National Park Service
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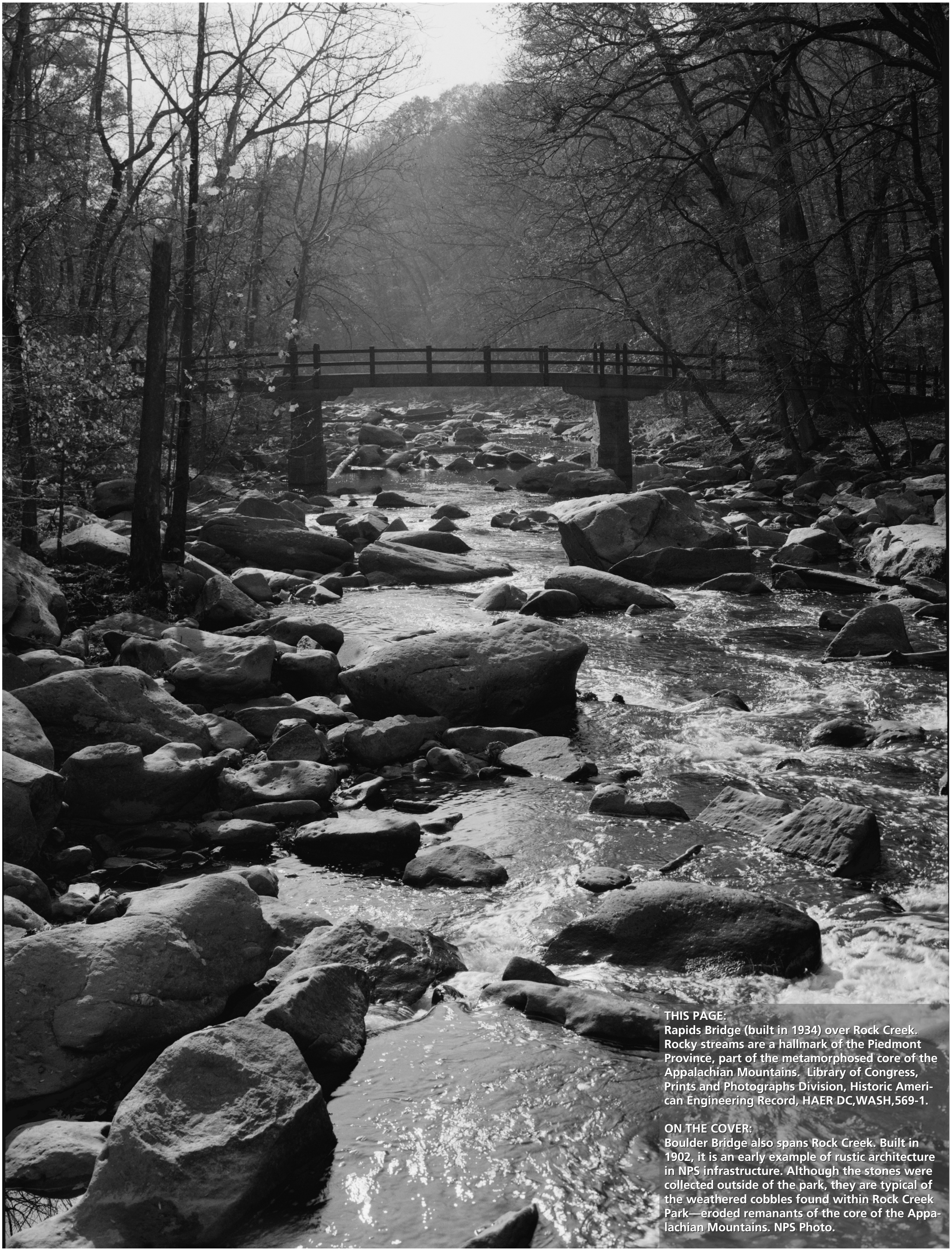
Natural Resource Program Center

Rock Creek Park

Geologic Resources Inventory Report

Natural Resource Report NPS/NRPC/GRD/NRR—2009/146



THIS PAGE:
Rapids Bridge (built in 1934) over Rock Creek. Rocky streams are a hallmark of the Piedmont Province, part of the metamorphosed core of the Appalachian Mountains. Library of Congress, Prints and Photographs Division, Historic American Engineering Record, HAER DC,WASH,569-1.

ON THE COVER:
Boulder Bridge also spans Rock Creek. Built in 1902, it is an early example of rustic architecture in NPS infrastructure. Although the stones were collected outside of the park, they are typical of the weathered cobbles found within Rock Creek Park—eroded remanants of the core of the Appalachian Mountains. NPS Photo.

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Geologic Resources Division
Natural Resource Program Center
P.O. Box 25287
Denver, Colorado 80225

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National Park Service
Natural Resource Program Center
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Executive Summary

This report accompanies the digital geologic map for Rock Creek Park in the District of Columbia, which the Geologic Resources Division produced in collaboration with its partners. It contains information relevant to resource management and scientific research. This document incorporates preexisting geologic information and does not include new data or additional fieldwork.

Rock Creek Park is one of the largest natural urban parks in the country. The park lies within the Piedmont physiographic province and contains metamorphosed sedimentary and igneous rocks of Cambrian to Ordovician age. They include granodiorite, gneiss, tonalite, schist, and serpentinitic rocks. The rocks are complex, having been intensely folded, deformed, and recrystallized during three separate tectonic events—the Taconic, Acadian, and Alleghanian orogenies—and in some areas are covered with a mantle of relatively young rock debris, alluvium, regolith, slope deposits, and soils.

Every landscape is determined by its past and present underlying rock structure. The experience of Rock Creek Park begins with the geology and with the processes through which today's environments, history, and scenery arose. Knowledge of the geologic resources directly influences resource management decisions related to the park. These issues include air and water quality, urbanization, flood risk, wildlife populations and invasive species, future scientific research projects, and interpretive needs.

Geologic processes gave rise to rock formations, hills and valleys, waterfalls and wetlands. The results of these processes played a prominent role in the history of the Potomac River and Rock Creek valleys and Washington, D.C. They develop a landscape that welcomes or discourages human use. The geology inspires wonder in visitors and should be emphasized to enhance visitor experience. Rock Creek Park is a natural geologic setting in which to emphasize the history of the area. Evidence of the early Paleozoic marine sediments and tectonic processes of the proto-Atlantic Ocean, the Paleozoic deformation of the rocks during three orogenies, and the Mesozoic and Cenozoic deposition of thick sediments shed from the mountain heights to the west are visible.

Rock Creek Park's richness in geological, historical, and cultural resources should be considered in land-use planning and in planning visitor use in the park. Production of a detailed geologic map, wayside exhibits, and a road or trail log, along with a guidebook that ties Rock Creek Park to the other parks in the National Capital Region, would meet visitor information needs. Availability of these items would enhance visitor appreciation of the geologic history and dynamic processes that created the natural landscape and emphasize the long history on display at the park. Humans have significantly modified the landscape surrounding Rock Creek Park. The geologic framework is also dynamic, operating on a human timescale. Urban developments threaten the health of the ecosystem. The dynamic system is capable of noticeable change within a human life span. The following issues, features, and processes (listed in detail in the report with suggestions for inventory, monitoring, and research) have geological importance and a high level of management significance within the park:

- Erosion and slope processes. The relatively wet climate of the eastern United States, combined with severe storms, loose soils along slopes, and streams at Rock Creek Park, makes the area susceptible to slumping, slope creep, and streambank erosion. These situations threaten historic buildings, trails, small bridges, and other features within the park. In addition, increased runoff from impervious surfaces such as parking lots can dramatically alter the landscape, create new hazard areas, and clog streams with excess sediment that affects hydrologic systems and aquatic life.

- Sediment load and channel storage. Erosion at Rock Creek Park increases the sediment carried by the park's streams. Sediment loads and distribution affect aquatic and riparian ecosystems. Sediment loading can change channel morphology and increase the frequency of overbank flooding. Fine-grained sediments transport contaminants in a water system. Hydrocarbon and pesticide levels are elevated in the Rock Creek sediments. Sediment loading follows a seasonal cycle and warrants further investigation.

- Water issues. Rock Creek, with its associated hydrogeologic system, is a primary resource at the park. The constant urban development in the Maryland–Washington, D.C., metropolitan area threatens the quality of the stream system. Threats include contamination by waste products and road salts, deforestation along the river edges that increases erosion and sediment load, and acidification from acid rain and acid snow. A working model of the hydrogeologic system within the park would help to predict environmental responses to contaminants and to remediate affected areas.

Other geologic parameters and issues, identified by scoping participants, include geologic research and recreational demands and are critical management issues for Rock Creek Park. For definitions of geologic terms used in the report, refer to the glossary.

Introduction

The following section briefly describes the National Park Service Geologic Resources Inventory and the regional geologic setting of Rock Creek Park.

Purpose of the Geologic Resources Inventory

The Geologic Resources Inventory (GRI) is one of 12 inventories funded under the National Park Service (NPS) Natural Resource Challenge designed to enhance baseline information available to park managers. The program carries out the geologic component of the inventory effort. The Geologic Resources Division of the Natural Resource Program Center administers this program. The GRI team relies heavily on partnerships with the U.S. Geological Survey, Colorado State University, state surveys, and others in developing GRI products.

The goal of the GRI is to increase understanding of the geologic processes at work in parks and provide sound geologic information for use in park decision making. Sound park stewardship relies on understanding natural resources and their role in the ecosystem. Geology is the foundation of park ecosystems. The compilation and use of natural resource information by park managers is called for in section 204 of the National Parks Omnibus Management Act of 1998 and in NPS-75, Natural Resources Inventory and Monitoring Guideline.

To realize this goal, the GRI team is systematically conducting a scoping meeting for each of the identified 270 natural area parks and providing a park-specific digital geologic map and geologic report. These products support the stewardship of park resources and are designed for nongeoscientists. Scoping meetings bring together park staff and geologic experts to review available geologic maps and discuss specific geologic issues, features, and processes.

The GRI mapping team converts the geologic maps identified for park use at the scoping meeting into digital geologic data in accordance with their Geographic Information Systems (GIS) Data Model. These digital data sets bring an interactive dimension to traditional paper maps by providing geologic data for use in park GIS and facilitating the incorporation of geologic considerations into a wide range of resource management applications. The newest maps come complete with interactive help files. This geologic report aids in the use of the map and provides park managers with an overview of park geology and geologic resource management issues.

For additional information regarding the content of this report and current GRI contact information please refer to the Geologic Resources Inventory Web site (http://www.nature.nps.gov/geology/inventory/).

Park History and Setting

Rock Creek Park, the fourth oldest national park, was created by Congress on September 27, 1890, and transferred to the NPS on August 10, 1933, from the Office of Public Buildings and Public Parks of the National Capital. The park was originally designed for the preservation "of all timber, animals, or curiosities…and their retention, as nearly as possible." The park highlights the link between the Potomac River and American history and protects a variety of cultural and natural resources in a heavily developed urban area. The park was a field site for the fifth International Congress for Geologists in 1891 and is one of the largest forested urban parks in the nation (O'Connor 1989a, 1989b). Tracts of land added to the park following its establishment include Meridian Hill Park (June 25, 1910), Montrose Park (March 2, 1911), Rock Creek and Potomac Parkway (March 4, 1913), and Dumbarton Oaks Park (December 2, 1940). Rock Creek Park is one of many NPS units in the National Capital Region (fig. 1).

Within or adjacent to Rock Creek Park and under its administration are Fort Totten Park, Fort Stevens Park, Fort DeRussy, and Fort Reno Park of the Civil War Defenses of Washington, Battleground Cemetery, Carter Barron Amphitheatre, 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 as well as a number of smaller parks and circles (fig 2., Southworth and Denenny 2006).

Rock Creek Park preserves a Piedmont stream valley in a heavily urbanized area and provides a sanctuary for many rare and unique species. The park is approximately 15 km (9.3 mi) long and as much as 1.6 km (1 mi) wide. It extends southward from the Maryland–Washington, D.C. border to the Potomac River along Rock Creek valley (fig. 2).

Rock Creek runs approximately 53 km (33 mi) from its source near Laytonsville, Maryland, in Montgomery County. It connects with the Chesapeake and Ohio (C&O) Canal 0.40 km (0.25 mi) upstream from the Potomac River confluence opposite Theodore Roosevelt Island. The Rock Creek watershed covers approximately 19,814 ha (48,960 acres), nearly a quarter of which is located within Washington, D.C. The National Park Service administers 710 ha (1,754 acres) of the basin as the original section of Rock Creek Park. Additional acreage includes the Rock Creek and Potomac Parkway and the other units listed above.

Geologic Setting

Rock Creek Park protects part of the upland section of the Piedmont Plateau, straddling the boundary between the eastern Piedmont physiographic province and the Atlantic Coastal Plain physiographic province to the east (figs. 1 and 2). Rock Creek Park lies within the Potomac River watershed, and Rock Creek, which regionally marks the Fall Line (described below), is one of the largest tributaries of the lower Potomac River in the Piedmont province (described below) (Southworth and Denenny 2006).

The Potomac River—616 km (383 mi) long from its source near Fairfax Stone, West Virginia to its mouth at Point Lookout, Maryland—is the second largest tributary of the Chesapeake Bay. The Potomac watershed stretches across Maryland, Pennsylvania, Virginia, the District of Columbia, and West Virginia. The drainage includes 38,018 square km (14,679 square mi), and covers five physiographic provinces, expressing differences in underlying bedrock, surficial deposits, and resultant landscape. From west to east, these five provinces are: (1) Appalachian Plateau; (2) Valley and Ridge; (3) Blue Ridge; (4) Piedmont—including the Potomac terrane and the Westminster terrane; and (5) Atlantic Coastal Plain (fig. 1). The Piedmont and Atlantic Coastal Plain provinces are discussed below as they relate to Rock Creek Park.

The bedrock of the area consists of deformed metamorphosed sedimentary rocks that were intruded by mafic and felsic igneous plutonic rocks during the Ordovician Period (Southworth and Denenny 2006; a geologic time scale is presented as fig. 11). A large, nearly vertical fault zone cuts the bedrock and trends north to south just west of Rock Creek. This fault was active during the igneous intrusive event and then reactivated during the late Paleozoic Alleghanian Orogeny (mountain building event). Following the last major uplift phase, the Piedmont was eroded into a plateau. Surficial deposits eroded from the mountains to the west combined with marine deposits from the east to form the Atlantic Coastal Plain (Southworth and Denenny 2006). Later contractional tectonic stress resulting in minor northwest-trending faults that thrust crystalline rocks over surficial deposits in the Rock Creek area, making it one of the few known tectonically active sites in the eastern United States (Southworth and Denenny 2006).

Rock Creek cuts through the deformed metamorphic crystalline rocks of the Piedmont Plateau. Its meanders are incised along bedrock fractures that trend northwest and northeast (Southworth and Denenny 2006). Incision by the ancestral Rock Creek and the Potomac River eroded away nearly all the Coastal Plain sediments except for a few isolated patches west of the park (Southworth and Denenny 2006). Geomorphic processes of weathering and erosion shape the landscape of the park, which contains a steep, craggy stream valley and rolling hills. The underlying geology and varied hydrological influences have resulted in a complex ecosystem. These variations and seasonal flooding along the Rock Creek floodplain support a diversity of habitats.

Piedmont Province

Encompassing the Fall Line, westward to the Blue Ridge Mountains, is the Piedmont physiographic province. The "Fall Line," or "Fall Zone," marks a transitional zone where harder, more resilient metamorphic rocks to the west intersect the softer, less consolidated sedimentary rocks of the Coastal Plain to the east, to form an area of ridges and waterfalls and rapids. This zone covers more than 27 km (17 mi) of the Potomac River from Theodore Roosevelt Island, in Washington, D.C., west to Seneca, Maryland. Examples of the falls formed by Piedmont rocks are present in the Potomac Gorge of the Chesapeake and Ohio Canal National Historical Park and at Great Falls Park.

The eastward-sloping Piedmont Plateau formed through a combination of folding, faulting, metamorphism, uplifting, and erosion. These processes resulted in a landscape of gently rolling hills starting at 60 m (200 ft) in elevation that become gradually steeper towards the western edge of the province at 300 m (1,000 ft) above sea level. The Piedmont Plateau is composed of hard, crystalline igneous and metamorphic rocks, such as schist, phyllite, slate, gneiss, and gabbro. Soils in the Piedmont Plateau are highly weathered and generally well drained.

Within the Piedmont (but outside of Rock Creek Park) are a series of Triassic-age extensional basins. These basins were formed by normal faults during crustal extension (pulling apart). The faults opened basins (grabens), and these basins rapidly filled with roughly horizontal layers of sediment. Examples include the Frederick valley in Maryland and the Culpeper valley of northern Virginia.

Atlantic Coastal Plain Province

Extending from New York to Georgia and from the Fall Line east to the Chesapeake Bay and Atlantic Ocean, the Atlantic Coastal Plain province consists of primarily flat terrain. Elevations range from sea level to about 100 m (300 ft) in Maryland. Sediments eroding from the Appalachian Highland areas to the west were intermittently deposited over the past 100 million years in a wedge-shaped sequence during periods of higher sea level. The deposits are more than 2,440 m (8,000 ft) thick at the Atlantic coast. These deposits were reworked by fluctuating sea levels and continual erosive action of waves along the coastline. The province continues as the submerged Continental Shelf for another 121 km (75 mi) to the east.

Atlantic Coastal Plain surface soils are commonly sandy or sandy loams that are well drained. Large streams and rivers in the province, including the James, York, and Potomac Rivers, are often influenced by tidal fluctuations and continue to transport sediment, extending the coastal plain eastward.

Figure 1. Map showing the physiographic provinces and selected NPS areas of the National Capital Region. Note the Fall Line—the boundary between the Piedmont and Coastal Plain provinces. Rock Creek Park is indicated with a red star. Modified from NPS Center for Urban Ecology map, courtesy Giselle Mora-Bourgeois (NPS CUE).

