THE RIVER AND THE ROCKS

The Geologic story of Great Falls and the Potomac River Gorge

UNITED STATES DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY—NATIONAL PARK SERVICE

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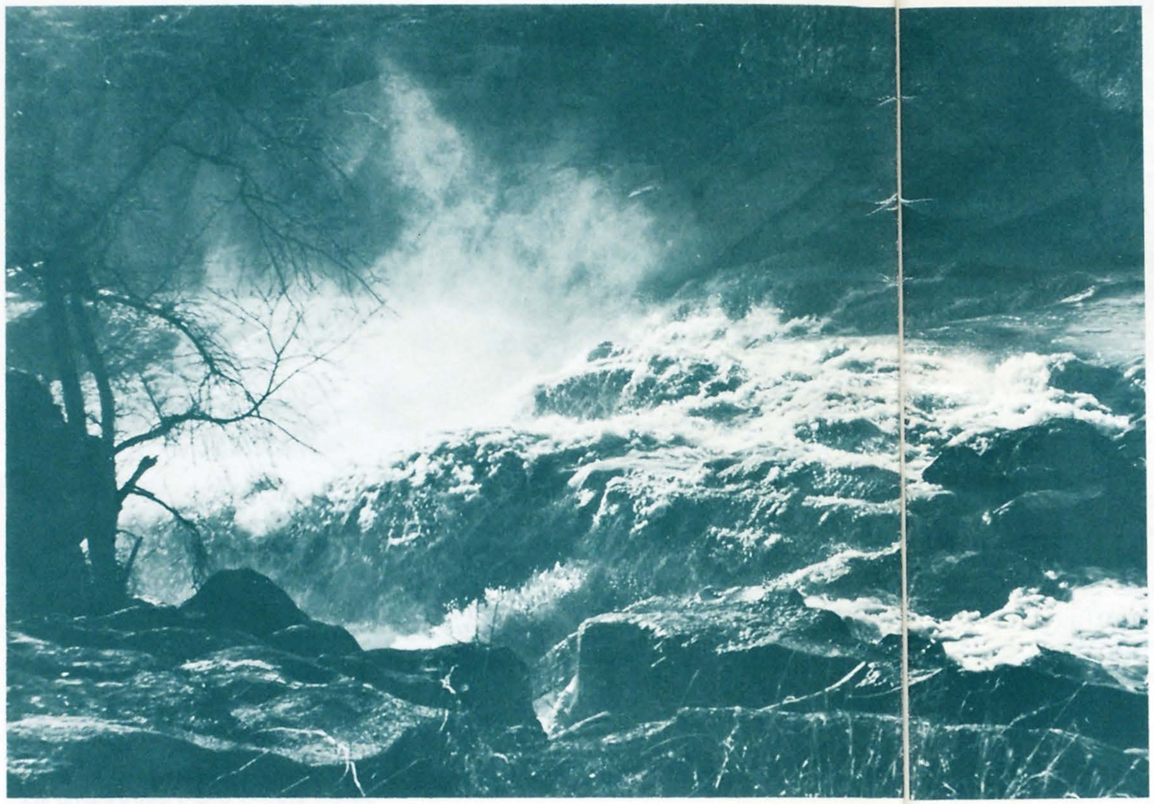

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Foreword

The Great Falls of the Potomac River has figured prominently in the purposes of men since prehistoric time. Long before John Smith reached the falls in 1609, groups of Indians from East and West met at this great river barrier to trade and perform ceremonies in honor of the spirit of the "Roaring Waters." As early as 1754 George Washington visualized the Potomac River as an important avenue of trade and communication with the interior.

Records show that with the exception of Mount Vernon, Great Falls was perhaps as intimately associated with George Washington's everyday life as any other place in the country. As first President of the "Patowmack Canal Company," Washington frequently visited the working parties as they constructed the canal and lock system which skirted the treacherous falls on the Virginia side. Matildaville, a town of about 40 acres named after the wife of "Light Horse" Harry Lee and consisting of various dwellings, grist mill, market house, forge, sawmill, and tavern, sprang up along the banks of the canal.

In 1802, the Patowmack Company canals were essentially completed, and hundreds of boats plied the river, bringing corn and wheat, coal and limestone, flaxseed and furs downstream from the mountainous region of Cumberland, Md. Many of the boats were sold for lumber in Georgetown, thus sparing the boatmen an arduous upstream journey.

After the establishment of the Nation's Capital, Great Falls became a popular scenic attraction for residents and visitors alike. But Great Falls was not always so easily accessible as it is today. In 1845, a newspaper columnist, after praising the beauty and historic interest of the region, added, ". . . the access to this interesting spot is, on both sides of the river, by the most infamous of roads and the accommodations for visitors anything but what they ought to be!"

Visitors to Great Falls now number close to a half million annually and, because of this continuing and mounting interest, the U.S. Geological Survey has joined with the National Park Service in preparing this booklet for better understanding and enjoyment of the Great Falls of the Potomac River.

