomac Avenue Metro Stations, and Twining Square. Many of the parks, medians, circles, squares and triangles of the Capitol Hill Parks evolved from the city plan by Pierre L'Enfant in 1790. A system of grand avenues, public buildings and grounds dominated the overall plan.

Fort Circle Parks

Fort Circle Parks are a ring of earthen fortifications that were the Civil War defenses of Washington. Counterclockwise from the east side of Anacostia River, they are Fort Mahan Park, Fort Chapin Park, Fort Dupont Park (the largest), Fort Davis, Fort Stanton, Fort Carroll, Fort Greble, Fort Foote, Fort Bunker Hill, Fort Totten, Fort Slocum, Fort Stevens, Fort DeRussy, Fort Bayard, Fort Reno, and Battery Kemble. Also included are Fort Marcy in Virginia, and Fort Washington in Maryland. The "Fort Circle" structures were built on high topographic vantage points that were provided by geology. Fort Marcy and Fort Bayard are the only forts built on conicle hills underlain by bedrock (Sykesville Formation and ultramafic rocks, respectively) and some gravel, whereas the rest were built on Cretaceous and Tertiary terraces of sediment that were easy to excavate.

The forts range in elevation from a low of 250 ft above sea level (asl) (Fort Slocum) to a high of 400 ft asl (Fort DeRussy and Fort Reno). Fort Totten is located on an upper-level terrace (Ttu) at 310 ft asl. Fort Slocum is situated on the Potomac Formation (Kp) at 250 ft asl. Fort Stevens sits on both an upper-level terrace (Tu) and on the Potomac Formation (Kp) at 310 ft asl. Fort DeRussy is located on the Potomac Formation (Kps) at 400 ft asl. Fort Bayard is located at 330 ft asl on ultramafic rock (CZu). Fort Reno sits on an upper level terrace (Ttu) at 400 ft asl, as does Battery Kemble at 370 ft asl.

Oxon Cove Park and Oxon Hill Farm

Oxon Cove Park contains the working early 20th century Oxon Hill Farm. The farm house, barns, stable, feed and livestock buildings, and a visitor activity barn exhibit basic farming principles and techniques as well as historical agricultural programs. From the 1890s until the 1950s, Oxon Hill Farm was operated by patients from St. Elizabeth Hospital. The land varies from the low shoreline along the river to high terraces with intermediate rolling hills that were created by a sanitary landfill reclaimed in the mid-1970s.

The oldest unit is the Potomac Formation (Kp), which consists of massive, mottled, silty clay with minor sand and thin beds of tan, clayey sand. These alluvial deposits are beneath the Brightseat Formation and Monmouth Group (TKb), which is mapped as one undivided unit. These marine deposits consist of dark-gray, micaceous sand in the lower part and greenish-gray, clayey sand in the upper part. The base of the unit is a gravel layer a few feet thick. The upper part of the unit is overlain by upland terrace deposits (Ttu) and terrace deposits (QTt) that consist of gravel and sand as much as 50 ft thick. A series of low-level terraces (Qt) are incised into the Potomac Formation along the alluvial (Qa) flood plain of the Potomac River. Much of the flood plain contains artificial fill. At least one large landslide has occurred in the past (Froelich and Hack, 1975).

Greenbelt Park

Greenbelt Park is a refuge for native plants and animals, just 12 miles from Washington, D.C. It is underlain by the Cretaceous Potomac Formation, upland terrace deposits (Ttu), low-level terraces (Qt), and alluvium (Qa) along flood plains.

Suitland Parkway

Suitland Parkway is a limited-access scenic roadway that opened on December 9, 1944 (during World War II), to serve as a rapid transit road between Camp Springs (later renamed Andrews Air Force Base) in Prince George's County, Md., to Bolling Air Force Base, the Pentagon, and downtown Washington, D.C. Today the parkway is a dual-lane roadway used by visitors and commuters approaching the Nation's Capital from the east, as well as by Congressional and military personnel and foreign dignitaries who fly into and out of Andrews Air Force Base. Suitland Parkway begins in Washington, D.C., and extends 9.35 mi to Maryland Highway 4. The Maryland portion of the parkway, which is about 6 mi in length and covers about 610 acres, is under the jurisdiction of National Capital Parks-East.

The parkway transects about eight different geologic units. The oldest unit is the clay-dominated lithofacies of the Potomac Formation (Kpc), consisting mostly of massive mottled, silty clay with minor sand. The Potomac Formation is overlain by the Brightseat Formation and Monmouth Group (TKb). They consist of sand and clay of marine origin, with dark-gray, micaceous sand in the lower part and greenish-gray, clayey sand in upper part; a gravel layer a few feet thick is at base of unit. The Brightseat Formation and Monmouth Group are overlain by the Aquia Formation (Ta), which consists of olive to black, micaceous, glauconitic quartz sand with silty clay and sandy silt layers that are extensively burrowed. The clay contains molds and clasts of pelecypods and gastropods, and locally abundant ilmenite. The Aquia Formation is overlain by the Calvert Formation (Tc), which consists of grayish-olive quartz sand and sandy clay, with brown layers of phosphatic grains, shells, and pebbles, and diatoms. The Calvert Formation is overlain by upland terrace deposits (Ttu), consisting of gravel and sand as much as 50 ft thick. Terrace deposits (QTt) are locally incised into the Potomac Formation. Alluvium (Qa) underlies modern drainages. Artificial fill is on alluvium where roads cross it.

Baltimore-Washington Parkway

Opened in 1954, the Baltimore-Washington Parkway is a 29-mi long scenic highway that connects Baltimore, Md., with Washington, D.C. The part of the parkway from Washington, D.C. to Fort Meade, Md., is managed by the NPS. Although the parkway was envisioned by Pierre L'Enfant in his 18th century plan, it was not approved until 1902 for use by bicyclists and horse-drawn carriages. The parkway is built on the

Cretaceous Potomac Formation and much of it is disturbed with fill. Flood plains are underlain by alluvium and a few terraces are near the Patuxent River.

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