Geologic Issues

The Geologic Resources Division held a Geologic Resources Inventory scoping session for Rock Creek Park on April 30–May 2, 2001, to discuss geologic resources, address the status of geologic mapping, and assess resource management issues and needs. This section synthesizes the scoping results, in particular those issues that may require attention from resource managers.

Potential research projects and topics of scientific interest are presented at the end of each section. Contact the Geologic Resources Division for technical assistance regarding the suggested projects.

Erosion, Slope Processes, and Stability

The topographic differences within Rock Creek Park are large in some places. Steep slopes are dangerous because of the likelihood of rock falls, landslides, slumps, and slope creep. This is a major concern in the areas of weaker, weathered rock units and unconsolidated surficial deposits. Stronger rock units, such as metamorphic rocks, are highly fractured and prone to failure as rock fall. The likelihood of landsliding increases with precipitation and undercutting of slopes by roads, trails, and other development in addition to natural erosion.

The extensive erosion of the steep slopes is responsible for the beautiful valleys, ravines, and exposures of ancient bedrock at the park. However, these erosion processes are also the cause of an important geological resource management issue—mass wasting and rock falls. Heavy rainstorms, common in the eastern United States, can quickly saturate valley slopes. Rock and soil may mobilize on slopes that lack stabilizing vegetation and slide downhill as a massive slump or debris flow.

Inventory, Monitoring, and Research Suggestions for Erosion, Slope Processes, and Stability

- Study erosion and weathering processes active at the park. Take into account the different rock formations as composition may relate to slope, location, and likelihood of instability.
- Evaluate aerial photographs for land-use changes, historic slope failures and problem areas, shoreline changes, and stream-morphology changes over time.
- Map rockfall susceptibility by plotting rock unit versus slope in a GIS; use the map in determining future infrastructure and current resource management, including trails, buildings, and recreational areas.
- Assess trails for stability and determine which trails are most at risk and in need of further stabilization.
- Use repeated light detection and ranging (LIDAR) measurements to document changes in shoreline location and elevation along Rock Creek. Document changes immediately after storms because storms may have impacts greater than the continuous processes operating in non-storm conditions.
- Monitor erosion rates by establishing key sites for repeated profile measurements to document rates of erosion or deposition, and remeasure, if possible, shortly after major storms. Repeat photography may be a useful tool.
- Monitor steep slopes for rock movement and manage undercut areas appropriately.
- In cooperation with the U.S. Geological Survey, or other agencies, inventory, map, and monitor slope changes in the park.
- Document locations of swelling clays and assess impacts to park infrastructure.

Sediment Load and Channel Storage

Erosion of the landscape within the Rock Creek watershed leads to increases in sediment carried by the park's streams. Sediment loads and distribution affect aquatic and riparian ecosystems, and sediment loading can change channel morphology and increase the frequency of overbank flooding.

Suspended sediment load is a resource management concern because it can contaminate sources of drinking water and increase concentrations of toxic chemicals formerly trapped in river-bottom sediments. However, fine-grained sediments are also vital in the overall fluvial transport of contaminants in a water system. Some pesticides can bond to soil particles that are then transported by erosion (Anderson et al. 2002). Channel storage of fine sediment and the contaminants contained therein follows a seasonal cycle. This cycle is subject to hydrologic variability, with increased availability during the high stands of spring and decreased availability during the low stands of autumn. Fine-grained sediments do not travel downstream in a single pulse but are often resuspended bottom material (Miller et al. 1984). This intermittent transport of contaminants and fine-grained sediment increases the affected area.

According to the 1999–2000 U.S. Geological Survey study of the sediment quality in Rock Creek, bed sediments contained 12 aromatic hydrocarbon compounds in concentrations above the recommended limits: acenaphthene, acenaphthylene, anthracene, fluorene, naphthalene, phenanthrene, benz(a)anthracene, benzo(a)pyrene, chrysene, dibenz(a,h)anthracene, fluoranthene, and pyrene (Anderson et al. 2002). Additionally, all tested pesticides and pesticide transformation products present in the bed sediment samples were above recommended levels. Bed sediments contained trace elements above threshold levels for all heavy metals except arsenic and silver (Anderson et al. 2002).

Inventory, Monitoring, and Research Suggestions for Sediment Load and Channel Storage

- Assess hydrologic conditions to identify actual and potential "problem reaches" (near roadways, trails, and visitor and administrative facilities) for prioritized monitoring. Monitor identified problem reaches with repeated aerial photographs.
- Perform monitoring of fine-sediment load in Rock Creek and tributaries.
- Use shallow (25 cm, or 10 in) and deeper core data to monitor rates of sediment accumulation and erosion and analyze changes in chemical constituents of sediments.
- Correlate watershed disturbance with sediment load in streams and any reductions in aquatic biological productivity.
- Inventory current channel morphological characteristics and monitor changes in channel morphology.
- Contact NPS Water Resources Division for assistance.

Water Issues

The hydrogeologic system at Rock Creek Park provides a unique opportunity to evaluate how a protected watershed (such as the drainage basins tributary to Rock Creek) responds to environmental change. The U.S. Geological Survey has an 80-year-old gauging station in the park that provides a historic record of the stream activity (O'Connor 1990). More than five decades of gauging data indicate a historic increase in floods along Rock Creek since 1930. Flood types include thunderstorm, hurricane, sequential rains, snowmelt, and frozen ground (preventing infiltration).

Floods increase management costs for keeping bike trails and the commuter parkway open. In addition to these costs, sedimentation and debris transport cause annual damage at Rock Creek Park (O'Connor 1980). Further investigation is needed to determine environmental stimuli and responses to flooding. This knowledge will aid in budgeting for cleanup after flooding.

Although water seems to be refreshed in streams, rivers, runoff, springs, and groundwater in the humid eastern climate of Virginia–D.C.–Maryland (precipitation averages about100 cm (39 in) per year), water resources are constantly under threat of contamination and overuse because of the development of the surrounding areas.

Sedimentation increases due to clearing of land for development. Water temperature increases because of the insulating nature of impervious surfaces. For example, runoff from a parking lot on a hot July day is much warmer than runoff from a grassy slope.

Much of Rock Creek's watershed is outside National Park Service jurisdiction. The strongest regional effects on water quality in the creek are due to increased urban development and increased surface runoff from the addition of impervious surfaces in the basin, including roads, parking lots, playgrounds, and other areas (Anderson et al. 2002).

The integrity of the watershed is directly reflected in the quality of water in the creek. Differences in water quality stem from a variety of natural and non-natural sources. For instance, major geochemical differences exist between water sampled from areas underlain by different rock units as controlled by hydrolysis, or the process that controls the chemical composition of most natural waters (Bowser and Jones 2002). It is important to know the mineral compositions for both the water and the surrounding rock units.

Knowledge of the chemicals used in regional agriculture and development combined with an understanding of the hydrogeologic system, including groundwater flow patterns, is essential to protect the park's watershed ecosystem. A study in 1982 indicated that airborne lead concentrations were highest within 10 m (33 ft) of the roadways at Rock Creek Park. This appeared to result from leaded gasoline (Kasim et al. 1982). This kind of contamination from auto traffic can end up in the soils and groundwater near roadways.

The U.S. Geological Survey in cooperation with the National Park Service completed an investigation of the water and sediment quality of Rock Creek in September 2000. The study focused on the effects of land use in the surrounding basin, including management of the Rock Creek Park and Golf Course by the National Park Service. Five pesticide compounds—carbaryl, chlorpyrifos, diazinon, dieldrin and malathion—were found at concentrations above the published recommended criteria for water quality (U.S. Environmental Protection Agency 1999; Anderson et al. 2002).

Results of this study indicated that both urban and agricultural land use influences water quality within Rock Creek Park. Pesticides and herbicides come from various sources, and pinpointing their specific origin is difficult (Anderson et al. 2002). Further research into the effects of these chemicals on the aquatic life in Rock Creek Park is a next step to determining the overall health of the watershed.

The movement of nutrients and contaminants through the hydrogeologic system can be modeled by monitoring the composition of system inputs, such as rainfall, and outputs, such as streamflow. Other input sources include wind, surface runoff, groundwater, sewage, landfills, and fill dirt. Groundwater in Rock Creek Park flows along discrete fractures and joints within the relatively impermeable metamorphic rocks of the Piedmont Plateau and through the overlying sediments. Groundwater discharges directly into Rock Creek and local springs where the water table intersects the surface. Streams integrate the surface runoff and groundwater flow of their watersheds. Thus, they provide a cumulative measure of the status of the watershed's hydrologic system. Consistent measurement of these parameters is necessary to establish baselines for comparison.

Inventory, Monitoring, and Research Suggestions for Water Issues

- Establish working relationships with the NPS Water Resources Division, U.S. Geological Survey, Environmental Protection Agency, Maryland Geological Survey, as well as other agencies and conservation groups, to study and monitor the park's watershed and the hydrology of the area. Compiled data would be useful for applications in hydrogeology, soil creep, streambank erosion, and other geologic hazards.
- Apply a mass transfer and/or balance model with a forward-modeling approach to the ground and surface water at the park to quantify geologic controls on water chemistry (Bowser and Jones 2002).
- Investigate geologic controls on water pollution patterns and target remediation efforts accordingly.
- Prepare educational exhibits to describe the natural processes of floods, including the benefits to soil fertility.
- Investigate and implement techniques to stabilize floodplain areas around cultural resources to protect them from damage

Recreational Demands

The National Park Service mission is to protect park resources and to provide opportunities for visitors to enjoy and learn from those resources. Rock Creek Park provides numerous recreational possibilities, including hiking, horseback riding, bird watching, jogging, bicycling, picnicking, and photography in an urban setting (fig. 3). The park promotes activities that do not damage the park's resources or endanger other visitors.

The park experiences high visitation. As many as 2,076,466 people entered the park in fiscal year 2008. This figure does not include the daily commuters of the Washington, D.C. metropolitan area. The large number of visitors places increasing demands on the resources of the park. Management concerns include trail erosion, water quality, meadowland health, and riverbank erosion.

Many trails wind through preserved biological, historical, and geological environments at the park. Many of these are especially fragile, and off-trail hiking promotes their degradation. The unconsolidated soils and sediments along the streams in Rock Creek Park are exposed on many slopes with sparse vegetation. This exposure and/or flooding render them highly susceptible to erosion and degradation.

The park attempts to concentrate the impacts of recreation using designated trails and picnic areas. Recreational use outside designated areas places ecosystems at risk.

Inventory, Monitoring, and Research Suggestions for Recreational Demands

- Develop resource management plans that include inventory and monitoring to identify human impacts on springs, seeps, wetlands, and meadowlands flora within the park.
- Monitor erosion rates along trails; repair and stabilize damage.
- Monitor soil compaction, erosion, and tree health at picnic sites.
- Plant stabilizing vegetation along slopes at risk for slumping and erosion.
- Map topography and geology in the park and relate to recreational use patterns to determine areas at high risk for degredation.

General Geology and Miscellaneous Action Items

As described in the sections above, potential uses of this GRI report and map could include: (1) identifying and describing critical habitats for rare and endangered plants; (2) assessing hazards for floods, rockfalls, slumps, etc.; (3) creating interpretive programs for illustrating, in layperson terms, the evolution of the landscape and earth history of the park; (4) identifying the source locations of aggregate and building stone for historical reconstruction; (5) determining environmental impacts for any new construction; (6) inventorying natural features such as springs, cliffs, marker beds, fossil localities, and caves; (7) characterizing land use; and (8) defining ecological zones and implementing conservation plans (Southworth and Denenny 2003).

A meeting held in August 2002 to assess geological monitoring objectives for the National Capital Region Vital Signs Network (including Rock Creek Park) identified the following geologic resource components: soils and bedrock, urban soil, groundwater, bare ground and exposed rock, karst, surface water, coastal areas, and riparian areas and wetlands. Any useful geologic resource management tool should include these components and their contributions to the entire ecosystem. Stresses to these components include 1) nutrient and chemical contamination, 2) sediment erosion and deposition, 3) disturbance of urban soils, 4) shoreline changes, and 5)geo-hazards such as mass wasting. These stressors are priorities for monitoring. Development, acid rain and atmospheric contaminant deposition, climate change, abandoned mines and wells, and visitor use were identified as primary sources of stress to the natural resources at Rock Creek Park.

Inventory, Monitoring, and Research Suggestions for General Geology and Miscellaneous Action Items

- Collect additional topographic information at higher resolutions. LIDAR and GPS are two possibilities to use for fine-scale topographic measurements. Relate topographic aspect and digital elevation models (DEMs) to the geology.

- Integration of digital geologic data with the park's soils database (projected for completion in 2011) would allow for correlation between the geologic parent material.
- Evaluate manipulated soils (engineered landscapes) related to visitor centers, trails, roadways, and picnic areas, and their connection to the underlying geology.
- Measure changes to physical components of engineered landscapes including areas affected by aggregate extraction or other quarrying, and landfills; correlate with changes in vegetation and wildlife, including exotic species.
- Evaluate presence of exotic species at sites characterized by disturbed or engineered soils, as well as soils having increased fertility as a result of disturbance (S. Salmons, written communication, 2009).
- Develop an interpretive exhibit for the geology of Rock Creek Park, including the relationship between bedrock of the Piedmont and Atlantic Coastal Plain physiographic provinces, which are separated by the Fall Line, and the surficial geologic story (terraces).
- Develop and interpretive exhibit to relate the current landscape, ecosystem, biology, and park history to the underlying geology.

Figure 3. Aerial view of Rock Creek Park illustrating the development of the Washington, D.C. area surrounding the park. Compiled from ESRI Arc Image Service, USA Prime Imagery.

Geologic Features and Processes

This section describes the most prominent and distinctive geologic features and processes in Rock Creek Park.

The Rock Creek Shear Zone and Other Structures

The Rock Creek shear zone is the major structural feature in the western Washington, D.C., area. This shear zone is a north-trending, 1- to 3-km-wide (0.6- to 1.9-mi-wide) belt of metamorphosed rocks (mylonite and phyllonite) that underlies the park area and adjacent land of the Maryland Piedmont (fig. 4). The exposed length is 25 km (16 mi) (Fleming et al. 1992; Southworth and Denenny 2006). The zone is widest near Peirce Mill, where concentrated bands of mylonite and phyllonite are as much as 777 m (2,550 ft) thick. The total length of the shear zone is difficult to determine. It extends north into Montgomery County, Maryland and south beneath unconsolidated sediments near the mouth of Rock Creek (Fleming et al. 1994). Rocks in the shear zone commonly display minerals and other features that were compressed and elongated ("smeared"), illustrating the tremendous temperatures and pressures required to deform the rocks deep within the Earth (fig. 5).

Rocks were sheared for about 1.5 km (0.93 mi) on either side of the zone (Fleming and Drake 1998; Southworth and Denenny 2006). Differences in tectonic history of rocks on either side of the shear zone suggest it is a major tectonic boundary within the Piedmont province. The Laurel Formation shows two prograde (increasing temperature and pressure during metamorphism) folding events, and the Sykesville Formation (located to the west) shows only one.

At least four phases of fault-related deformation are evident in exposures along the Rock Creek shear zone. The first is an early Rock Creek fault that juxtaposed rocks of the Cambrian-aged Sykesville and Laurel formations. That was followed by ductile deformation at middle-amphibolite metamorphic conditions. The deformation was accommodated by sinistral (relative motion across the feature is to the left) shearing having top-to-the-northwest motion, which resulted in broad zones of mylonitic and phyllonitic rocks about 463 million years ago (Fleming and Drake 1998; Aleinikoff et al. 2002; Southworth and Denenny 2006).

The ductile deformation zone increases in intensity from east to west, forming a system of oblique-slip faults in a narrow zone that is the boundary between the Early Cambrian Laurel Formation on the east and the igneous rocks of the Georgetown Intrusive Suite and Kensington Tonalite on the west. The igneous rocks intrude the metamorphosed sedimentary rocks of the Sykesville Formation and overlying thrust sheet consisting of metamorphosed graywacke and quartz-rich schist and amphibolite sills of the Mather Gorge Formation, which is not exposed in Rock Creek Park (Fleming et al. 1992). Relative movement along these faults and throughout the north-trending zone is to the left (sinistral), as evident from shear bands, grooves, and other linear features along planar surfaces, with the eastern side of the zone having moved up and to the north.

Later, smaller scale oblique-slip faulting during and after ductile deformation consisted of an initial sinistral slip overprinted by subsequent dextral (relative motion across the feature is to the right) slip and offset deformation features about 320 to 310 million years ago (Kunk et al. 2004; Southworth and Denenny 2006). Approximately 281 million years ago, oblique, west-side-up, dextral offset faults were active near the transition zone between brittle and ductile deformation (Kunk et al. 2004; Southworth and Denenny 2006).

Reverse Faults

The most recent activity was minor post-Cretaceous, northeast-directed thrusting and high-angle reverse faulting. This deformation resulted from contractional tectonic stress pushing igneous and metamorphic rocks (hundreds of millions of years old) over much younger (perhaps a few million years old) surficial deposits along northwest-trending faults. This faulting (described in detail below) is evidence that Rock Creek Park is in one of the few known areas in eastern North America that is currently tectonically active (Southworth and Denenny 2006). However, no earthquakes have been centered within Washington, D.C. during historic times (http://earthquake.usgs.gov/earthquakes/states/district/history.php).

Local tectonic adjustments in the underlying bedrock caused reactivation along preexisting areas of weakness with a thrust motion during the Neogene and Quaternary, perhaps as recently as a few million years ago (Fleming et al. 1992). These faults are of limited displacement, less than 10 m (33 ft). Narrow bands of gouge and/or breccia mark their surfaces. A few faults exposed in the Taft Quarry have larger deformation zones and offsets. A well known reverse fault is located adjacent to Rock Creek Park near Adams Mill Road and Clydesdale Place, now inside an enclosure (fig. 6). These faults may have resulted from isostatic uplift.