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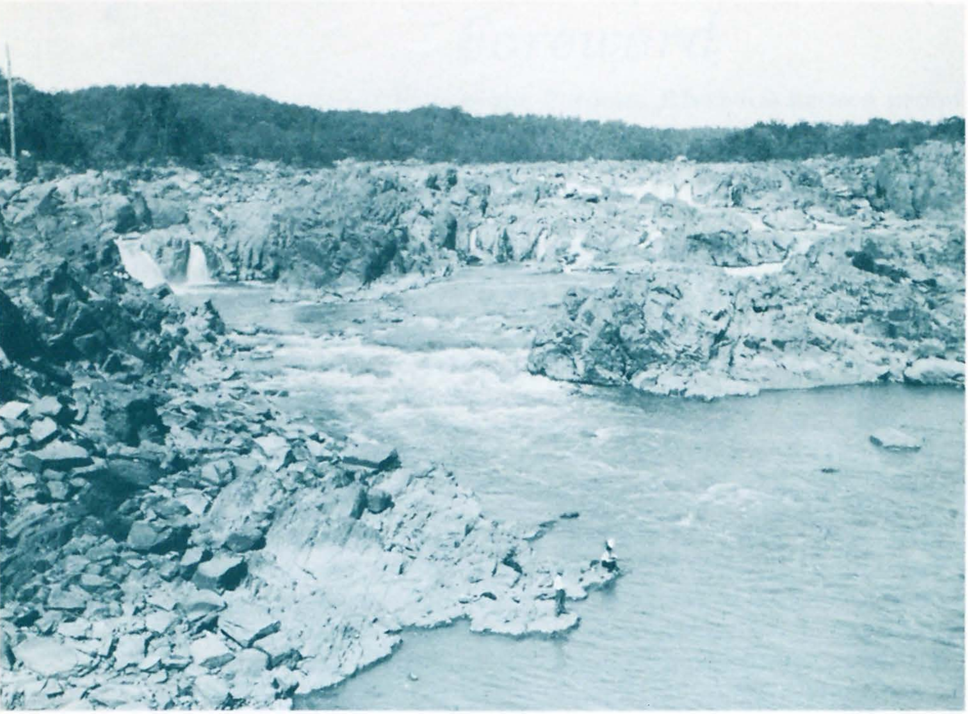

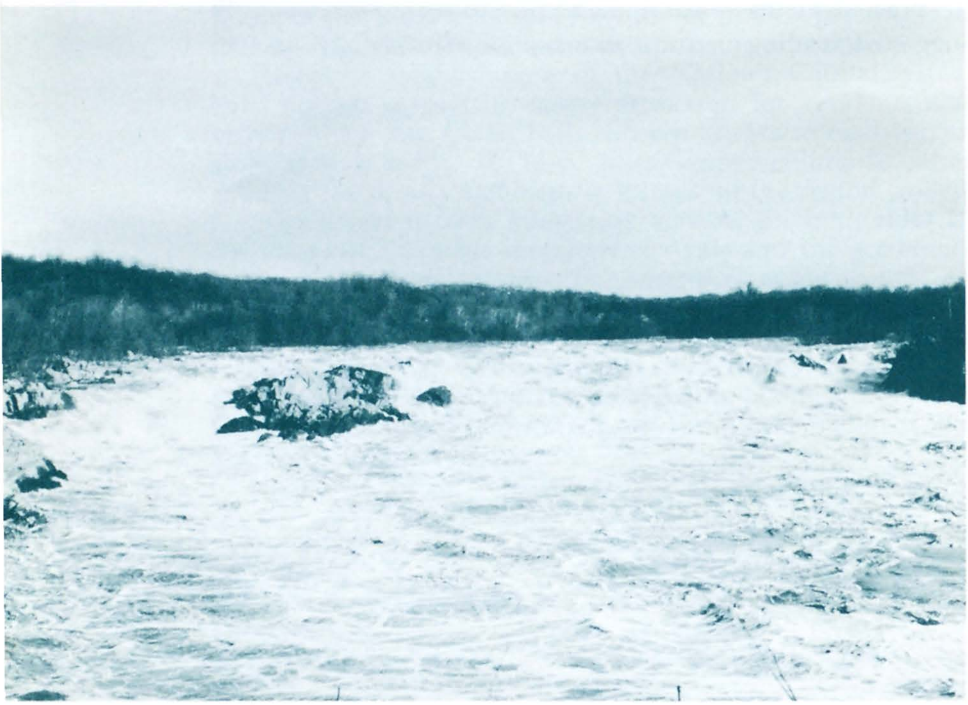

The falls today

The Great Falls of the Potomac River is the most spectacular landscape feature of the Washington metropolitan area, and it has influenced the lives and fortunes of man in the Potomac Valley for centuries. For countless generations of Indians it was a place to gather, to trade, and to fish. For the early settlers it was a barrier to river navigation, an obstacle that canal builders struggled to overcome. For the past 100 years the river above the falls has been the principal source of water for the city of Washington.

In its seaward course, the Potomac River crosses many small rapids and cascades, but these are insignificant in comparison with the foaming fury of Great Falls, where the river drops 40 feet in about 200 yards and is channeled into a narrow rock-walled gorge in places less than 80 feet wide. In the summer the flow may be less than 10 thousand gallons a second, but, during floods, the flow commonly reaches a million gallons a second. The average flow is 82,500 gallons of water pouring over the falls every second and in a year, more than two and a half trillion gallons—enough water to flood the entire District of Columbia to a depth of 180 feet.

During two periods of recent flooding—once in 1936 and again in 1942—water covered the towpath of the C. and O. (Chesapeake and Ohio) Canal on the Maryland side of the river and also spread across the Visitor Center, parking lots, and maintenance building on the Virginia side. Floods of this size are most unusual, but about once every 2 years floodwaters rise to the brink of the gorge at the falls, covering the overlooks on the Maryland side and reaching to within 15 or 20 feet of the trails along the Virginia cliffs. There have been 18 such floods since 1930.