Foliation and Joints

Structures on both sides of the shear zone are remarkably consistent in the Rock Creek area. They appear little affected by the deformation along the shear zone and the variations in rock type. Foliation (from metamorphic recrystallization under tectonic stress) of most of the igneous and metamorphic map units present at Rock Creek trend northeast and dip westward, locally dipping steeply eastward (Fellows 1950; Fleming et al. 1994). Linear features on foliation surfaces plunge gently to the southwest. Joints occur in three major sets: one oriented perpendicular to the northeast foliation and is vertical; the other two form a cross-joint set oriented to the northeast and northwest, respectively, and both dip eastward at a steep angle (Fellows 1950). Meanders of Rock Creek, particularly evident near the National Zoological Park (fig. 2), are incised along generally northeast and northwest joints in the bedrock (Southworth and Denenny 2006).

Folds

Though intrusive rocks obscure many of the geologic folds in the area, the Silver Spring and Sligo Creek folds are present locally. The Silver Spring syncline is marked in outcrop by the youngest rocks in the Laurel Formation. The Sligo Creek fold complex refolds the Silver Spring syncline. This is a set of northeast-trending antiforms (structural ridges) and synforms (structural troughs). Several northwest-trending folds (herein called the Rock Creek folds after Fleming et al. 1994) refold both the Sligo Creek folds and the Silver Spring syncline.

Terraces of the Potomac River

The deposition and erosion that defines the landscape of the Potomac River valley began more than five million years ago. The distribution of ancient river terraces and flood-plain deposits records the evolution of the drainage system. Most evidence indicates the river has cut straight down through bedrock along its earliest course instead of migrating laterally to any great extent (Southworth et al. 2001). Terrace gravels of the Potomac are within walking distance of Rock Creek Park's visitor center (O'Connor 1990).

There are 5.3 million year old (Miocene–Pliocene) fluvial deposits in the park area that are more than 101 m (331 ft) above the present level of the Potomac River and more than 5 km (3 mi) away, above nearby Great Falls Park. Historically, it appears the river's slope has not changed much, and geologists attribute the downcutting to global sea level changes or local uplift (Zen 1997a, 1997b).

Terraces form when a river increases its rate of downcutting in response to a change in climate or tectonic conditions. A new channel incises into the stream bottom, and the former riverbed is left behind as a remnant, which becomes weathered and vegetated. Hence, the higher river terraces represent older riverbeds. As many as six different terrace levels exist along different stretches of the Potomac River (Southworth et al. 2001).

These terraces formed many of the higher elevation areas in Washington, D.C. As described in the "Geologic Influences on History" section, river terraces also provided strategically important high points for the Civil War Defenses of Washington administered by Rock Creek Park.

Potential Paleontological Resources

According to a paleontological resource inventory report for Rock Creek Park, the park has at least 44 paleontological specimens in the museum (Kenworthy and Santucci 2004). These were probably used during the 1950s and 1960s in natural resource education programs and probably did not come from rocks within park boundaries. The Cretaceous Potomac Formation is likely the only geologic unit exposed in Rock Creek Park that may contain fossil resources (Kenworthy and Santucci 2004). The Potomac Formation is famous for its dinosaur and plant fossils, which include some of the oldest known flowering plant fossils, found throughout the National Capital Region.

A large petrified log, discovered during excavation of the Ronald Reagan Building in Federal Triangle, is on exhibit within the park's nature center and planetarium (fig. 7). The cypress log is approximately 100 million years old, likely from the Potomac Formation sediments. Petrified wood is common in Potomac Formation and younger Pleistocene terrace deposits throughout Washington, D.C. area (Kenworthy and Santucci 2004).

Geologic Influences on the History of Rock Creek Park

Archeological Resources

The entire Potomac River valley is rich in archaeological resources that document human inhabitation of the area for the past 10,000 years. The river provided American Indians (Piscataway tribe) with a concentration of fish, game, and numerous plant species, as well as wood, stone, shell, and bones necessary for tools and trade.

The geology of the area has always attracted people to its vast natural resources and it plays a significant role in the archaeological history of Rock Creek Park. Ancient people came to use the particular stone found there, establishing base camps and tool-making sites in several locations. Soapstone and quartzite provided raw materials for tools and other implements such as bowls (S. Potter, NPS, National Capital Region archeologist, personal communication, December 2009). Soapstone, a soft hydrothermally altered metamorphic rock, common in the Rock Creek shear zone, was quarried along the appropriately named Soapstone Valley Park (Southworth and Denenny 2006). The Rose Hill soapstone quarry was located near the intersection of Connecticut Avenue and Albemarle Street, at the west end of Soapstone Valley Park (Robbins and Welter 2001).

The Piney Branch quarries within the park were sources of large quartzite cobbles, also used for tool manufacture. The site was very important for resolving questions regarding early history of humans in North America (Holmes 1897). The Piney Branch quarries in the park took advantage of the large quartzite cobbles of the sand and gravel facies of the Potomac Formation (also referred to as the Patuxent Formation of the Potomac Group). These cobbles were commonly used to manufacture tools known as "Savannah River" points from about 2,500 to 1,500 B.C.E. (Before Common Era, "B.C") (S. Potter, NPS, National Capital Region archeologist, personal communication, December 2009). A petrographic study of flakes recovered from the Piney Branch quarries and sites near Barney Circle and the Whitehurst Freeway revealed that artifacts found at Barney Circle and Whitehurst Freeway were made of quartzite extracted from the Cambrian Weverton and Gun Hill Formations (located to the west of Rock Creek Park) (S. Potter, NPS, National Capital Region archeologist, personal communication, December 2009; La Porta 2000). This metaquartzite developed a characteristic foliation during recrystallization that was useful in tool making (La Porta 2000).

Historical Resources

Geology played a vital role in early European settlement of the area. In the area around Washington, D.C., the rivers supported local trade, developed fertile floodplains, and provided resources for the inhabitants. The geology influenced placement of the local river crossings and fords. Early railroads and roads followed the trends of natural geologic features. Emphasis on geologic controls affecting settlement and history can educate the public about the connection between history and geology and promote a deeper understanding of the landscape.

"Lovers Lane" begins at the southwest end of the Massachusetts Avenue Bridge. This historic roadway, now a gravel path, served as an escape route during the 1814 burning of the Capitol. This roadway also marks the vertical contact of the Atlantic Coastal Plain terrace gravels with the metamorphic Piedmont bedrock (O'Connor 1989a, 1989b). The springs and seeps along the middle of Lovers Lane result from water flowing along that rock boundary. Pierce Mill Spring, Quarry Road Spring, and a number of other unnamed springs within or near what is now Rock Creek Park provided water supplies for early residents of local area (Robbins and Welter 2001).

A number of the Civil War Defenses of Washington, sometimes referred to as the Fort Circle Parks, are administered by Rock Creek Park. They include grassed over earthworks, batteries, rifle trenches, and buttresses that are used today primarily for recreation and open space around the Nation's Capital. Natural land features, such as hills and river terraces, factored in to the site selection and construction of fortifications for the defense of Washington, D.C. during the American Civil War. These fortifications placed the Union capital among the world's most fortified cities at the time (see http://www.nps.gov/cwdw/). Exemplifying the strategic advantages of high ground, Fort Reno occupied the highest natural point in the city at 125 m (409 ft) elevation.

Though there are no active quarries in Washington, D.C., at present, the Rock Creek Park area formerly had 22 active quarries during the period of urban development more than 80 years ago. The Broad Branch quarry provided radiometric dating standards to geologists. The Kensington metatonalite quarry, operated by the Peirce family, was the source of some building stones for the new capitol in the District of Columbia. Taft quarry is the largest abandoned quarry in the park. Dumbarton quarry is the second largest quarry in the parklands. Hornblende metadiorite and metadiorite are exposed on the north-northeastern wall and east-facing back wall, respectively. Newark Street quarry provided Kensington granite gneiss for buildings around Cleveland Park (O'Connor 1989a, 1989b). These quarries, along with Broad Branch and Klingle valleys, reveal the metamorphic and structural geology of the area (O'Connor 1990). Milky quartz veins are common along Dumbarton Run. The veins contain small amounts of gold and probably piqued early mining interest in the area. Historic gold mines are located along the eastern margin of the Piedmont province within Maryland (Kuff 1987). Soapstone, also used by ancient peoples, was quarried in the Little Falls area through the early 1900s for a variety of uses, including laboratory bench tops (S. Potter, NPS, National Capital Region archeologist, personal communication, December 2009).

One of the major goals of the National Park Service is to preserve the historical context of the area (figs. 8-10). This includes preserving and restoring historic structures and the landscape around them, including Millers Cabin, Old Stone House (one of the oldest buildings in Washington, D.C.), and Peirce Mill (the last of at least eight 19th-century mills formerly operating on Rock Creek) at Rock Creek Park (Bushong 1990). Topographic variability, associated with crossing the Fall Line, along Rock Creek made it an attractive location for such water-powered mills.

Maintaining this landscape often means resisting natural geologic processes. Geologic slope processes such as landslides, slumps, chemical weathering, and slope creep are constantly changing the landscape at the park. Runoff erodes sediments from any open areas and carries them down streams and gullies. Erosion naturally diminishes higher areas and fills in the lower areas, distorting the historical context of the landscape.

Issues may arise from opposing values between cultural and natural resource management. For example, a proposal for restoration of a historic building may include removing surrounding natural resources or installing exotic plants. Streams and rivers in many parks are sometimes changed to preserve fish habitat and to protect trails, buildings, and stream banks from being undercut. These efforts may entail alteration of natural geologic processes.

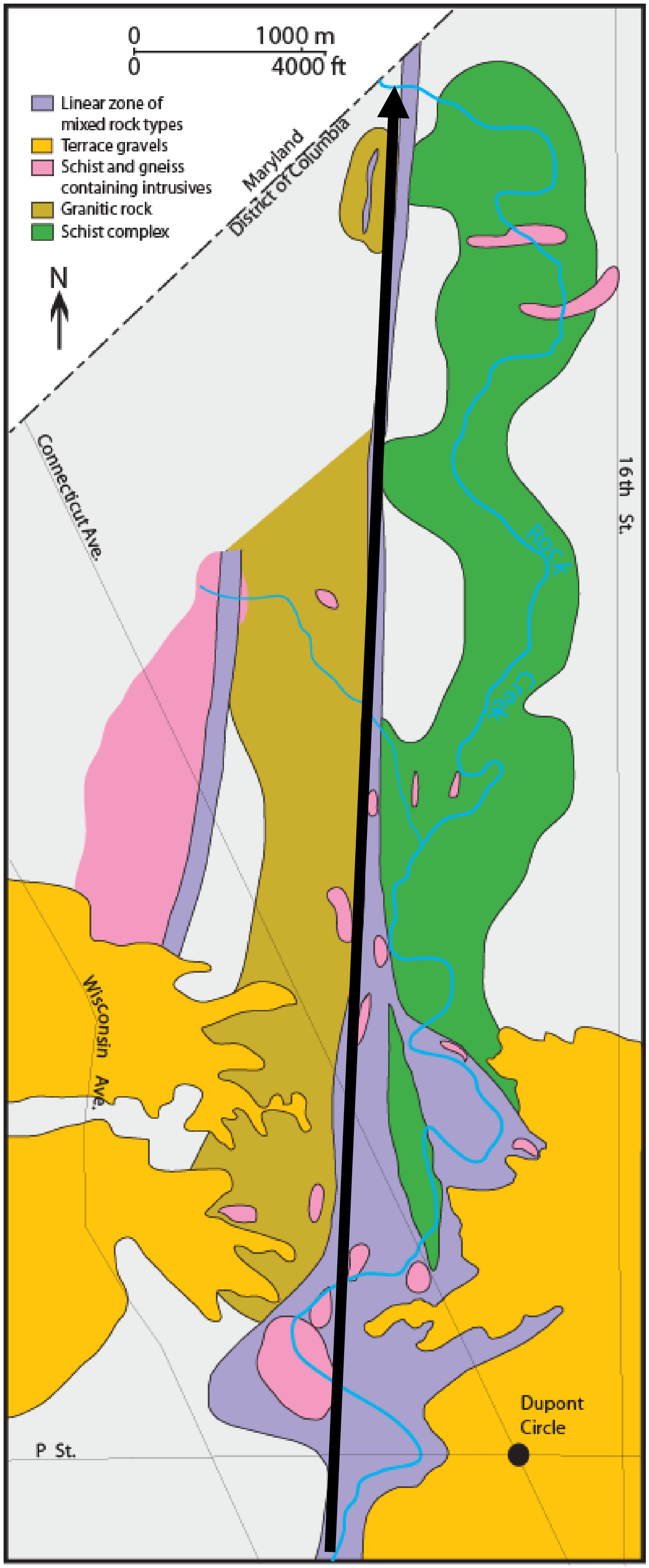

Figure 4. Generalized geologic map of Rock Creek Valley, showing linear trends of units related to the Rock Creek shear zone (thick black arrow). Graphic adapted from Fellows (1950) by Trista L. Thornberry-Ehrlich (Colorado State University).

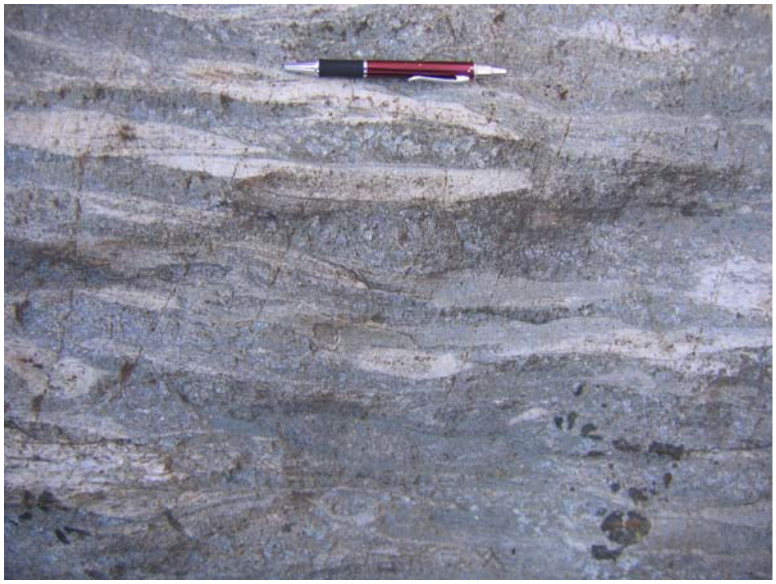

Figure 5. Flattened and sheared metamorphosed conglomerate of the Cambrian Laurel Formation in Klingle Valley Park. Such "smeared" rocks are characteristic of the Rock Creek shear zone. Pen for scale. Photo courtesy Callan Bentley (Northern Virginia Community College).

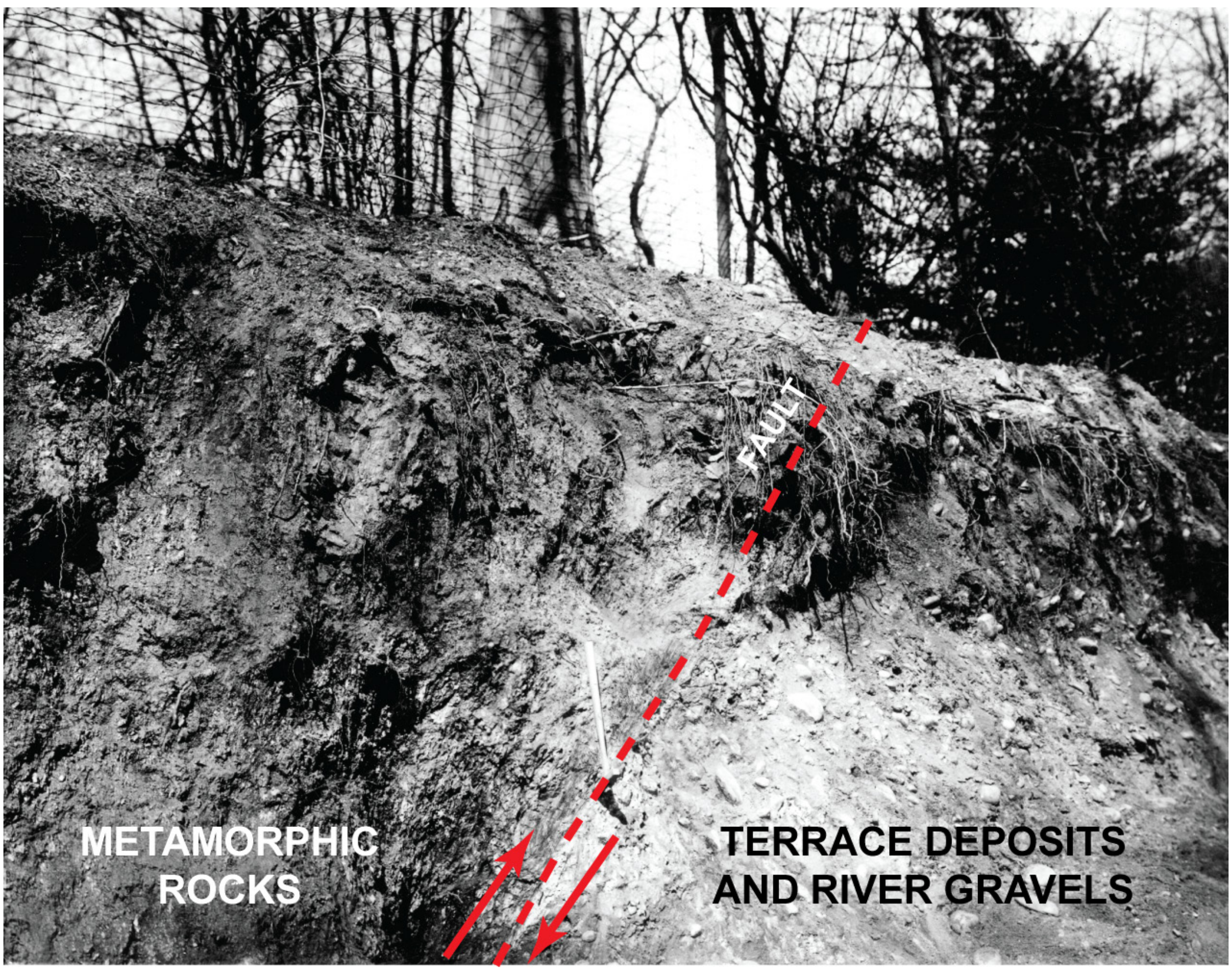

Figure 6. Historic (1925) image of reverse fault near the intersection of Adams Mill Road and Clydesdale Place, adjacent to Rock Creek Park. Arrows indicate the relative motion that thrust metamorphic rocks of the Rock Creek shear zone (hundreds of millions of years old) atop much younger (perhaps a few million years old) terrace deposits and river gravels. The fault is now enclosed in a shelter and vegetation obscures much of the exposure. Hammer on fault line, lower center of image, for scale. Modified from U.S. Geological Survey photo by N.H. Darton.