Today Great Falls of the Potomac, Mather Gorge, and the surrounding scenic area administered by the National Park Service provide splendid opportunities for outdoor recreation. But perhaps most important of all, the area serves as a unique outdoor laboratory for nature studies and is a place to reflect on the impact of man on his natural environment.

Such studies require an understanding of the landscape—the geologic story concealed behind the scenery. This booklet presents a brief account of the geology of Great Falls, summarizing what is known of the events that formed the rocks and shaped the land.

A few words about the forests

The original forests of Great Falls Park have been almost completely cut over since 1790; only a few trees on the hill north of Difficult Run remain from presettlement times. After repeated cutting and clearing, fires, and high water, the bulk of the forest lands now supports second- or third-growth trees.

The various types of plants growing in the area reflect differences in landscape features and the availability of water. Forty-three species of trees have been recognized; their distribution and the associated groupings of shrubs and wild flowers for the five major subdivisions of the forest landscape are summarized in the following table.

Although the nature of the presettlement forests is not known, the present confinement of certain trees and shrubs to specific environments suggests that the bulk of the plant cover, except for the age and size of trees, is much like it was more than 150 years ago. A recent change in the forest is the disappearance of chestnut trees from the piedmont uplands because of the chestnut blight.

The sketches of leaves shown in the trail logs have been added to assist you in identifying the numerous species of trees growing in the park.

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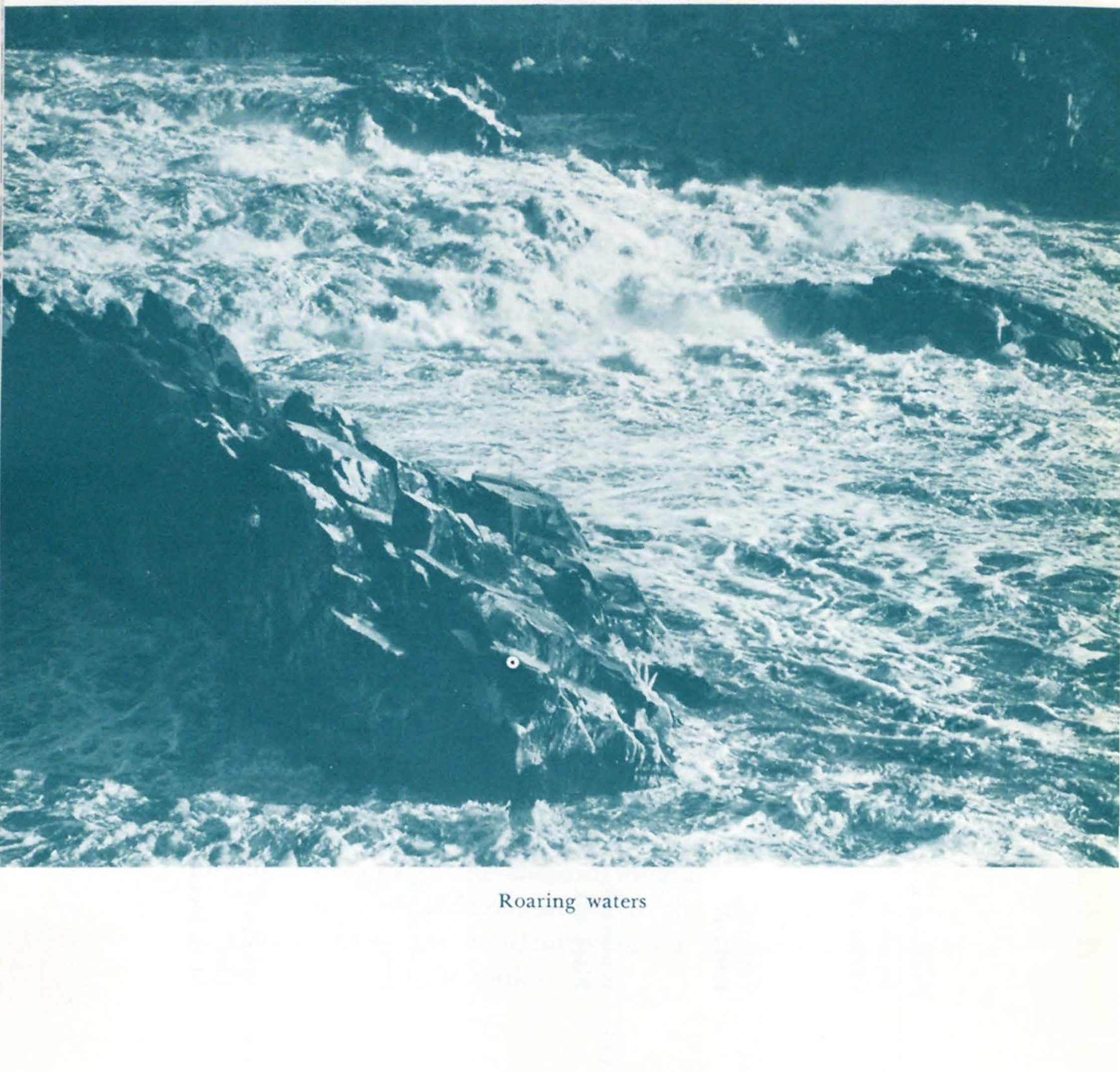
Landscape features and forest subdivisions

Landscape features	Forest subdivisions			Appearance	Environmental influence
	Prominent species	Other species	Small trees and shrubs		
Flood plains	Sycamore Green ash	Elm Boxelder Silver maple River birch Cottonwood	American hornbeam Spicebush Pawpaw Silky cornel	White trunks and branches of sycamore are typical.	Floods at least once every two years.
Bedrock terrace	Post oak Red oak	Virginia pine Pignut hickory White oak Chestnut oak Redcedar	Blueberries American holly Dogwood Fringetree Mountain-holly	Small, stunted, heavily branched trees.	Rocky ground of Bear Island and along cliffs. Rarely floods.
Piedmont uplands	White oak Black oak	Red oak, Scarlet oak, Chestnut oak, Southern Red oak, Yellow poplar, Virginia pine, Shortleaf pine	Mountain-laurel Dogwood, Shadbush Mapleleaf viburnum	Variable: from small, second-growth saplings to tall, straight-trunked large trees; dense to open undergrowth.	Hills and slopes underlain by deep soil. Never floods.
Swamps	Red maple Oaks	Pin oak Willow oak Swamp white oak Sourgum	Spicebush Southern arrowroot Poison-sumac Alder	Dense tangle of shrubs.	Poorly drained depressions and low areas. Water close to surface or standing. Floods rarely on Bear Island.
Areas of past use	Boxelder Elm Black locust	Yellow poplar Honey locust Black walnut	Spicebush Japanese honeysuckle "Escaped" cultivated shrubs	Bent, poorly formed trees; weedy ground.	Intense activity by man at Matildaville and around canal lockhouses.