Figure 7. Petrified cypress trunk on display at the Rock Creek Park nature center (2005 photo). The trunk was uncovered from Potomac Group sediments during excavation of the Ronald Regan Building in Federal Triangle. The specimen is about 100 million years old and suggests a much warmer climate in the National Capital Region during the Cretaceous. NPS Photo.

Figure 8. Old Stone House in Georgetown. Built in 1765 of Piedmont province rocks quarried near Little Falls, this is one of the oldest buildings in Washington, D.C. NPS photo.

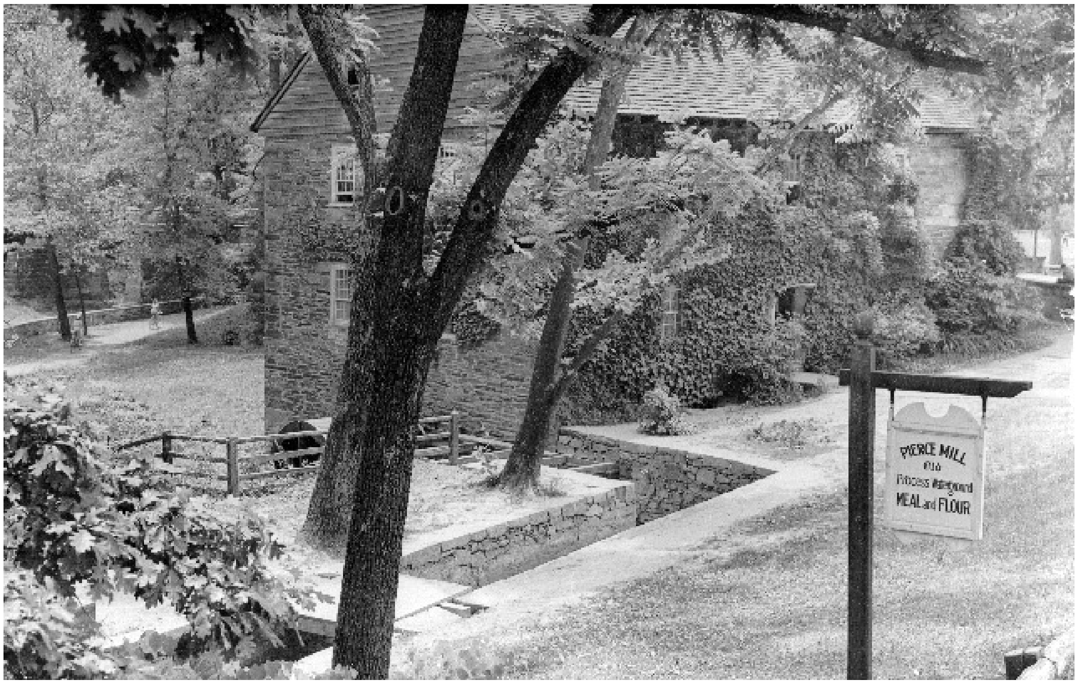

Figure 9. Pierce Mill in 1940s. Pierce Mill was one of at least eight mills operating along Rock Creek during the 1800s and 1900s. NPS photo.

Figure 10. Pierce Mill dam and waterfall. Topographic variability, associated with the Fall Line, along Rock Creek made it an attractive location for water-powered mills. Human alteration of the landscape (such and dams and millraces) helped harness this natural power source. NPS photo.

Map Unit Properties

This section identifies characteristics of map units that appear on the Geologic Resources Inventory digital geologic map of Rock Creek Park. The accompanying table is highly generalized and for background purposes only. Ground-disturbing activities should not be permitted or denied on the basis of information in this table.

Geologic maps facilitate an understanding of Earth, its processes, and the geologic history responsible for its formation. Hence, the geologic map for Rock Creek Park informed the "Geologic History," "Geologic Features and Processes," and "Geologic Issues" sections of this report. Geologic maps are essentially two-dimensional representations of complex three-dimensional relationships. The various colors on geologic maps illustrate the distribution of rocks and unconsolidated deposits. Bold lines that cross or separate the color patterns mark structures such as faults and folds. Point symbols indicate features such as dipping strata, sample localities, mines, wells, and cave openings.

Incorporation of geologic data into a Geographic Information System (GIS) increases the usefulness of geologic maps by revealing the spatial relationships to other natural resources and anthropogenic features. Geologic maps are indicators of water resources because they show which rock units are potential aquifers and are useful for finding seeps and springs. Geologic maps do not show soil types and are not soil maps, but they do show parent material, a key factor in soil formation. Furthermore, resource managers have used geologic maps to make connections between geology and biology; for instance, geologic maps have served as tools for locating sensitive, threatened, and endangered plant species, which may prefer a particular rock unit.

Although geologic maps do not show where earthquakes will occur, the presence of a fault indicates past movement and possible future seismic activity. Geologic maps do not show where the next landslide, rockfall, or volcanic eruption will occur, but mapped deposits show areas that have been susceptible to such geologic hazards. Geologic maps do not show archaeological or cultural resources, but past peoples may have inhabited or been influenced by various geomorphic features that are shown on geologic maps. For example, alluvial terraces may preserve artifacts, and formerly inhabited alcoves may occur at the contact between two rock units.

The geologic units listed in the following table correspond to the accompanying digital geologic data. Map units are listed in the table from youngest to oldest. Please refer to the geologic timescale (fig. 11) for the age associated with each time period. This table highlights characteristics of map units such as susceptibility to hazards; the occurrence of fossils, cultural resources, mineral resources, and caves; and the suitability as habitat or for recreational use.

The GRI digital geologic maps reproduce essential elements of the source maps including the unit descriptions, legend, map notes, graphics, and report. The following references contain source data for the GRI digital geologic map for Rock Creek Park:

Southworth, S., and D. Denenny. 2006. *Geologic map of the national parks in the National Capital Region, Washington D.C., Virginia, Maryland and West Virginia*. Scale 1:24,000. Open-File Report OF 2005-1331. Reston, VA: U.S. Geological Survey.

Southworth, S., D.K. Brezinski, R.K. Orndorff, P.G. Chirico, and K. Lagueux. 2001. *Digital Geologic Map and Database of the Chesapeake and Ohio Canal National Historical Park, District of Columbia, Virginia, Maryland, and West Virginia*. Scale 1:24,000. Open File Report OF 2001-188A and 2001-188B. Reston, VA: U.S. Geological Survey.

The GRI team implements a geology-GIS data model that standardizes map deliverables. This data model dictates GIS data structure including data layer architecture, feature attribution, and data relationships within ESRI ArcGIS software, increasing the overall quality and utility of the data.

GRI digital geologic map products include data in ESRI personal geodatabase and shapefile GIS formats, layer files with feature symbology, Federal Geographic Data Committee (FGDC)-compliant metadata, a Windows help file that contains all of the ancillary map information and graphics, and an ESRI ArcMap map document file that easily displays the map. GRI digital geologic data are included on the attached CD and are available through the NPS Data Store (http://science.nature.nps.gov/nrdata/).

Map Units within Rock Creek Park

The map units exposed along Rock Creek include those of the Potomac Terrane of the Piedmont physiographic province. The sedimentary and volcanic rocks thrust along faults during deposition in a Neoproterozoic–Early Cambrian oceanic trench setting mixed with unconsolidated sediments to form a mélange, or mixture, of rocks. This mélange then metamorphosed into deformed crystalline rocks that now comprise the map units found at the park. Late Proterozoic–Early Cambrian amphibolite, metagabbro, and actinolite schist occur locally throughout the area (Fleming et al. 1994), and the oldest rocks exposed in Rock Creek Park are metamorphosed mafic and ultramafic volcanic and igneous rocks occurring as bodies within the diamictite of the Laurel Formation (Southworth and Denenny 2006). Further alteration changed some of the ultramafic rocks into soapstone, talc schist, and actinolite. American Indians quarried soapstone from these units to make implements (Southworth and Denenny 2006).

The pelitic schist, metagraywacke, and diamictite of the Wissahickon Group in the park include the Mather Gorge, Sykesville, and Laurel formations as well as various igneous intrusive rocks. The Wissahickon is locally well foliated and highly sheared, consisting of 15- to 30-cm (6- to 12-in.) layers containing flattened quartz pebbles; dark, lens-shaped inclusions of schist; and garnet and tourmaline crystals. This formation is in intrusive and non-conformable contact with the Kensington granite gneiss and the hornblende tonalite gneiss of the Georgetown Intrusive Suite (Widatalla and Wilson 1988).

The sedimentary mélange of diamictite within the Laurel Formation crops out in Rock Creek Park. The Laurel Formation and the metasedimentary mélange are separated by the Rock Creek shear zone (Fleming et al. 1992). The variety of rock types in these formations ranges from migmatite, ultramafic rocks (talc, actinolite schist, serpentinite), amphibolite, vein quartz, and granitoid and schist cobbles (Drake and Morgan 1981). This formation locally consists of more than 50% meta-arenite clasts. Some exposures contain pegmatite and show evidence of partial melting and migmatization (Southworth and Denenny 2006).

The Cambrian Laurel Formation closely resembles the Sykesville Formation (Flanagan and Carroll 1976; Southworth et al. 2001). The Sykesville Formation and similar bedrock underlie much of northwestern Washington, D.C. In Rock Creek Park, the Sykesville Formation consists of a gray matrix of quartz and feldspar that supports distinctive white and clear quartz cobbles and irregular blocks of metamorphic rock including: dark-gray phyllonite, light-gray migmatite, and metagraywacke, and dark-greenish-black mafic rock, ultramafic rock, and metagabbro, and light-gray metafelsite and plagiogranite. This unit crops out at the mouth of Rock Creek (Southworth and Denenny 2006). Several igneous intrusions penetrate the Sykesville Formation. These include the Georgetown Intrusive Suite, Kensington Tonalite, light-colored granite, and quartz bodies in Rock Creek Park (Southworth and Denenny 2006). The Georgetown Intrusive Suite occurs in bodies structurally aligned in a north trend along the Rock Creek shear zone and includes gabbro and three varieties of tonalite in Rock Creek park (Southworth and Denenny 2006).

Most of the bedrock in the Rock Creek Park area is covered by a mantle of rock debris, regolith, soils, and transported alluvium and colluvium. Within the Rock Creek basin are scattered remnants of Cretaceous Atlantic Coastal Plain deposits, including the Potomac Formation. These typically occur in the higher elevations. These deposits include unconsolidated sand, gravel, silt, and clay. On the east side of Rock Creek park are a clay-dominated facies and a sand-dominated facies of the Potomac Formation (Southworth and Denenny 2006). Terrace deposits along Rock Creek at various levels may be related to the ancestral Potomac River and contain coarse gravel and sand (Southworth and Denenny 2006).

Gravel, sand, silt, and clay of Holocene alluvium line the creek valley. Unsorted colluvium and fine and coarse debris fill local hillslope depressions. Younger terraces form at least three levels of deposits along Rock Creek (Southworth and Denenny 2006). Flood deposits are also present locally. Elsewhere, artificial fill is associated with the human development of the area (Maryland Geological Survey 1968; Southworth et al. 2001).

Geologic History

This section describes the rocks and unconsolidated deposits that appear on the digital geologic map of Rock Creek Park, the environment in which those units were deposited, and the timing of geologic events that created the present landscape.

Rock Creek Park is in the eastern part of the Piedmont province, at the Fall Line—the zone between the Piedmont and Atlantic Coastal Plain physiographic provinces. It therefore has features that reflect the long geologic history of the Appalachian Mountains. The regional perspective presented here connects the landscape and geology of the park with its surroundings.

The history recorded in the rocks of the Appalachian Mountains begins in the Proterozoic (fig. 11). In the mid-Proterozoic, during the Grenville Orogeny, a supercontinent formed that consisted of most of the continental crust in existence at that time, including the crust of North America and Africa. The sedimentation, deformation, plutonism (the intrusion of igneous rocks), and volcanism are manifested in the metamorphic gneiss in the core of the modern Blue Ridge Mountains northwest of Washington, D.C. (Harris et al. 1997). These rocks formed over a period of a 100 million years and are more than a billion years old, making them among the oldest rocks known in this region. They form a basement upon which all other rocks of the Appalachians were deposited (Southworth et al. 2001).

The late Proterozoic (fig. 11), roughly 800–600 million years ago, brought extensional rifting to the area. The crustal extension created fissures through which massive volumes of basaltic magma were extruded (fig. 12A). This volcanic extrusion lasted tens of millions of years and alternated between flood-basalt flows and ash falls. Extension continued, causing the supercontinent to break up, and a sea basin formed that eventually became the Iapetus Ocean. This basin collected many of the sediments that would eventually form the rocks of the Appalachian Mountains and Piedmont province (fig. 12B). Depositional environments were near-shore, deltaic, barrier island, and tidal flat areas. The earliest sediments are exposed in areas to the west of the park as the Chilhowee Group (Southworth et al. 2001). In addition, huge masses of carbonate sediments were deposited atop the Chilhowee Group. They represent a grand platform, thickening to the east that persisted during the Cambrian and Ordovician periods (545–480 million years ago) (fig. 12A) (Means 1995).

The eastern Piedmont province consists of an amalgamation of rock types that were deposited, deformed, metamorphosed, and intruded by igneous rocks in different places, at various times, and under varying conditions. Thick layers of sand, silt, and mud were deposited in the Iapetus Ocean, part of which became the Sykesville and Laurel formation. The heterogeneous mixture of metasediments and meta-igneous rocks at Rock Creek Park suggests a complex depositional setting at this time, such as a deep trench in oceanic crust (Southworth and Denenny 2006). The stack of sediments was buried and partially melted during high-grade metamorphism to form migmatite. At depth in the crust, the metamorphosed sediments were intruded by a suite of mafic and felsic magmas, including the Georgetown Intrusive Suite and the Kensington Tonalite, from about 478 to 463 million years ago (Aleinikoff et al. 2002; Southworth and Denenny 2006). The Rock Creek shear zone was active in the late Middle Ordovician during this intrusion of igneous plutonic rocks. It forms the contact between the Sykesville and Laurel formations. At this time, the predominant sense of movement along the structure was sinistral shearing (relative motion to the left) under amphibolite-facies metamorphic conditions (pressure in excess of 300 MPa, nearly 3,000 times atmospheric pressure; at temperatures between 450 and 700°C [840 and 1,300°F]) (Aleinikoff et al. 2002; Southworth and Denenny 2006).

Several episodes of mountain building and continental collision that resulted in the Appalachian Mountains contributed to the heat and pressure that deformed and metamorphosed the entire eastern Piedmont sequence of sediments, intrusive rocks, and basalt into schist, gneiss, marble, slate, and migmatite (Southworth et al. 2000b).

Taconic Orogeny

In the early Paleozoic, mountain building activity along the eastern margin of the continent began again. Known as the Taconic Orogeny (~440-420 million years ago in the central Appalachians), this activity was a convergence between the continent and a volcanic arc. Oceanic crust and the volcanic arc from the Iapetus basin were thrust onto the eastern edge of the North American continent. The Taconic Orogeny resulted in the closing of the ocean, subduction of oceanic crust during the creation of volcanic arcs within the disappearing basin, and the uplift of continental crust (fig. 12C) (Means 1995). Initial metamorphism of the igneous and sedimentary rocks of the Sykesville and Laurel formations into schist, diamictite, gneiss, migmatite, and phyllonite occurred during this orogenic event.

Acadian Orogeny

The Acadian Orogeny (~360 million years ago) continued the mountain building of the Taconic Orogeny as the African continent drifted toward North America (Harris et al. 1997). Similar to the preceding Taconic Orogeny, the Acadian event involved collision of land masses, mountain building, and regional metamorphism (Means 1995). This event was focused farther north than central Maryland and Virginia.

Alleghanian Orogeny

Following the Acadian Orogeny, the proto-Atlantic Iapetus Ocean closed during the Late Paleozoic as the North American and African continents collided. This collision formed the Pangaea supercontinent and the Appalachian mountain belt visible today. This mountain-building episode, termed the Alleghanian Orogeny (~325–265 million years ago), is the last major orogeny that affected the Appalachians (fig. 12D) (Means 1995).

During this Orogeny, rocks of the Great Valley, Blue Ridge, and Piedmont provinces were transported along the North Mountain fault as a massive block (Blue Ridge□Piedmont thrust sheet) westward onto younger rocks of the Valley and Ridge. The amount of crustal shortening was very large. Estimates of 20–50% shortening would amount to 125–350 km (80–220 mi) of displacement (Harris et al. 1997).

Deformed rocks in the eastern Piedmont were also folded and faulted, and existing thrust faults were reactivated as both strike-slip and thrust faults during the Alleghanian Orogeny (Southworth et al. 2001). The Rock Creek shear zone was active again from about 320 to 310 million years ago in the Late Mississippian to Early Pennsylvanian. At this time, the sense of movement was dextral (relative motion to the right) shearing under greenschist-facies metamorphic conditions (temperatures of approximately 300 to 500°C [570 to 930°F]) (Kunk et al. 2004; Southworth and Denenny 2006). Later, during the Early Permian, a series of west-side-up, dextral faults were locally active near the transition from ductile to brittle deformation (Kunk et al. 2004; Southworth and Denenny 2006).

Paleoelevations of the Alleghanian Mountains were estimated at approximately 6,000 m (20,000 ft), analogous to the modern-day Himalaya Range in Asia. These mountains have been beveled by erosion to elevations less than 1,070 m (3,500 ft) west of Rock Creek Park, in Shenandoah National Park (Means 1995).

Triassic Extension to the Present

Following the Alleghanian Orogeny, during the late Triassic, a period of rifting began as the deformed rocks of the joined continents began to break apart from about 230 to 200 million years ago (fig. 12E). The supercontinent Pangaea was segmented into roughly the same continents that persist today. This episode of rifting, or crustal fracturing, initiated the formation of the current Atlantic Ocean and caused many block-fault basins to develop with accompanying volcanism (Harris et al. 1997; Southworth et al. 2001). Large streams carried debris shed from the uplifted Blue Ridge and Piedmont provinces, creating alluvial fans at their mouths. These were deposited as non-marine mud and sand in fault-created troughs, such as the Culpeper basin in the western Piedmont of central Virginia. Many of these rift openings became lacustrine basins and collected thick deposits of silt and sand (Southworth and Denenny 2006). Such rift basin sediments are not found within Rock Creek Park, but are present within Manassas National Battlefield Park.

Large faults formed the western boundaries of the basins and provided an escarpment that was quickly covered with eroded debris. Magma was intruded into the new sandstone and shale strata as sills (sub-horizontal sheets) and nearly vertical dikes that extend beyond the basins into adjacent rocks. After this magma was emplaced approximately 200 million years ago, the region underwent a period of slow uplift and erosion. The uplift was in response to isostatic adjustments within the crust, which forced the continental crust upwards and exposed it to erosion (fig. 12C).

More than 65 million years of erosion spanning the Jurassic to the Cretaceous reduced the Piedmont to a plateau (Southworth and Denenny 2006). Thick deposits of unconsolidated gravel, sand, and silt were shed from the eroded mountains. These were deposited at the base of the mountains as alluvial fans and spread eastward to become part of the Atlantic Coastal Plain (Duffy and Whittecar 1991; Whittecar and Duffy 2000; Southworth et al. 2001). The fan-delta deposits were later uplifted and eroded, and became a source of material for deposits farther eastward (McCartan 1989). A delta-plain environment persisted throughout much of the Cretaceous (McCartan 1989), resulting in widespread deposition of the Cretaceous Potomac Formation as a clastic sedimentary wedge. High-level Coastal Plain and terrace deposits found east of Rock Creek Park originated from the erosion of the mountains west of Harpers Ferry (Southworth and Denenny 2006).

The distribution of Cretaceous, Paleogene and Neogene deposits, as well as the more recent Quaternary terraces, suggest the west side of the Rock Creek shear zone has been uplifted, incised, and eroded more than the east side of the structure. A system of post-Cretaceous, north- to northwest-directed thrust faults (fig. 6) in crystalline rocks cut unconsolidated Atlantic Coastal Plain sediments as late as the Quaternary, or less than about two million years ago (Southworth and Denenny 2006). This recent activity makes Rock Creek Park one of the more tectonically active areas along the eastern margin of the North American continent.

The landscape and geomorphology of the greater Potomac River Valley are the result of erosion and deposition from about the middle of the Cenozoic Era to the present, or at least the last five million years (fig. 12F). The erosion continues today with the Potomac, Rappahannock, Rapidan, Monocacy, and Shenandoah rivers and tributaries such as Rock Creek stripping the Piedmont Plateau and Atlantic Coastal Plain sediments, lowering the mountains, and depositing alluvial terraces along the rivers, thus creating the present landscape (fig. 12D). The Potomac, flowing southeast, cuts obliquely across north-trending geologic units. The river flows straight through Mather Gorge, following the trend of joints and other fractures. There is little to no evidence that the river migrated laterally across a broad, relatively flat region. It seems the river cut downward through very old, resistant rocks, overprinting its early course (Southworth et al. 2001).

A marine regression (relative sea level drop) in the late Miocene allowed fluvial processes to dominate, carving channels into marine deposits and leaving a thin gravel sheet over the coastal plain by the end of the Pliocene (Newell et al. 2006; McCartan et al. 1995). Following deposition of these units, the development of the modern Potomac River estuary began with a marine transgression (relative sea-level rise) that drowned regional river valleys (McCartan 1989).

The distribution of flood-plain alluvium and ancient fluvial terraces of the regional rivers and adjacent tributaries record the historical development of both drainage systems. Fluvial and estuarine sand, silt, and gravel associated with each set of terraces reflect deposition during interglacial highstands of the Atlantic Ocean, whereas downcutting commenced during glacially influenced periods of low sea level (Mixon et al. 2000). There are at least six different terrace levels of the Potomac River in the Rock Creek Park area, four of which occur in Rock Creek Park. At least three terraces flanking Rock Creek are Paleogene-Neogene to Holocene in age. The oldest, upper-level terraces sit atop flat benches incised into bedrock (Southworth and Denenny 2006).

Although glaciers from the Pleistocene never reached the Washington, D.C., area (the southern terminus was in northeastern Pennsylvania), the colder climate played a role in the formation of the landscape at the park. Immense quantities of water bound up as glacial ice caused a relative drop in global sea level and increased downcutting by rivers as mentioned above. The cooler periglacial conditions that existed close to the glaciers intensified weathering and other erosional processes (Harris et al. 1997). Glaciers, as powerful erosive agents, increased the sediment supply to the area's rivers, building terraces and filling basins. Freeze-and thaw-cycles inherent in a colder climate would have increased weathering, especially for sloping areas. Frozen ground would cause an increase in sheetflow and runoff, and the extra water would have flowed into the ancestral river channels, enhancing downcutting and erosion by waterways (Means 1995; Zen 1997a, 1997b).

Alluvium (clay, silt, sand, gravel, and cobbles) lines stream channels, point-bars, and floodplains with clasts such as quartzite and metamorphic rocks that record long transport from source areas in the highlands of the Piedmont to the west. Debris and colluvium are poorly sorted deposits formed by active slope processes and consist of reworked clasts of older units. Debris was deposited by gravity, water, and mass wasting. In Rock Creek Park, colluvium is present on the berm of the terraces flanking Rock Creek (Southworth and Denenny 2006).

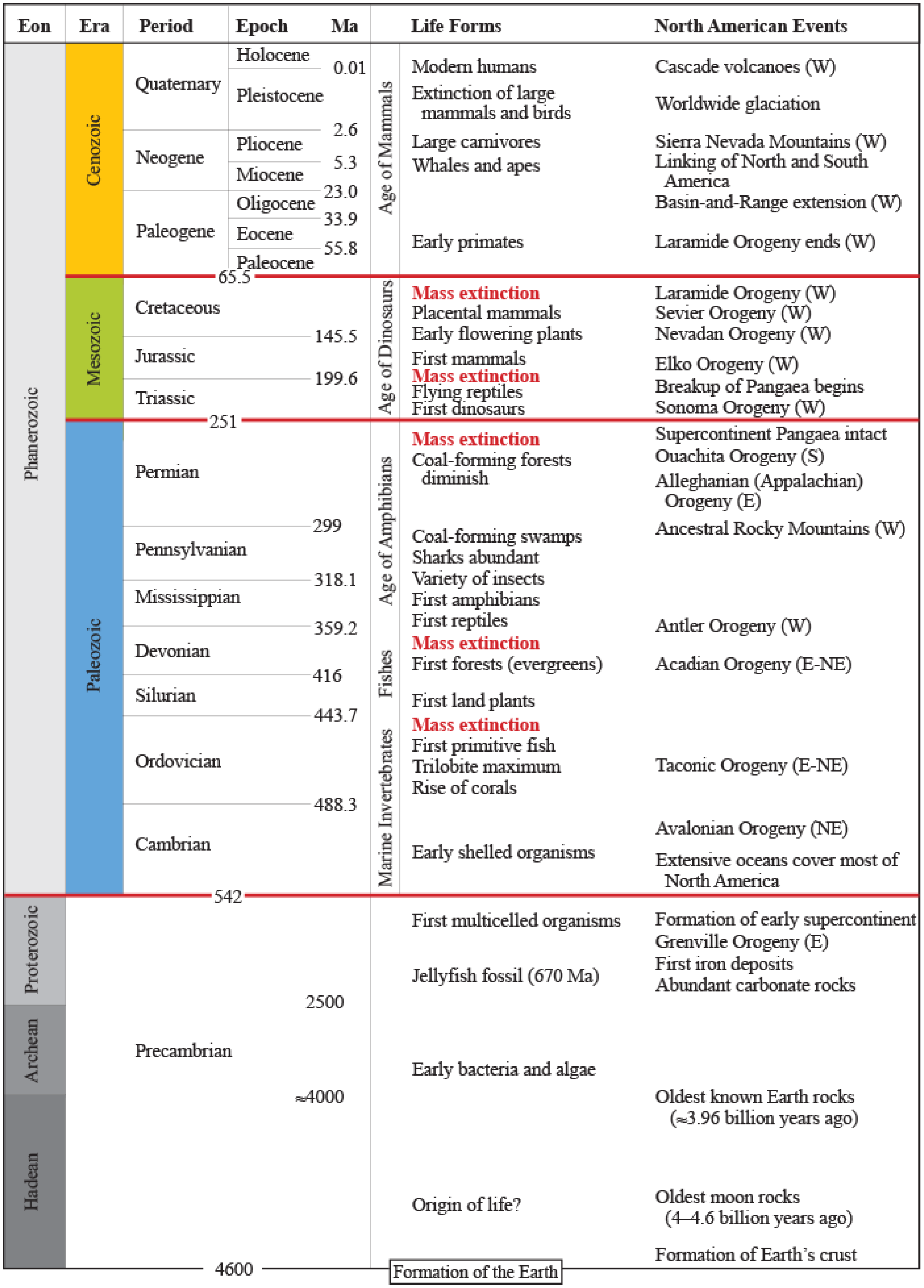

Figure 11. Geologic timescale. Included are major life history and tectonic events occurring on the North American continent. Red lines indicate major unconformities between eras. The historic term "Tertiary" refers to the Paleogene and Neogene periods. Radiometric ages shown are in millions of years (Ma). Compass directions in parentheses indicate the regional location of individual geologic events. Adapted from the U.S. Geological Survey, (http://pubs.usgs.gov/fs/2007/3015/) with additional information from the International Commission on Stratigraphy (http://www.stratigraphy.org/view.php?id=25). Note this timescale includes the August 2009 revised boundary of the Pliocene-Pleistocene at 2.59 Ma rather than 1.8 Ma.

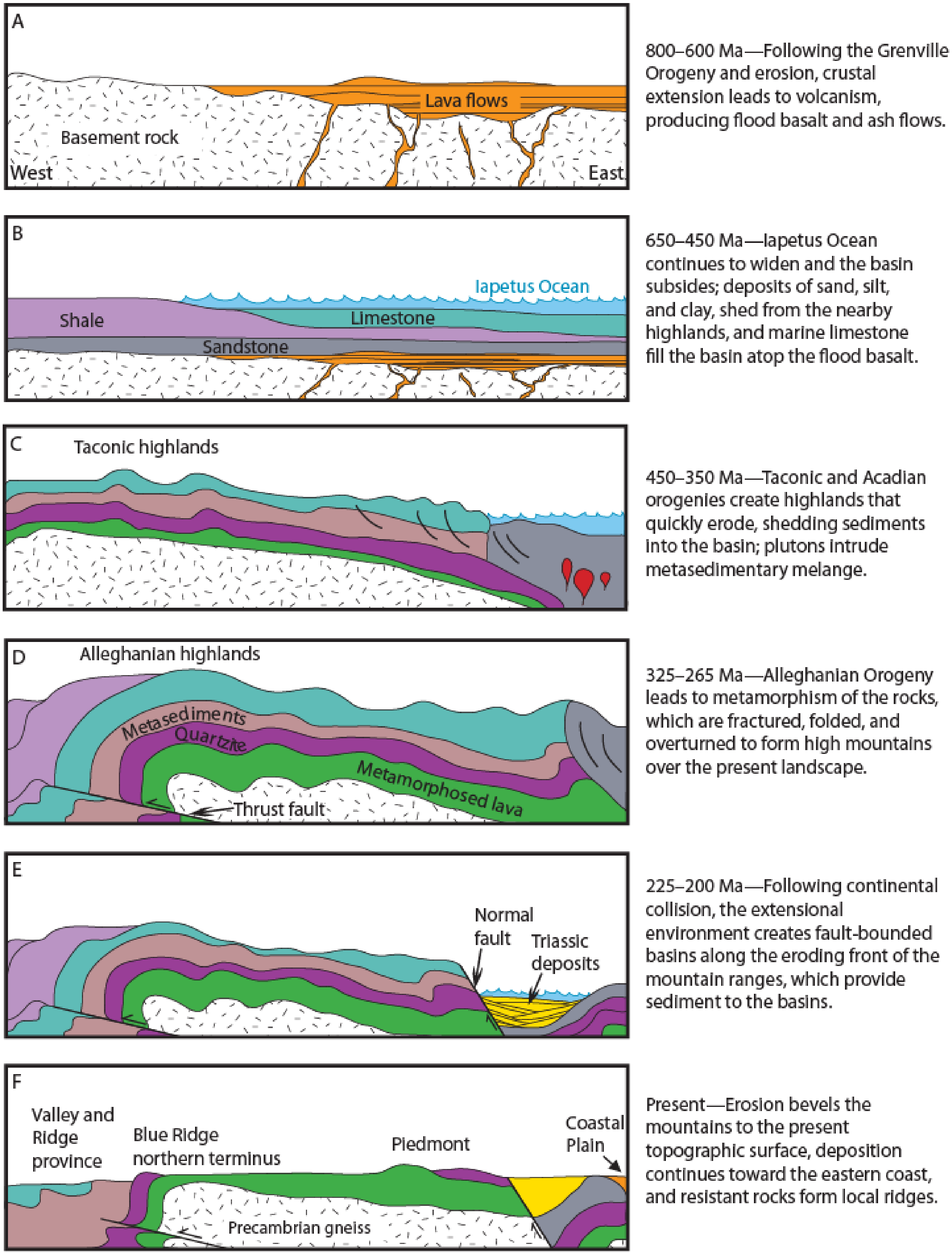

Figure 12. Evolution of the landscape in the National Capital Region from the Precambrian through the present. Rock Creek Park spans the "Fall Line" between the Coastal Plain and the Piedmont. Triassic basins are not present within the park, but are present to the west at Manassas National Battlefield Park. Graphic by Trista L. Thornberry-Ehrlich (Colorado State University), adapted from Means (1995) and Fedorko et al. (2004).

Glossary

This glossary contains brief definitions of technical geologic terms used in this report. Not all geologic terms used are referenced. For more detailed definitions or to find terms not listed here please visit: http://geomaps.wr.usgs.gov/parks/misc/glossarya.html.

alluvial fan. A fan-shaped deposit of sediment that accumulates where a hydraulically confined stream flows to a hydraulically unconfined area. Commonly out of a mountain front into an area such as a valley or plain.

alluvium. Stream-deposited sediment.

anticline. A fold, generally convex upward, whose core contains the stratigraphically older rocks.

anticlinorium. A composite anticlinal structure of regional extent composed of lesser folds.

aquifer. A rock or sedimentary unit that is sufficiently porous that it has a capacity to hold water, sufficiently permeable to allow water to move through it, and currently saturated to some level.

basement. The undifferentiated rocks, commonly igneous and metamorphic, that underlie the rocks exposed at the surface.

basin (sedimentary). Any depression, from continental to local scales, into which sediments are deposited.

basin (structural). A doubly-plunging syncline in which rocks dip inward from all sides.

bed. The smallest sedimentary strata unit, commonly ranging in thickness from one centimeter to a meter or two and distinguishable from beds above and below.

bedding. Depositional layering or stratification of sediments.

block (fault). A crustal unit bounded by faults, either completely or in part.

brittle. Describes a rock that fractures before sustaining deformation.

calcareous. Describes rock or sediment that contains calcium carbonate.

cementation. Chemical precipitation of material into pores between grains that bind the grains into rock.

chemical weathering. The dissolution or chemical breakdown of minerals at the Earth's surface via reaction with water, air, or dissolved substances.

clastic. Describes rock or sediment made of fragments of pre-existing rocks.

clay. Can be used to refer to clay minerals or as a sedimentary fragment size classification (less than 1/256 mm [0.00015 in]).

colluvium. A general term applied to any loose, heterogeneous, and incoherent mass of rock fragments deposited by unconcentrated surface runoff or slow continuous downslope creep, usually collecting at the base of gentle slopes or hillsides.

conglomerate. A coarse-grained, generally unsorted, sedimentary rock consisting of cemented rounded clasts larger than 2 mm (0.08 in).

continental crust. The crustal rocks rich in silica and alumina that underlie the continents; ranging in thickness from 35 km (22 mi) to 60 km (37 mi) under mountain ranges.

convergent boundary. An active boundary where two tectonic plates are colliding.

craton. The relatively old and geologically stable interior of a continent.

cross-bedding. Uniform to highly varied sets of inclined sedimentary beds deposited by wind or water that indicate distinctive flow conditions (e.g., direction and depth).

cross section. A graphical interpretation of geology, structure, and/or stratigraphy in the third (vertical) dimension based on mapped and measured geological extents and attitudes depicted in a vertically oriented plane.

crust. The Earth's outermost compositional shell, 10 to 40 km (6 to 25 mi) thick, consisting predominantly of relatively low-density silicate minerals (also see "oceanic crust" and "continental crust").

crystalline. Describes a regular, orderly, repeating geometric structural arrangement of atoms.

debris flow. A moving mass of rock fragments, soil, and mud, more than half the particles of which are larger than sand size.

deformation. A general term for the process of faulting, folding, and shearing of rocks as a result of various Earth forces such as compression (pushing together) and extension (pulling apart).

dextral. Relative motion to the right.

delta. A sediment wedge deposited where a stream flows into a lake or sea.