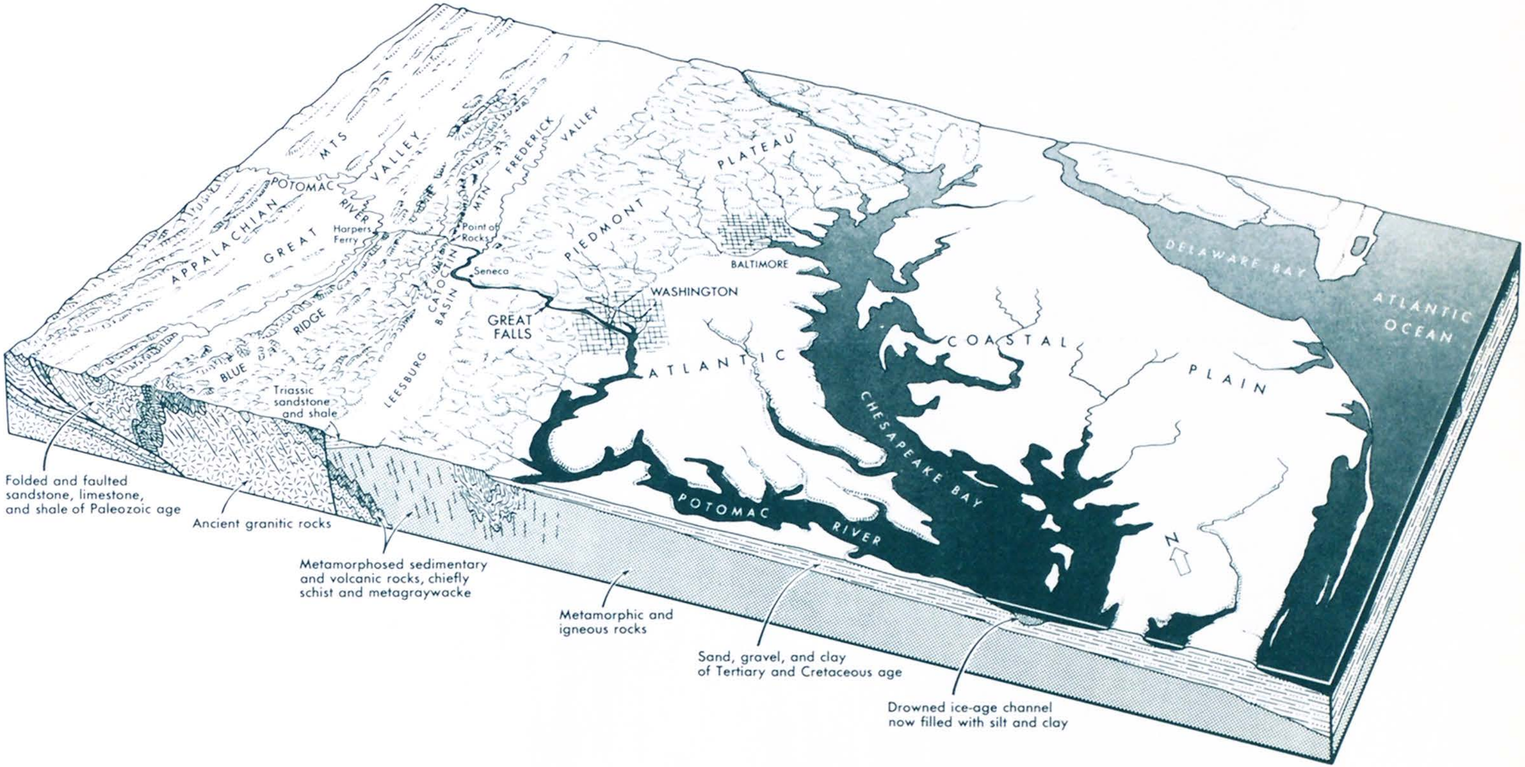


Roaring waters

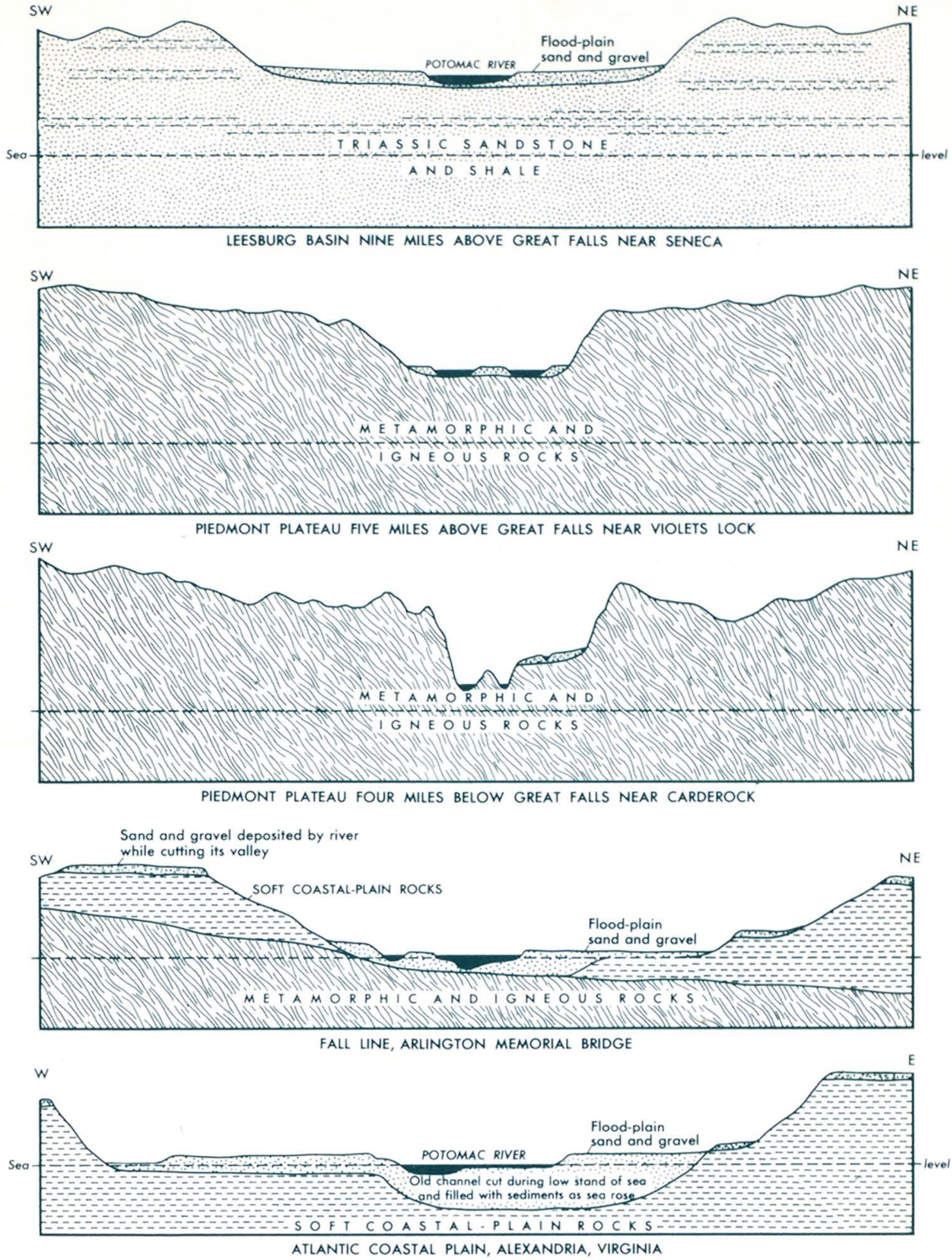
The river and the land

All landscapes are the result of a continuing struggle between the deep-seated earth forces that raise the land above sea level and the forces of erosion that gradually wear down the land's surface. Sedimentation—the deposition of the products of erosion—modifies the landscape only slightly. Erosion begins with the weathering of rocks—the chemical decay and solution of mineral grains and the mechanical disintegration of rocks by frost. The resulting debris is carried into streams and rivers by running water, again aided by frost action and the slow creep of soil down the slopes. Once in the streams the debris is transported seaward, partly in solution, partly as mud and silt in suspension, and partly as sand, gravel, and boulders. The Potomac River is estimated to carry more than 1.6 million tons of sediment and 1.1 million tons of dissolved material over the falls each year. This amounts to 230 tons of material removed from each square mile of the river's drainage area above the falls.

The Potomac, like other Atlantic seaboard rivers, heads in the Appalachian Mountains and flows eastward to the Atlantic Ocean. The river crosses the Blue Ridge through a narrow gap below Harpers Ferry and cuts across Catoctin Mountain, the easternmost ridge of the Appalachians, through a similar gap at Point of Rocks. From there to its mouth at Chesapeake Bay, the river flows across three major landscape provinces: a broad lowland between Point of Rocks and Seneca that is called the Frederick Valley in Maryland and the Leesburg Basin in Virginia; the Piedmont Plateau, between Seneca and Washington; and the Atlantic Coastal Plain, between Washington and Chesapeake Bay.



BLOCK DIAGRAM OF THE D. C. REGION SHOWING PHYSIOGRAPHIC PROVINCES AND GEOGRAPHIC AND GEOLOGIC FEATURES



CROSS SECTIONS OF POTOMAC RIVER VALLEY
SHOWING TYPICAL SHAPE IN EACH LANDSCAPE PROVINCE
Each cross section is approximately 4 miles long

The nature of the landscape and river valley in each of these provinces is determined largely by the nature of the underlying rocks. The Frederick Valley and Leesburg Basin are underlain principally by red sandstone and shale that were deposited during the Triassic Period, about 200 million years ago. Because these rocks are rather easily eroded, the land's surface is nearly flat; slopes are gentle and smooth. The river is wide, sluggish, and shallow and is flanked by broad flats frequently covered by floodwaters.

The Piedmont Plateau is a rolling, hilly upland underlain by hard rocks. Although these rocks are very resistant to erosion, they are subject to chemical decay which in places extends to depths of 100 feet and produces deep red clayey soils. The smaller streams on the uplands have not cut through the blanket of soil and decayed rock and thus flow in broad valleys and wide flood plains, but the larger streams have cut through to hard rocks and flow within narrow steep-sided valleys having constricted flood plains.

The nature of the valley of the Potomac across the Piedmont Plateau is quite variable. Above Great Falls the valley is steep sided but wide, and in most places the river is broad, shallow, and placid; in a few places, however, riffles and rapids break the quiet water as it passes across resistant ledges of rock. The numerous islands are composed of sand and gravel laid down by the river, and none of them rise much above the level of the flood that occurs about once every 2 years. At Great Falls the character of the river changes abruptly. From there to Theodore Roosevelt Island it flows within a series of narrow rock-girded channels twisting between cliffs and flat-topped bedrock islands that rise high above the level of the highest known floods. Passing over a series of rapids and low falls, including Yellow Falls, Stubblefield Falls, and Little Falls, the river reaches approximately the level of the sea at Chain Bridge.

As the river flows beneath the Arlington Memorial Bridge, it leaves the Piedmont Plateau and enters the Atlantic Coastal Plain. The Coastal Plain is underlain by layered deposits of sand, clay, gravel, and shells laid down in the sea when it encroached onto the eastern edge of the continent at various times during the past 100 million years. In cross section, these deposits resemble a gigantic wedge ranging from thicknesses of a few feet near the inland edge to nearly 10,000 feet along the Maryland coast. Chesapeake Bay and its system of estuaries are ancient valleys cut in the soft sediments of the Coastal Plain when sea level stood much lower. When the sea rose to its present level, the valleys were flooded. The Potomac River occupies one of these "drowned" valleys between Washington and its mouth at Point Lookout. The broad river, here affected by tides and navigable by oceangoing ships, is flanked by wide low flood plains and, in a few places, by bluffs carved out of the soft Coastal Plain rocks by waves.

The boundary between the hard rocks of the Piedmont Plateau and the soft, easily eroded rocks of the Coastal Plain is called the Fall Line because it is the line along which falls and rapids are first encountered in ascending the major rivers. It marks the head of navigation for oceangoing ships and the farthest point downstream that the streams can be crossed by fords or small bridges. For this reason, many of the cities of the eastern seaboard from Trenton, N. J., to Macon, Ga., were established along the Fall Line.

Although the nature of the river valley is largely controlled by the properties of the underlying rocks, these alone are not sufficient to explain the origin of the falls and the Potomac Gorge. If they were, one would expect Great Falls to lie at the Fall Line, rather than 15 miles upstream in the middle of the Piedmont Plateau. The reason for the present location of Great Falls must be sought through studies of the geologic history of the Potomac River valley.

The carving of the falls continues

The origin of the Potomac River valley and the carving of Great Falls

As the sea finally withdrew from the Atlantic Coastal Plain in the Washington area between 10 and 20 million years ago, streams draining eastward from the Appalachian Highlands spread a blanket of sand and gravel over the newly exposed sea floor and nearby parts of the Piedmont Plateau. This deposit was not laid down by a single major river, but by numerous streams that constantly shifted their courses back and forth to form a complex series of fan-shaped deposits that coalesced into the blanket of sand and gravel. Remnants of this blanket are still preserved capping some of the highest hills in the Piedmont near Tysons Corner, Va., 5 miles south of Great Falls. The deposit is a source of sand and gravel used for construction purposes in the metropolitan area.

Continued slow uplift of the Piedmont Plateau and the Appalachian Highlands to the west increased the slope of the land surface, causing the streams to deepen their valleys and eventually to coalesce into a river which was to become the Potomac. As this river deepened its valley, scattered remnants of its former flood plains were left at various levels as gravel-covered terraces. About 2 million years ago the river had succeeded in carving a broad, open valley in approximately its present position.

With the beginning of continental glaciation in the Pleistocene Epoch — about 2 to 3 million years ago — sea level was lowered, and the Potomac River began deepening this early valley. As water was withdrawn from the oceans to form the great ice sheets on the land, sea level around the world fell by as much as 500 feet. Most of the continental shelf off the eastern United States was exposed, and the shoreline lay as much as 75 miles east of its present position. Actually, continental glaciation occurred not just once, but at least four times in the last 2 to 3 million years. The last glacial episode ended only about 15 thousand years ago.