dike. A tabular, discordant igneous intrusion.

dip. The angle between a bed or other geologic surface and horizontal.

dip-slip fault. A fault with measurable offset where the relative movement is parallel to the dip of the fault.

discordant. Having contacts that cut across or are set at an angle to the orientation of adjacent rocks.

drainage basin. The total area from which a stream system receives or drains precipitation runoff.

ductile. Describes a rock that is able to sustain deformation before fracturing.

extrusion. The emission of relatively viscous lava onto the Earth's surface, as well as the rock so formed.

extrusive. Of or pertaining to the eruption of igneous material onto the Earth's surface.

facies (metamorphic). The pressure-temperature regime that results in a particular, distinctive metamorphic mineralogy (i.e., a suite of index minerals).

facies (sedimentary). The depositional or environmental conditions reflected in the sedimentary structures, textures, mineralogy, fossils, etc. of a sedimentary rock.

fault. A break in rock along which relative movement has occurred between the two sides.

felsic. Describes an igneous rock having abundant light-colored minerals such as quartz, feldspars, or muscovite. Compare to "mafic."

foliation. A preferred arrangement of crystal planes in minerals; in metamorphic rocks, the term commonly refers to a parallel orientation of planar minerals such as micas.

formation. Fundamental rock-stratigraphic unit that is mappable, lithologically distinct from adjoining strata, and has definable upper and lower contacts.

fracture. Irregular breakage of a mineral. Any break in a rock (e.g., crack, joint, fault).

frost wedging. The breakup of rock due to the expansion of water freezing in fractures.

geology. The study of the Earth, including its origin, history, physical processes, components, and morphology.

graben. A down-dropped structural block bounded by steeply dipping, normal faults (also see "horst").

horst. Areas of relative up between grabens, representing the geologic surface left behind as grabens drop. The best example is the basin and range province of Nevada. The basins are grabens and the ranges are weathered horsts. Grabens become a locus for sedimentary deposition.

hydrogeologic. Refers to the geologic influences on groundwater and surface water composition, movement and distribution.

hydrolysis. A decomposition reaction involving water, frequently involving silicate minerals.

igneous. Describes a rock or mineral that originated from molten material. One of the three main classes of rocks—igneous, metamorphic, and sedimentary.

intrusion. A body of igneous rock that invades (pushes into) older rock. The invading rock may be a plastic solid or magma.

isostasy. The process by which the crust "floats" at an elevation compatible with the density and thickness of the crustal rocks relative to underlying mantle.

isostatic uplift. Uplift in the Earth's crust caused by the release of pressure from rock layers that have been eroded away or melting ice sheets.

joint. A semi-planar break in rock without relative movement of rocks on either side of the fracture surface.

karst topography. Topography characterized by abundant sinkholes and caverns formed by the dissolution of calcareous rocks.

lacustrine. Pertaining to, produced by, or inhabiting a lake or lakes.

landslide. Any process or landform resulting from rapid, gravity-driven mass movement.

lava. Still-molten or solidified magma that has been extruded onto the Earth's surface though a volcano or fissure.

levees. Raised ridges lining the banks of a stream. May be natural or artificial.

lithosphere. The relatively rigid outmost shell of the Earth's structure, 50 to 100 km (31 to 62 miles) thick, that encompasses the crust and uppermost mantle.

mafic. Describes dark-colored rock, magma, or minerals rich in magnesium and iron. Compare to "felsic."

magma. Molten rock beneath the Earth's surface capable of intrusion and extrusion.

mantle. The zone of the Earth's interior between crust and core.

matrix. The fine grained material between coarse (larger) grains in igneous rocks or poorly sorted clastic sediments or rocks. Also refers to rock or sediment in which a fossil is embedded.

mechanical weathering. The physical breakup of rocks without change in composition. Synonymous with physical weathering.

member. A lithostratigraphic unit with definable contacts; a member subdivides a formation.

meta-. A prefix used with the name of a sedimentary or igneous rock, indicating that the rock has been metamorphosed.

metamorphism. Literally, a change in form. Metamorphism occurs in rocks through mineral alteration, genesis, and/or recrystallization from increased heat and pressure.

mid-ocean ridge. The continuous, generally submarine, seismic, median mountain range that marks the divergent tectonic margin(s) in the Earth's oceans.

migmatite. Literally, "mixed rock" with both igneous and metamorphic characteristics due to partial melting during metamorphism.

mud cracks. Cracks formed in clay, silt, or mud by shrinkage during subaerial dehydration.

normal fault. A dip-slip fault in which the hanging wall moves down relative to the footwall.

obduction. The process by which the crust is thickened by thrust faulting at a convergent margin.

oblique-slip fault. A fault in which motion includes both dip-slip and strike-slip components (also see "dip-slip fault" and "strike-slip fault").

oceanic crust. The Earth's crust formed at spreading ridges that underlies the ocean basins. Oceanic crust is 6 to 7 km (3 to 4 miles) thick and generally of basaltic composition.

orogeny. A mountain-building event.

outcrop. Any part of a rock mass or formation that is exposed or "crops out" at the Earth's surface.

overbank deposits. Alluvium deposited outside a stream channel during flooding.

Pangaea. A theoretical, single supercontinent that existed during the Permian and Triassic periods.

parent (rock). The original rock from which a metamorphic rock was formed. Can also refer to the rock from which a soil was formed.

passive margin. A margin where no plate-scale tectonism is taking place; plates are not converging, diverging, or sliding past one another. An example is the east coast of North America. (also see "active margin").

pebble. Generally, small rounded rock particles from 4 to 64 mm (0.16 to 2.52 in) in diameter.

permeability. A measure of the relative ease with which fluids move through the pore spaces of rocks or sediments.

plate tectonics. The concept that the lithosphere is broken up into a series of rigid plates that move over the Earth's surface above a more fluid asthenosphere.

plateau. A broad, flat-topped topographic high (terrestrial or marine) of great extent and elevation above the surrounding plains, canyons, or valleys.
plutonic. Describes igneous rock intruded and crystallized at some depth in the Earth.
porosity. The proportion of void space (e.g., pores or voids) in a volume of rock or sediment deposit.
radiometric age. An age in years determined from radioactive isotopes and their decay products.
recharge. Infiltration processes that replenish groundwater.
regression. A long-term seaward retreat of the shoreline or relative fall of sea level.
relative dating. Determining the chronological placement of rocks, events, or fossils with respect to the geologic time scale and without reference to their absolute age.
reverse fault. A contractional high-angle (greater than 45°) dip-slip fault in which the hanging wall moves up relative to the footwall (also see "thrust fault").
rift valley. A depression formed by grabens along the crest of an oceanic spreading ridge or in a continental rift zone.
roundness. The relative amount of curvature of the "corners" of a sediment grain, especially with respect to the maximum radius of curvature of the particle.
sandstone. Clastic sedimentary rock of predominantly sand-sized grains.
saprolite. Soft, often clay-rich, decomposed rock formed in place by chemical weathering.
scarp. A steep cliff or topographic step resulting from displacement on a fault, or by mass movement, or erosion.
seafloor spreading. The process by which tectonic plates diverge and new lithosphere is created at oceanic ridges.
sediment. An eroded and deposited, unconsolidated accumulation of rock and mineral fragments.
sequence. A major informal rock-stratigraphic unit that is traceable over large areas and defined by a major sea level transgression-regression sediment package.
shale. A clastic sedimentary rock made of clay-sized particles that exhibit parallel splitting properties.
shear zone. A tabular zone of rock that has been crushed and brecciated by many parallel fractures due to shear strain.
sill. A tabular, igneous intrusion that is commonly sub-horizontal.
silt. Clastic sedimentary material intermediate in size between fine-grained sand and coarse clay (1/256 to 1/16 mm [0.00015 to 0.002 in]).
siltstone. A variably lithified sedimentary rock composed of silt-sized grains.
sinistral. Relative motion to the left.
slope. The inclined surface of any geomorphic feature or rational measurement thereof. Synonymous with gradient.
slump. A generally large, coherent mass movement with a concave-up failure surface and subsequent backward rotation relative to the slope.
soapstone. A soft metamorphic rock with fibrous or flakey texture and a soapy feel; composed primarily of talc with variable amounts of other minerals such as micas, chlorite, amphiboles, and pyroxenes. Frequently used as dimension or building stone.
soil. Surface accumulation of weathered rock and organic matter capable of supporting plant growth and often overlying the parent material from which it formed.
spring. A site where water issues from the surface due to the intersection of the water table with the ground surface.
strata. Tabular or sheetlike masses or distinct layers of rock.
stratigraphy. The geologic study of the origin, occurrence, distribution, classification, correlation, and age of rock layers, especially sedimentary rocks.
strike. The compass direction of the line of intersection of an inclined surface with a horizontal plane.
strike-slip fault. A fault with measurable offset where the relative movement is parallel to the strike of the fault.
subduction zone. A convergent plate boundary where oceanic lithosphere descends beneath a continental or oceanic plate and is carried down into the mantle.
subsidence. The gradual sinking or depression of part of the Earth's surface.
syncline. A downward curving (concave up) fold with layers that dip inward; the core of the syncline contains the stratigraphically-younger rocks.
synclinorium. A composite synclinal structure of regional extent composed of lesser folds.
tectonic. Relating to large-scale movement and deformation of the Earth's crust.
terraces (stream). Step-like benches surrounding the present floodplain of a stream due to dissection of previous flood plain(s), stream bed(s), and/or valley floor(s).
terrane. A large region or group of rocks with similar geology, age, or structural style.
terrestrial. Relating to land, the Earth, or its inhabitants.
thrust fault. A contractional dip-slip fault with a shallowly dipping fault surface (less than 45°) where the hanging wall moves up and over relative to the footwall.
topography. The general morphology of the Earth's surface, including relief and locations of natural and anthropogenic features.
trace (fault). The exposed intersection of a fault with the Earth's surface.
trace fossils. Sedimentary structures, such as tracks, trails, or burrows, that preserve evidence of organisms' life activities, rather than the organisms themselves.
transgression. Landward migration of the sea as a result of a relative rise in sea level.
trend. The direction or azimuth of elongation of a linear geological feature.
uplift. A structurally high area in the crust, produced by movement that raises the rocks.
volcanic. Related to volcanoes. Igneous rock crystallized at or near the Earth's surface (e.g., lava).
volcanic arc. A commonly curved, linear, zone of volcanoes above a subduction zone.
water table. The upper surface of the saturated zone; the zone of rock in an aquifer saturated with water.
weathering. The set of physical, chemical, and biological processes by which rock is broken down.

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Appendix A: Geologic Map Graphic

The following page is a snapshot of the geologic map for Rock Creek Park. For a poster-size PDF of this map or for digital geologic map data, please see the included CD or visit the Geologic Resources Inventory publications Web page (http://www.nature.nps.gov/geology/inventory/gre_publications.cfm).

Appendix B: Scoping Summary

The following excerpts are from the GRI scoping summary for Rock Creek Park. The contact information and Web addresses in this appendix may be outdated. Please contact the Geologic Resources Division for current information.

Executive Summary

Geologic Resources Inventory (GRI) workshops were held for National Park Service (NPS) Units in the National Capital Region (NCR) over April 30-May 2, 2001. The purpose was to view and discuss the park's geologic resources, to address the status of geologic mapping for compiling both paper and digital maps, and to assess resource management issues and needs. Cooperators from the NPS Geologic Resources Division (GRD), Natural Resources Information Division (NRID), individual NPS units in the region, and the United States Geological Survey (USGS) were present for the workshop.

This involved half-day field trips to view the geology of Catoctin Mountain Park, Harpers Ferry NHP, Prince William Forest Park and Great Falls Park, as well as another full-day scoping session to present overviews of the NPS Inventory and Monitoring (I&M) program, the GRD, and the on-going GRI. Round table discussions involving geologic issues for all parks in the National Capital Region included the status of geologic mapping efforts, interpretation, paleontologic resources, sources of available data, and action items generated from this meeting.

Overview of Geologic Resources Inventory

It is stressed that the emphasis of the inventory is not to routinely initiate new geologic mapping projects, but to aggregate existing "baseline" information and identify where serious geologic data needs and issues exist in the National Park System. In cases where map coverage is nearly complete (ex. 4 of 5 quadrangles for Park "X") or maps simply do not exist, then funding may be available for geologic mapping.

After introductions by the participants, Tim Connors presented overviews of the Geologic Resources Division, the NPS I&M Program, the status of the natural resource inventories, and the GRI in particular.

He also presented a demonstration of some of the main features of the digital geologic database for the Black Canyon of the Gunnison NP and Curecanti NRA in Colorado. This has become the prototype for the NPS digital geologic map model as it reproduces all aspects of a paper map (i.e. it incorporates the map notes, cross sections, legend etc.) with the added benefit of being geospatially referenced. It is displayed in ESRI ArcView shape files and features a built-in Microsoft Windows help file system to identify the map units. It can also display scanned JPG or GIF images of the geologic cross sections supplied with the map. Geologic cross section lines (ex. A-A') are subsequently digitized as a line coverage and are hyperlinked to the scanned images.

Joe Gregson further demonstrated the developing NPS Theme Manager for adding GIS coverages into projects "on-the-fly." With this functional browser, numerous NPS themes can be added to an ArcView project with relative ease. Such themes might include geology, paleontology, hypsography (topographic contours), vegetation, soils, etc.

Pete Chirico (USGS-Reston, VA) demonstrated the digital geology of Harpers Ferry and also showed the group potential uses of a digital geologic coverage with his examples for Anacostia and Cumberland Island. The USGS also showed various digital products that they've developed already for Chesapeake and Ohio Canal NHP and Great Falls.

Geologic Mapping

Existing Geologic Maps and Publications
After the bibliographies were assembled, a separate search was made for any existing surficial and bedrock geologic maps for the National Capital Region parks. The bounding coordinates for each map were noted and entered into a GIS to assemble an index geologic map. Separate coverages were developed based on scales (1:24,000, 1:100,000, etc.) available for the specific park. Numerous geologic maps at varying scales and vintages cover the area. Index maps were distributed to each workshop participant during the scoping session.
Status

The index of published geologic maps is a useful reference for the NCR. However, some of these maps are dated and are in need of refinement, and in other places there is no existing large-scale coverage available. The USGS began a project to map the Baltimore-Washington, D.C., area at 1:100,000 scale and as a result it was brought to their attention that modern, large-scale geologic mapping for the NCR NPS areas would be beneficial to NPS resource management.

Because of this, the USGS developed a proposal to re-map the NCR at large scale (1:24,000 or greater) and to supply digital geologic databases to accompany this mapping. Scott Southworth (USGS-Reston, VA) is the project leader and main contact.

The original PMIS (Project Management Information Systems) statement is available in Appendix C and on the NPS intranet (PMIS number 60900); of note is that portions of it need to be changed to reflect that the source of funding will be Inventory and Monitoring funds and NOT NRPP.

Desired Enhancements in the Geologic Maps for NCR Parks

To better facilitate the geologic mapping, Scott Southworth would like to obtain better topographic coverage for each of the NCR units. Tammy Stidham knows that some of these coverages are already available and will supply them to Scott and the USGS. In general, anything in Washington, D.C., proper has 1 meter topographic coverage and Prince George's county has 1:24,000 coverage.

Notes on Rock Creek Park

Rock Creek Park (ROCR) has been mapped by the USGS at 1:24,000 scale. At the time of the mapping, they focused in on the structural geology. Scott would like to refine the mapping to 1:12,000 scale, and to revisit some of the previous mappers interpretations. Tammy Stidham says that a 1:200 topographic base is available. Additionally, the USGS would like to obtain the topographic contours, hydrography, roads, buildings and structures, and digital ortho quarter quadrangles for use in a base map. Tammy mentioned that soils data is available but that it is dated.

Digital coverage exists and has been compiled for the entire area at 1:100,000 scale. Springs and many historic quarries (commodity unknown) are present; there may also be paleontological quarries too; USGS has historical maps for area; topographic coverage of 1 meter.
Digital Geologic Map Coverage

The USGS will supply digital geology in ArcInfo format for all of the NCR parks. GRI staff will take this data and add the Windows help file and NPS theme manager capability to the digital geology and will supply to the region to distribute to each park in NCR.

Other Desired Data Sets for NCR

Soils

Pete Biggam (GRD Soil Scientist) supplied the following information in reference to soils for parks:

National Capital Parks–Central is covered by the "District of Columbia" Soil Survey (State Soil Survey Area ID MD099). It has been mapped, and is currently being refined to match new imagery. An interim digital product is available to us via NRCS, but the "final certified" dataset most likely will not be available until FY03.

National Capital Parks–Eastern is covered by portions of three soil survey areas: "District of Columbia" (MD099), "Charles County, Maryland" (MD017), and "Prince George's County, Maryland" (MD033). Both Charles County and Prince George's County are currently being updated, with Charles County scheduled to be available sometime in calendar year 2002, and Prince George's County sometime within calendar year 2003.

Paleontology

Greg McDonald (GRD Paleontologist) would like to see an encompassing, systematic Paleontological inventory for the NCR describing the known resources in all parks with suggestions on how to best manage these resources. In addition to the parks containing paleo resources in NACE, according to his current database, the following are considered "paleo parks" in the NCR:

- Chesapeake & Ohio Canal NHP
- George Washington Memorial Parkway
- Manassas NBP
- Prince William Forest Park
- Harpers Ferry NHP

Geologic Report

A "stand-alone" encompassing report on each park's geology is a major focus of the GRI. As part of the USGS proposal to map the NCR, they will be summarizing the major geologic features of each park in a report to accompany their database. It was suggested that after the individual reports are finished a regional physiographic report will be completed for the entire NCR.

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Appendix C: Report of the National Park Service Monitoring Workshop: Planning for the Future in the National Capital Network p. 29-43

The following excerpts are from the National Capital Region Network monitoring workshop held on July 9–11, 2002 in Shepherdstown, West Virginia. Pages 29–44 from that report are included in this appendix because they have direct relevancy to the geologic resource inventory of Rock Creek Park.