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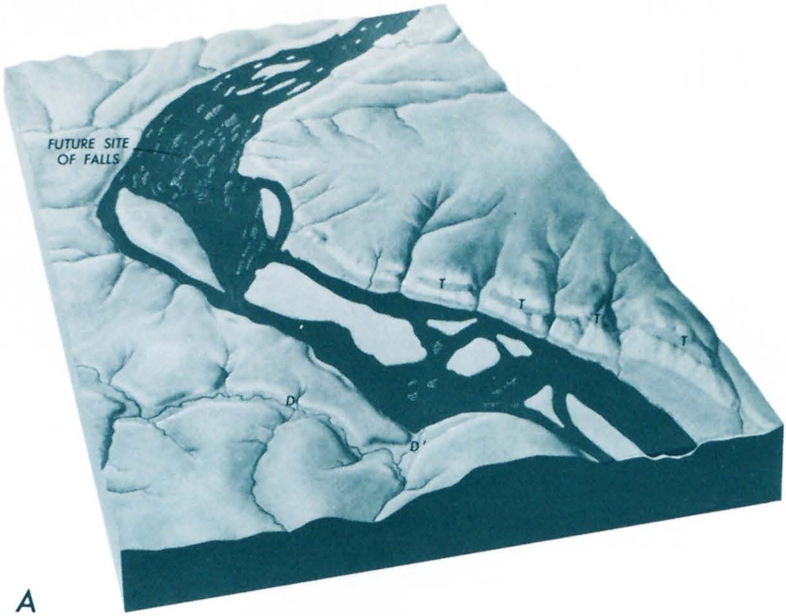

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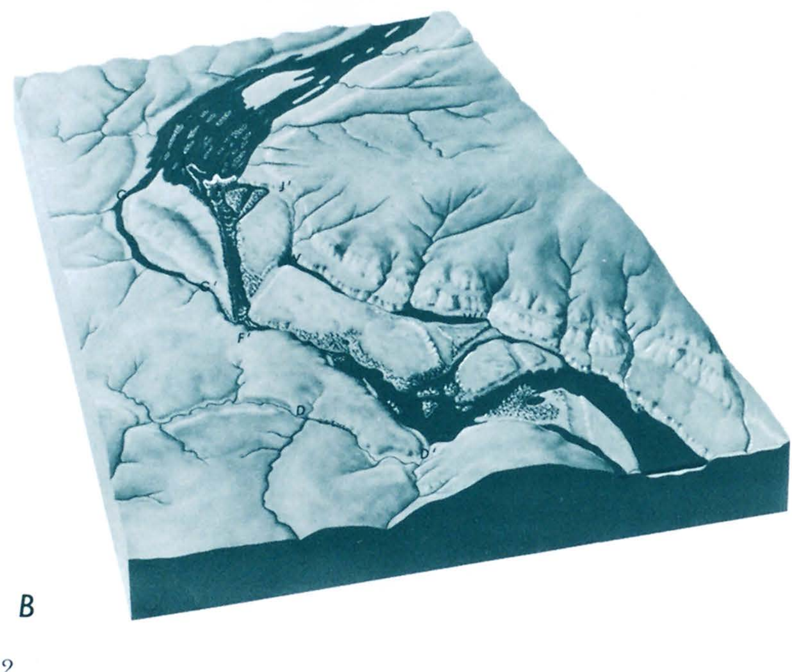


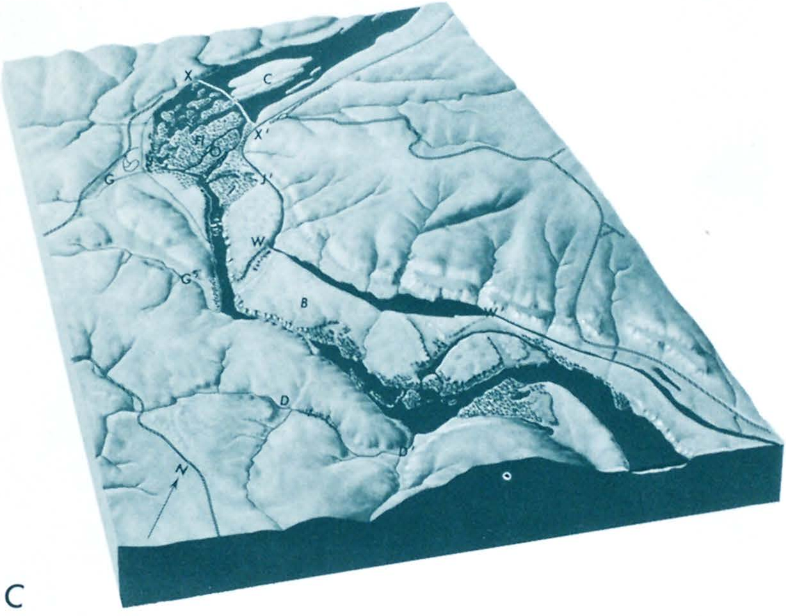
B

STAGES IN THE CARVING OF GREAT FALLS. The area of the block diagrams covers about the same area as that shown on the map. Refer to the map for scale and names of geographic features.

A. The Great Falls area as it probably appeared before the Ice Age. The river occupies a broad valley, and the future site of the falls is marked by rapids and ledges of resistant rock. Gravel-covered benches *(T)* are remnants of an older, higher valley floor. Difficult Run *(D–D')* flows across a broad, flat flood plain to empty into the Potomac River.