B. Geology Workgroup

Purpose:

Continue the development of vital signs indicators for geologic resources in the National Capital Region of the National Park Service to provide essential information needed to preserve and enhance the region's most important geologic resources.

Outcomes:

1) Complete the geology table from previous meetings, allowing time to clarify items already in the table and identify additional information gaps

2) Prioritize items in the geology table for future monitoring efforts

3) Develop monitoring objectives for high=priority threats in the geology table.

4) Develop a list of potential protocols that would meet the above monitoring objectives from the geology table.

Overview

This breakout session began by reviewing the conceptual model describing the geologic resources developed by the geology workgroup of the SAC, including (1) resource components, (2) stressors to those resources, (3) sources of stressors, (4) ecological effects, and (5) potential vital signs monitoring indicators. Terminology was clarified, existing information was edited, and new information was added. The results of this discussion are captured in table 4 below.

One point that was not captured in table 4 (but which should be noted) is that the geology workgroup examined soil from an agricultural perspective, rather than from an engineering perspective. In addition, several people in the group commented that geology is an integrative, long-term perspective for monitoring, although there are both short- and long-term indicators that may be used to examine threats to the geological resources in the NCN.

Other topics of discussion during the morning session were urban soils and "engineered or created landscapes." Urban soils are generally horticultural in context, some of which may be "engineered" but, by far, most urban soils are not. Urban soils tend to be non-agricultural or non-forest situations where man has, to one degree or another, manipulated the landscape such that the natural soil regime no longer exists. In most cases, soil structure has been lost or redeveloped. In many cases, urban soils were composed from subsurface soils and, therefore, nothing resembling an "A" horizon exists.

Urban soils are often compacted, resulting in high bulk densities, and, as a result, have reduced oxygen content (e.g., trails, campsites, etc.). In addition, these soils are poorly drained, low in organic matter, retain little moisture, may be disconnected from the water table or capillary water, could be contaminated or have considerable "artifacts" (ash, glass, etc.), and are often depauperate in microfauna (bacteria, fungi) and macrofauna such as worms (even if most worms are non-native). Thus, many of the highly important landscape areas of the National Capital Region, including the National Mall, battlefield cemeteries, visitor centers, picnic areas, trails, tow paths, etc., are places where manipulated soils need to be understood from their creation, through use and then management.

In addition, created landscapes were identified as one of the more unique, geological components of the National Capital Network (and especially, Washington, D.C.), and for which the group felt that very little information currently was available. On one hand, these changed environments could lead to increased diversity due to the potentially more complex mosaic of soils and resulting vegetation communities. On the other hand, these landscapes are commonly affected by human manipulation, horticultural and agricultural practices, and urban landscaping efforts, all of which tend to lower biodiversity and lead to an increased occurrence of exotic species.

Several potential research topics were discussed: historical records of floods, sedimentation, and land use in the region. Historical records of floods should be relatively easy to find for the National Capital Region. For example, metropolitan records and historical documents may provide an indication of historic structures affected by flooding on a sequential basis. In addition, Jim Patterson (NPS–retired) may have a lot of background information on NCR parks.

Sediment coring may also be used to provide a historical perspective on sediment "cycling" throughout the history of this region. The use of aerial photos, as available, may provide the necessary data to examine land-use change over time, changes in stream morphology over time, and shoreline change over time. Finally, through the use of newer technologies such as LIDAR and GPS, it is possible to examine changes in topography and geomorphology, at a fine scale, which is especially important in the Piedmont and Coastal Plain areas of the National Capital Region that have little or no topographic relief (e.g., Dyke Marsh).

In the afternoon session, the workgroup focused upon ways to condense the list of 30 threats to geological resources into a more manageable size (table 5). This proved to be a difficult task due to the varied nature of some of the components in table 4. The first two categories, (1) nutrients and contaminants and (2) erosion and sedimentation, were natural groupings of many of the entries in table 4. The remaining components of table 4 were more difficult to categorize because they did not fit nicely into a single group heading. However, the workgroup was finally able to group the components into the following subject headings: nutrient and contaminant cycling, sediment cycling, engineered lands and urban soils, shoreline change, geo-hazards, human influences within the park boundary, and human influences outside the park boundary. The group next began to prioritize these subject areas, but decided that some of these categories were too contrived, or overlapped too much, to be separated out in this way.

The final geology working group session was held on Thursday morning. The group decided to continue through the prioritization process by beginning with the categories that they were satisfied with—nutrient and contaminant cycling, and sediment cycling. For these two groupings, the group suggested established protocols for monitoring, wrote monitoring goals and objectives, and identified potential collaborators. Once this analysis was completed for nutrient/contaminant and sediment cycling, the discussion continued for engineered lands and urban soils, shoreline change, and geo-hazards.

The categories of human influences within the park boundary and human influences outside the park boundary were considered to be too broad and thus were eliminated from table 4.
Categories were then ranked by considering the significance of the threat to the parks in the NCN, which included the following factors: amount of area affected by the threat, intensity of the threat to the resource, urgency of the threat to the resource, monitoring feasibility, and cost of monitoring.

By the end of the morning session, the group had decided upon the following categories, in priority order: nutrient and contaminant cycling, sedimentation and erosion, lack of understanding of engineered lands, shoreline change, and geo-hazards. The workgroup then went back through table 4 to assign all 30 elements to one (or more) of these specific groupings.

In addition to the work above, the workgroup noted information needs and studies of interest throughout the discussion. These are summarized below.

Information Needs:

A more recent and complete soils map for the region is needed.

Inventory information regarding land changes and the creation of lands for baseline data as well as how these lands change towards equilibrium is needed.

Are locations of air quality monitoring stations that also capture atmospheric deposition known? They need to be checked at the National Atmospheric Deposition Program (http://nadp.sws.uiuc.edu) or discussed with the air workgroup.

What about non-point source pollution monitoring in the region?

Is anyone considering the effects of acid rain on monuments in the region? There was, at one time, a long-term monitoring project regarding this process (in D.C.)?

Has anyone examined the flood and floodplain history of this area?

Previous Studies of Interest in NCR:

There were studies at 4-Mile Run beginning in the 1950s (pre-urbanization) to look at or capture the effects of urbanization.

Jeff Houser (Oak Ridge) has looked at the effects of sedimentation on streams and stream biota.

Personnel Involved:

Facilitator: Christina Wright, NPS—NCN I & M Program: and Dale Nisbet, NPS—HAFE
Participants: Joe Calzarette, Michelle Clements, Sid Covington, Dick Hammerschlag, Bob Higgins, Wright Horton, Lindsay McClelland, Wayne Newell, Scott Southworth, L. K. Thomas, and Ed Wenschhof.

Table 1. Priority threats, vital signs, and monitoring goals and objectives for geological resources in the NCN.

Threats (in priority order)	Vital Sign	Monitoring Goal	Monitoring Objectives
Nutrient and chemical contamination	Changes in soil and ground water chemistry.	Use an input/output approach to understand nutrient and contaminant cycling in the ecosystem.	(1) Measuring nutrient inputs from sources pertinent to each park unit. (2) Measuring contaminant inputs from sources pertinent to each park unit. (3) Tie information from numbers 1 and 2 to the hydrologic cycle, flood history, flood effects, and flood impacts.
Erosion and sedimentation	Changes in topography, sediment loading and deposition, shoreline change, wetland extent and condition.	Use survey and analysis methods to evaluate changes in topography, sediment loading, and flow rates.	(1) Measure loss of soil, growth of gulleys, changes in streambanks…. (2) Track sedimentation history, effects, and impacts (including streams and ponds, hillslopes and gulleys).
Lack of understanding of urban soils and engineered lands	Compaction, runoff, chemical composition, soil profile and structure, biodiversity.	To understand the functioning and components of urban soils engineered landscapes and their effects upon resident biota. Components include: highly impacted soil (compaction in and around trails, visitor centers), landfills, engineered soil, etc.	(1) Measure changes to physical components of urban soils and engineered lands and correlate with changes in resident biota (and exotic species). (2) Measure contaminant outflow from landfills, abandoned mines, etc.
Shoreline change	Inundation of wetlands, erosion and sedimentation processes.	Use mapping or survey methods to track shoreline change and depositional patterns.	(1) Measure shoreline change using aerial photos, LIDAR and survey methodologies and correlate changes to development, when possible. (2) Use sediment coring and historical data to understand long-term flood histories.
Geo-hazard	Physical failure, rock falls, landslides, sinkhole collapse.	Use observation and assessment to provide an early warning of physical failure to protect the resource, visitors, and park infrastructure.	(1) Monitor areas of potential hazard due to unstable slopes, rockfalls, etc. (2) Monitor for changes in unstable engineered sites or areas that are geologically active (e.g. Potomac Gorge). (3) Document and monitor areas underlain by swelling clays.

Table 4. Revised conceptual model for geological resources in the NCN.

Resource Component	Stressor	Sources	Ecological Effects	Priority of Threat to Resource	Grouping used in priority table	Indicator/ Vital Sign	Protocol	Monitoring Goal	Potential contacts or collaborators
Soil	Pesticide loading	Agricultural, residential, and commercial use	Accumulation of pesticides that adhere to soil particles, causing changes to or the elimination of non-target soil fauna populations	High	1	Test soils and sediment for suite of pesticides commonly used in local area	Lithogeochemical studies (USGS), mass balance or input/output approach	Use an input/output approach to understand nutrient and contaminant cycling in the ecosystem.	Owen Bricker, Nancy Simon, Wayne Newell, Wright Horton, David Russ (USGS - Reston), Mark Nellis (USGS - Denver), USDA, EPA, USGS - NAWQA
Soil/Bedrock	Nutrient loading	Agricultural, residential and commercial use	Acidification of the soil, reduction of soil organic matter, change in soil fertility status	High	1	Soil pH, soil N and P status, soil organic matter levels	Lithogeochemical studies (USGS), mass balance or input/output approach	Use an input/output approach to understand nutrient and contaminant cycling in the ecosystem.	Owen Bricker, Nancy Simon, Wayne Newell, Wright Horton, David Russ (USGS - Reston), Mark Nellis (USGS - Denver), USDA, EPA, USGS - NAWQA
Soil/Bedrock	Change in pH, loss of buffering capacity	Acid rain, atmospheric deposition	Change in vegetation types, mycorrhiza and other soil flora, fauna	Unknown	1	Soil pH, acid neutralizing capacity (ANC)	Lithogeochemical studies (USGS), mass balance or input/output approach. Mass flow/hydrologic modeling.	Use an input/output approach to understand nutrient and contaminant cycling in the ecosystem.	Owen Bricker, Nancy Simon, Wayne Newell, Wright Horton, David Russ (USGS - Reston), Mark Nellis (USGS - Denver), USDA, EPA, USGS - NAWQA
Soil	Temperature Change	Climate change	Changes in soil micro-climate	Unknown, locally high		Soil temperature/moisture regime, changes in soil flora, fauna and mycorrhiza suite	Soil temperature and moisture monitoring. Soil organism analysis.		
Soil/Surficial Factors	Clearing of land	Soil surface exposure, development, agriculture, zoning laws (local and county governments)	Loss of soil surface cover, increased soil surface and groundwater temperatures	High	2 and 3	Soil and groundwater temperature/moisture regime. Change in vegetation community. Land use change.	Measurement of soil surface and groundwater temperature, monitoring of bare soils in region. Land use change analysis, vegetation community analysis.	Use survey and analysis methods to evaluate changes in topography, sediment loading and water flow rates.	Rebecca Beavers (NPS - GRD), Wayne Newell, Nancy Simon, Pete Chirico (USGS - Reston), EPA - Office of Water and ORD, USGS - NAWQA, Loren Setlaw (?), Doug Curtis (NPS - CUE), Don Weeks (NPS - Denver)

Resource Component	Stressor	Sources	Ecological Effects	Priority of Threat to Resource	Grouping used in priority table	Indicator/ Vital Sign	Protocol	Monitoring Goal	Potential contacts or collaborators
Soil	Erosion	Developmen t, land clearing, increasing impervious surface	Increased siltation, reduced productivity/healt h/abundance of soil, plants, and aquatic organisms	High	2 and 4	Sediment loading, increased sedimentation and changes in sedimentation patterns, land use change, change in topography, shoreline change, change in wetland extent and condition.	Shoreline change/Wetland extent - aerial photo analysis. Change in topography - LIDAR, GPS. Changes in sedimentation - bedload analysis, storm water event sampling, total suspended solids, light penetration in water column. Condition of wetland - changes in wetland plant species, multiband aerial photography.	Use survey and analysis methods to evaluate changes in topography, sediment loading and water flow rates.	Rebecca Beavers (NPS - GRD), Wayne Newell, Nancy Simon, Pete Chirico (USGS - Reston), EPA - Office of Water and ORD, USGS - NAWQA, Loren Setlaw (?), Doug Curtis (NPS - CUE), Don Weeks (NPS - Denver)
Soil/Surficial Factors	Erosion	Developmen t	Change in "normal" sedimentation sequence and composition	Unknown, low	2 and 4	Increased deposition, change in scouring and deposition patterns, change in hydrologic flow regimes.	See above protocols. Also, analysis of sediment cores, including an analysis of historical sediment records.	Use survey and analysis methods to evaluate changes in topography, sediment loading and water flow rates.	Rebecca Beavers (NPS - GRD), Wayne Newell, Nancy Simon, Pete Chirico (USGS - Reston), EPA - Office of Water and ORD, USGS - NAWQA, Loren Setlaw (?), Doug Curtis (NPS - CUE), Don Weeks (NPS - Denver)
Soil	Change in vegetation /exotics	Developmen t, nursery use of exotics	Change in soil organic matter composition, changes in soil flora and fauna, pH, nitrification rates	Unknown		Exotic species monitoring and control measures, soil chemistry, soil organic matter levels, soil pH, soil nitrification rates			
Soil, creation of new soils	Fill dirt: complete changes in soil physical and chemical compositi on resulting from filling in land areas with soil from another location (esp. DC)	Landfills, abandoned mines, land engineering	Changed, destroyed, or new soil profile, change in chemical composition of soil, introduction of toxics, introduction of impervious structures into soil profile, compaction. Resultant changes to biodiversity and vegetation communities. Changes to hydrologic cycle.	High - esp. urban	1 and 3	Assessment and description of soil profile, change in subsurface temperatures, change in land surface elevation profile, movement of physical debris from land, soil compaction, change in biodiversity of flora and fauna	Assessment and description of soil profile, surface and ground water monitoring (lithogeochemical studies), bulk density, porosity or other soil compaction measures.	To understand the functioning and components of engineered landscapes (components - landfills, engineered soils, etc.)	USDA - NRCS, Dick Hammerschlag (USGS - Patauxent), Wright Horton (USGS - Reston). Also see contacts for nutrient and sediment cycling.
Soil	Compacti on	Visitor Use	Changes in vegetation survival, changes in soil physical properties, creation of soil crusts (an impervious surface).	Urban, locally - high	1 and 3	Monitor soil compaction, bulk density, porosity, or other soil compaction measures. Formation of soil crusts.	Soil coring, bulk density, porosity or other soil compaction measures.	To understand the effects of visitor use upon the soil profile - includes social and official trails.	

Resource Component	Stressor	Sources	Ecological Effects	Priority of Threat to Resource	Grouping used in priority table	Indicator/ Vital Sign	Protocol	Monitoring Goal	Potential contacts or collaborators
Soil	Impervious surfaces	Paving, walls, armored banks	Scouring, cutting/changing shoreline, flooding,	High	1 and 3	Increased velocity of storm water flow, land use change	Storm water event sampling, aerial photos to examine land use change.	To understand the effects of increasing impervious surfaces in the watershed upon hydrology.	Pat Bradley - EPA, USGS - NAWQA, EPA - Office of Water
Unique soils: calcareous and serpentine soils	Lack of information for these soils and soil in general	Lack of information for these soils and soil in general	Potential for damage to unknown/unmapped resource	unknown	1	Soils inventory work necessary.	Complete, up-to-date, high resolution soil maps	N/A	Pete Biggam - NPS, USDA - NRCS
Groundwater	Consumption of groundwater in excess of replenishment	Human, agricultural, residential, commercial use and domestic animal use	Reduced groundwater quantity, and quality. Loss of springs and seeps, wetland loss, changed of soil saturation zones. Change in drinking water quality and quantity.	High	1 and 2	Changes in groundwater table, Changes or loss of springs and seeps, change in extent of wetlands, changes in soil moisture profile.	Survey of groundwater table and groundwater chemistry. Groundwater flow monitoring wells		
Groundwater	Introduction of toxics, acid drainage (natural and mining)	Landfills, abandoned mines, land engineering, bedrock.	Reduced groundwater quality	high	1	Change in groundwater quality, quantity, and temperature. Increased toxics in groundwater.	Groundwater monitoring wells in conjunction with lithogeochemical studies (USGS), Mass balance or input/output approach	Use an input/output approach to understand nutrient and contaminant cycling in the ecosystem.	Owen Bricker, Nancy Simon, Wayne Newell, Wright Horton, David Russ (USGS - Reston), Mark Nellis (USGS - Denver), USDA, EPA, USGS - NAWQA
Groundwater	Physical Failure	Landfills, abandoned mines, land engineering	Change in subsurface water flow patterns, change in subsurface temperatures, introduction of contaminants	High	5	Groundwater monitoring wells (flow and mapping), subsurface temperature changes	Aerial photo mapping of areas with potential physical failures. Park staff observations of potential geo-hazard sites. Expert analysis of geo-hazard sites on a periodic basis.	To use observation and assessment to provide an early warning of physical failure in order to protect the resource, visitors, and park infrastructure.	John Pallister, Bula Gori, Gerry Wieczoff - USGS
Groundwater	Water bypasses the soil profile	Old - abandoned wells (farms)	Increased groundwater contamination with nutrients, pesticides and other chemicals	Unknown	1	Change in groundwater quality, increased toxics in groundwater.	Groundwater monitoring and monitoring of abandoned wells in conjunction with lithogeochemical studies (USGS), Mass balance or input/output approach. Abandoned wells need to be found and sealed to minimize contamination.	Use an input/output approach to understand nutrient and contaminant cycling in the ecosystem.	Owen Bricker, Nancy Simon, Wayne Newell, Wright Horton, David Russ (USGS - Reston), Mark Nellis (USGS - Denver), USDA, EPA, USGS - NAWQA

Resource Component	Stressor	Sources	Ecological Effects	Priority of Threat to Resource	Grouping used in priority table	Indicator/ Vital Sign	Protocol	Monitoring Goal	Potential contacts or collaborators
Groundwater	Impervious Surfaces	Roads, buildings, infrastructure	Reduced water infiltration leading to reduced groundwater recharge, movement of water between watersheds	Medium	1 and 2	Map and monitor groundwater recharge areas, monitor groundwater table levels and chemistry, subsurface temperature monitoring.			
Exposed rock	Cutting the toe of slopes, over-steepened slopes, dipslopes	Development, roads, structures, trails, flooding, vegetation death (hemlock etc.), logging	Reduced slope stability	Low	5	Slope failure, reduced slope stability, movement of materials downslope, erosion, gully formation	Aerial photo mapping of areas with potential physical failures. Park staff observations of potential geo-hazard sites. Expert analysis of geo-hazard sites on a periodic basis. Monitoring for gulley formation or increasing erosion.	To use observation and assessment to provide an early warning of physical failure in order to protect the resource, visitors, and park infrastructure.	John Pallister, Bula Gori, Gerry Wieczoff - USGS. Also see personnel under erosion categories.
Karst	Toxics: pesticides, dumping, spills	Agriculture, septic systems, sewage, dumping, industry, spills	Rapid movement of contaminants to ground water, change in ground water chemistry and resulting in change in biology	High – locally	1	Subterranean invertebrates, ground water chemistry/ quality	Analysis of subterranean invertebrates. Lithogeochemical studies (USGS), Mass balance or input/output approach	Use an input/output approach to understand nutrient and contaminant cycling in the ecosystem.	Smithsonian Institute Invertebrate specialists. Owen Bricker, Nancy Simon, Wayne Newell, Wright Horton, David Russ (USGS - Reston), Mark Nellis (USGS - Denver), USDA, EPA, USGS - NAWQA
Karst	Nutrient loading	Agriculture, septic systems, sewage, dumping, industry, spills	Rapid movement of nutrients to ground water resulting in change to ground water quality and change in biology	High – locally	1	Subterranean invertebrates, ground water nutrient content	Analysis of subterranean invertebrates. Lithogeochemical studies (USGS), Mass balance or input/output approach	Use an input/output approach to understand nutrient and contaminant cycling in the ecosystem.	Smithsonian Institute Invertebrate specialists. Owen Bricker, Nancy Simon, Wayne Newell, Wright Horton, David Russ (USGS - Reston), Mark Nellis (USGS - Denver), USDA, EPA, USGS - NAWQA
Karst	Structural collapse, sinkholes	Inappropriate construction practices, dissolution in karst areas	Change in biology due to changes in air flow and temperature, volume and flow of water increased in areas dissolution of bedrock	High – locally	5	Change in sinkhole size, aerial photos to capture surface changes, subsurface temperature monitoring	Aerial photo mapping of areas with sinkholes. Park staff observations of potential geo-hazard sites. Expert analysis of geo-hazard sites on a periodic basis.	To use observation and assessment to provide an early warning of physical failure in order to protect the resource, visitors, and park infrastructure.	John Pallister, Bula Gori, Gerry Wieczoff - USGS

Resource Component	Stressor	Sources	Ecological Effects	Priority of Threat to Resource	Grouping used in priority table	Indicator/ Vital Sign	Protocol	Monitoring Goal	Potential contacts or collaborators
Surface water	Impervious surfaces	Infrastructure, development, residential and agricultural use, rip rap, armoring etc.	Increased storm water flow, increased erosion, changes in sedimentation, changes in stream morphology, increased exposure to nutrients/pesticides, change in hydrologic cycle effecting floodplains, and floodplain/riparian buffer capacity, change in base flow	High	1 and 2	Stream storm water flow, flood frequency, sedimentation load, stream morphology. Photo points. Storm event sampling, Mass flow/hydrologic modeling	Lithogeochemical studies (mass balance approach).Shoreline change/Wetland extent - aerial photo analysis. Change in topography - LIDAR, GPS. Changes in sedimentation - bedload analysis, storm water event sampling, total suspended solids, light penetration in water column. Condition of wetland - changes in wetland plant species, multiband aerial photography.	Use an input/output approach to understand nutrient and contaminant cycling in the ecosystem. Use survey and analysis methods to evaluate changes in topography, sediment loading and flow rates.	Rebecca Beavers (NPS - GRD), Owen Bricker, Nancy Simon, Wayne Newell, Pete Chirico, Wright Horton, David Russ (USGS - Reston), Mark Nellis (USGS - Denver), USDA, EPA - Office of Water, USGS - NAWQA
Surface water	Pesticide loading	Agricultural, residential, and commercial use	Reduced water quality, fishery health, and aquatic invertebrate communities and populations	High	1	Test for suite of pesticides commonly used in local area.	Lithogeochemical studies (USGS), Mass balance or input/output approach	Use an input/output approach to understand nutrient and contaminant cycling in the ecosystem.	Owen Bricker, Nancy Simon, Wayne Newell, Wright Horton, David Russ (USGS - Reston), Mark Nellis (USGS - Denver), USDA, EPA, USGS - NAWQA
Surface water	Nutrient loading	Agricultural, residential and commercial use	Reduced water quality, fishery health, and aquatic invertebrate communities and populations. Algal blooms, eutrophication	High	1	Soil water and stream levels of N and P. High algal growth, low light penetration	Lithogeochemical studies (USGS), Mass balance or input/output approach	Use an input/output approach to understand nutrient and contaminant cycling in the ecosystem.	Owen Bricker, Nancy Simon, Wayne Newell, Wright Horton, David Russ (USGS - Reston), Mark Nellis (USGS - Denver), USDA, EPA, USGS - NAWQA
Coastal areas	Impervious surfaces	rip rap, armoring, coastal walls, dredging	Changes in water flow rates, unnatural erosion and deposition, changes in natural shoreline, changes in sedimentation, wetland flooding, changes in wetland extent.	High – locally	1 and 2	Sedimentation coring (deep cores - research, shallow cores - monitoring), mapping of shoreline change, use of Pope's Creek as a reference area	Using aerial photos or survey methods to map shoreline and shoreline change over time.	Use mapping or survey methods to track changes in shoreline and depositional patterns, over time.	NOAA (?)
Lakes, ponds, seeps, vernal pools	Nutrient loading	Agriculture, residential lawn care, vegetation change	Eutrophication, change in fauna (esp. herps), effect upon T&E species	Unknown	1	Size/volume, chemistry, and temperature of surface water component	Lithogeochemical studies (USGS), Mass balance or input/output approach	Use an input/output approach to understand nutrient and contaminant cycling in the ecosystem.	Owen Bricker, Nancy Simon, Wayne Newell, Wright Horton, David Russ (USGS - Reston), Mark Nellis (USGS - Denver), USDA, EPA, USGS - NAWQA

Resource Component	Stressor	Sources	Ecological Effects	Priority of Threat to Resource	Grouping used in priority table	Indicator/ Vital Sign	Protocol	Monitoring Goal	Potential contacts or collaborators
Lakes, ponds, seeps, vernal pools	Pesticide loading	Agriculture, residential, and commercial use	Addition of herbicides and pesticides to surface water, change in fauna, effect upon T&E species	Unknown	1	Pesticide, herbicide content of surface water component	Lithogeochemical studies (USGS), Mass balance or input/output approach	Use an input/output approach to understand nutrient and contaminant cycling in the ecosystem.	Owen Bricker, Nancy Simon, Wayne Newell, Wright Horton, David Russ (USGS - Reston), Mark Nellis (USGS - Denver), USDA, EPA, USGS - NAWQA
Riparian areas, Wetlands	Change in soil surface elevation and horizontal dimensions	Land engineering resulting in changes to deposition and erosion, dredging, dumping, creation of impoundments and dams	Disruption to the wetland/riparian ecosystems, change in storm water flow rates, vegetation change, wildlife change, change in stream bed characteristics	High	4	High resolution riparian/ wetland elevation monitoring, vegetation monitoring, sediment budget, changes in size of wetland area	Changes in wetland extent - aerial photo analysis. Change in topography - LIDAR, GPS. Changes in sedimentation - bedload analysis, storm water event sampling, total suspended solids, light penetration in water column. Condition of wetland - changes in wetland plant species, multiband aerial photography.	Use survey and analysis methods to evaluate changes in topography, sediment loading and water flow rates.	Rebecca Beavers (NPS - GRD), Wayne Newell, Nancy Simon, Pete Chirico (USGS - Reston), Richard Lowrance (USDA/ARS), EPA - Office of Water and ORD, USGS - NAWQA, Loren Setlaw (?), Doug Curtis (NPS - CUE), Don Weeks (NPS - Denver)

Appendix D: Geoindicators Notes

NCR Geoindicators Meeting May 20, 2002

Attendees:

NPS
Christine Wright, Data Manager, CUE
Marcus Koenen, Monitoring Coord., CUE
Pat Toops, Nat. Res. Chief, NCR
Bob Higgins, GRD - Denver
Sid Covington, GRD - Denver
Lindsay McClelland, GRD - Washington
Rijk Morawe, Nat. Resources Mgt. Specialist, GEWA

USGS
Nancy Simon, WRD
Marty Gurtz, Water Quality Program
Bill Bartlett, Water Quality Program
Owen Bricker, WRD (Geochem./Hydrology)
Wayne Newell
Scott Southworth
Peter Chirico

Vital Signs Network - Marcus Koenen
1. National Capital Region (NCR) began monitoring about 3 yrs ago
2. Planning process will help determine what the important issues are; what specific indicators need to be monitored.
3. Final plan should be completed by Spring 2004

Geology Overview
by Scott Southworth

1. Antietam NB and Monocacy NB
a. Share similar geology
b. Underlain by carbonates; karst topography
2. Catoctin Mountain Park
a. Quaternary alluvium
b. Debris flows
c. Few slope hazard issues
d. Completely clear-cut by mid-1930s
3. Rock Creek; George Washington Mem. Parkway; Wolf Trap Farm; Prince William Forest
a. Share similar geology and issues
b. Similar land use, but different surfaces
c. Landscape has been extremely modified and altered (esp. Rock Creek)
4. Prince William Forest
a. Acid mine drainage
b. Heavily forested; highly altered
5. General
a. Groundwater is an issue is almost all the NCR parks
b. Data on river pollution should become available on a CD ROM
c. Need to look at processes along the strike of faults, esp. in Piedmont and Blue Ridge provinces
d. Potomac Conservancy Plan - developed by the NPCA; common link on geologic provinces
e. Lithochemical studies - study the path of nutrients through various rock lithologies (McClelland)
f. Rates of erosion are increasing from the incising effects of runoff.

Soils

1. No one is doing soil science based on geology; the chemistry of soils is based on the geology. How and from what rock type are the soils derived?
2. Look at the "geochemical landscape"
3. Soil studies are needed at Catoctin Mt.; can be used as an example
4. Partnering needed with the Natural Resources Conservation Service (NRCS)
5. Biologists are most interested in soils developed from ultramafic rocks
6. Need long-term monitoring:
a. Atmospheric stations to see what is coming in from the air (e.g., acid deposition)
b. Stream-flow site monitoring
c. Suite of biological components to monitor change.
7. Need to monitor what comes into the system, what's in the system and what leaves the system.

George Washington Birthplace (Nancy Simon)

1. Maybe less altered; looking at "natural" processes: sediment transport from pastures fertilized with sewage sludge from sewage treatment plants
2. Compare with areas not using sludge, using GEWA as a reference site
3. Very good watershed to study; use as a baseline (also Oxon Run estuary, rather than Anacostia)
4. Draw in surrounding people (landowners) to interpret study
5. Arboretum - has funding been cut?
6. Need to look at:
a. "Natural" (e.g., Catoctin) v. changing areas (e.g., George Washington Parkway)
b. Parks with geologic similarities and compare with vegetation (Toops); similar vegetation areas may vary geologically along strike
c. A larger, more inclusive perspective - areas outside the parks that have similar characteristics
d. Water quality (w/NAQWA) and effects of urbanization
e. Certain indicator parks at different stages:
(1) Unaltered ("natural")
(2) Slightly or moderately altered
(3) Greatly altered
(4) Altered, but recovering
f. Historic forestation (or deforestation), e.g., conditions during the Civil War (Chirico)

Geoindicators Worksheet

1. Surface Water

a. Stream channel morphology
(1) C & O Canal (no jurisdiction of channel)
(2) Antietam Creek
(3) Catoctin Mt.
(4) Manassas - Bull Run Creek
(5) Rock Creek - greatly effected by urbanization; removing barriers to herring spawning
(6) George Washington Parkway and Great Falls - urbanized
b. Need to look at tributaries as well as major streams
c. Human impacts on surface water flow (Chirico)
(1) What was the topography prior to human impact? Some streams have been filled 20–30 meters with coal ash, brick, dirt fill; Tiger Creek is now the Red Metro line
(2) What do we monitor from now on?
(3) Stream have been converted to wastewater and stormwater discharges
(4) Some trend to "daylight" streams—reopening streams that were buried, exposing the stream bed down to the drainage pipes
(4) Much of the urbanized land that was cleared has been stripped and moved down into steam valleys; this can be studied by coring (Bricker)
(5) There has been a flattening out of the topography by removing hills and filling in the streams; changes in slope affect channel morphology; between 1888 and today, the amount of material removed is equivalent to the material deposited by Mt. St. Helens in 1980.
(6) Surface streams have been converted to ground-water channels; comparisons of surface drainage in 1888 to 1999 shows very little similarity; difficult to compare.
(7) Look at old studies and publications: Leopold, Walden, Hack (Newell)
d. Need better topography data
(1) Topographic data for Catoctin Mt. is very poor
(2) Counties are doing better work and producing better maps than the GS. Sometimes the data is available but not to the federal employees; may need to purchase.
e. What kind of data is needed for stream flow? Not much baseline data; need cross sections; not much stream flow data in D.C. metro area; how important are streams to a particular unit?
f. Maybe need to look at the geoindicator table as, for example, what factors affect stream morphology?
g. Need "event sampling"—sample streams during flood or high water events (Simon)
h. Stream flow is more than just monitoring; need index of hydrologic alteration (Nature Conservancy).Hhow has stream flow changed? look at historic versus today's conditions; TNC has added predictability and looks at it slightly differently than the GS; need to look at historic data; in some cases, we have the information but no analysis of the data (Gurtz).

2. Sediment Influx

a. Oxon Run; GW Parkway below National AP (Dike Marsh); Anacostia; C&O Canal (effects of locks and channelization); Piscataway Creek (Newell)
b. What does park management want the parks to look like? Need to know where you want to go; e.g., should we be looking at the morphology of Bull Run Creek at Manassas? (Toops)
c. Look at what will happen if we further alter a stream (Gurtz)

3. Wetlands

a. Not a major issue
b. Anacostia has/is recreating wetlands
c. Some studies done by the D.C. Dept. of Health and USGS MD District.
d. NOAA studies mostly water quality

4. Ground water

a. Ground-water level
(1) Level in MD is dropping, wells are running dry; vegetation is probably changing; moratorium on new home construction in Frederick Co., MD, due to low ground-water level
(2) Drought and growth has made ground water a big issue; removal is outpacing recharge (surface water is still sufficient for now; Potomac is heavily used for water and for sewage, run-off and sewage treatment recharge).
(3) MD has a network of 17 monitoring wells
b. Ground-water quality
(1) Does the NPS need to drill monitoring wells to monitor level and quality and impact on biota (e.g. plants, amphibians)?
(2) Manassas, Antietam, Catoctin, and Anacostia all need monitoring wells (Newell and Chirico)
(3) Aquifers (except in the Coastal Plain) are fairly small and isolated in fault blocks, by lithology, and fractures; no large aquifers like the Midwest.

5. Karst

a. Karst topography at Antietam, C&O Canal, and Harpers Ferry
b. Seeps and springs are important to some parks: C&O Canal has streams that flow into underground karst and seep out into the Potomac.
c. Southworth has done some mapping in the C&O Canal/Antietam area
d. C&O has 8 abandoned mines and 14 caves; no active cave interpretation; some of the caves are open, but not a major resource to the park.
e. Problems with contamination from pesticides, fertilizers, sewage, run-off, etc.

6. Hazards

a. Colluvial rock slides an issue at Harpers Ferry

7. Relative Sea Level

a. Most shorelines are armored (see: Andy Miller, USGS, Rates of erosion around the Potomac area)
b. George Washington Birthplace (GEWA)
(1) Mouth of Popes Creek has an accreting delta derived from eroded material at GEWA.
(2) Cores from Popes Creek shows agricultural influx from about 1650 on; can see effects of land clearing, tobacco farming, and other agricultural uses in cores.
(3) Need PMIS statement for coring.
c. Need to document changes in shoreline both historically and from recent events
d. What are the impacts of armoring, and what would be the impacts of further armoring?
e. Piscataway Park - shoreline erosion
f. Shorelines around the NCR coastal parks has been greatly altered.

8. Soils (Redux)

a. Soils are derived from a variety of basement rocks: limestones, greenstones, saprolites, red shales, and quartzites.
b. Coastal Plain - stripped of sediment and soils since Colonial time (≈1650); soil dumped into streams
c. Beavers have become an important factor by retarding the loss of sediment; beaver dams trap sediment
d. Indicators: Change in acidity; Ca and Mg replaced by Al
e. Monitor acid deposition (PMIS?).Where?

Rock Creek Park

Geologic Resources Inventory Report

Natural Resource Report NPS/NRPC/GRD/NRR—2009/146

National Park Service
Director • Jonathan Jarvis

Natural Resource Stewardship and Science
Associate Director • Bert Frost

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