B. The same landscape during a period late in the Ice Age. The lowered sea level has caused the river to cut deeply into the floor of its former valley. Floods at this time may have been even higher and more frequent than they are today because of greatly increased snowfall. The downcutting has been relatively rapid in the slightly softer rocks below Great Falls and especially rapid where the rocks are broken along a fault *(F–F')*. At F the river encounters a series of closely spaced fractures or joints. This zone of weakness has caused the river to cut laterally *(J–J')*. Diversion of water into the deeply cut channels along the fault and fracture zone has caused the river to abandon several channels on the Maryland side, including the one now occupied by Widewater *(W–W')*. The channel around Glade Hill *(G–G')* still carries water, but it is rapidly being cut off. Deepening of the river valley has caused Difficult Run to correspondingly deepen the lower part of its valley *(D–D')*, destroying its old flood plain and building a new lower one.

C. Great Falls today. Continued erosion along the fracture zone *(J–J')* has diverted all the water from the channel around Glade Hill *(G–G')*. Channelways are now being cut upstream from the fracture zone, leaving Olmsted *(O)* and Falls *(Fl)* Islands above water level. Construction of the dam *(X–X')* to divert water into the Washington aqueduct has further modified the details of the landscape above the falls. Most of Conn Island *(C)*, for example, has been built since the construction of the dam. The abandoned channel north of Bear Island *(B)* has been flooded by building dams at W and W' so that it could be used as part of the C. and O. Canal. Difficult Run *(D–D')* continues to deepen its valley so that its old flood plain survives only above the first rapids *(D)*.



C

As sea level fell, the river cut correspondingly deeper into the floor of its former valley. The valley was rapidly deepened in the soft, easily eroded materials in the Coastal Plain, but in the hard rocks of the Piedmont Plateau the downcutting was much slower. It was this downcutting into the hard bedrock floor of the older wider valley that produced the spectacular rocky gorge of the Potomac between Little Falls and Great Falls. At Great Falls the river encounters a series of thick layers of metamorphosed sandstone that are particularly resistant to erosion, and these hard ledges have slowed the progress of valley cutting. The river valley above Great Falls thus remains essentially the unmodified, original pre-Pleistocene valley, but below the falls the river flows in a gorge excavated within the last 2 million years. Along the gorge the original valley floor can be recognized as a flat gravel-covered bench 50 to 60 feet above the present river level. MacArthur Boulevard follows this bench from Cabin John to Anglers Inn. Some of the details of the cutting of the gorge and the sculpturing of Great Falls are illustrated in the block diagrams.

The origin of the rocks

As the Potomac River strips away the soil and cuts into the underlying bedrock, it lays bare a fascinating record of events stretching back in time 500 million years or more. In order to reconstruct this story, we must look beyond the obvious cracks and fractures which control the form of the river gorge, and study the more subtle features of the rocks. A brief search around the Great Falls area reveals five distinct kinds of rock: mica schist, metagraywacke, amphibolite, granite, and lamprophyre (see table on page 17). The mica schists, metagraywackes, and amphibolites are rocks that have been deeply buried within the earth's crust and transformed (metamorphosed) by heat and pressure to their present state. Prior to metamorphism the schists were muds or shales, the metagraywackes were beds of muddy sandstone, and the amphibolites were originally sheets of lava or once-molten rock similar to basalt.

◀ Waterworn rocks keep silent vigil over the Potomac River

GEOLOGIC AGE		TIME IN MILLIONS OF YEARS	PRINCIPAL EVENTS
CENOZOIC ERA	QUATERNARY	0	Carving of the Potomac Valley
	TERTIARY		Deposition of sediments on Atlantic Coastal Plain
MESOZOIC ERA	CRETACEOUS	100	
	JURASSIC		
	TRIASSIC	200	Deposition of sedimentary rocks in Leesburg Basin and Frederick Valley
PALEOZOIC ERA	PERMIAN		Final uplift of Appalachian Mountains
	PENNSYLVANIAN	300	
	MISSISSIPPIAN		
	DEVONIAN		Intrusion of lamprophyre dikes
	SILURIAN	400	? Intrusion of granite ?
	ORDOVICIAN		Metamorphism and folding of older sedimentary rocks ?
	CAMBRIAN	500	?
PRECAMBRIAN		600	Deposition of sedimentary rocks, chiefly shale and sandstone ?
		1100	Formation of Baltimore Gneiss

GEOLOGIC TIME CHART

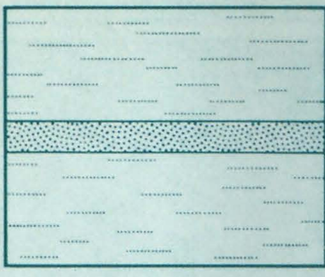
The rocks at Great Falls

Name	*Description*	*Color*	*Original rock*
Mica schist	Abundant coarse flakes of mica oriented along parallel planes. Thin veinlets of quartz cutting the schist stand out as a delicate network of ribs on weathered outcrops.	Silvery gray; weathers to reddish brown.	Shale or mudstone.
Metagraywacke	Fine-grained quartz and some mica. Rock has a sugary texture on weathered outcrops; occurs interstratified with mica schist in layers 3 inches to 3 feet in thickness.	Light bluish gray to buff.	Muddy sandstone.
Amphibolite	Black crystals of hornblende in white to pink feldspar; occurs in layers 2 to 100 feet in thickness.	Dark green to black.	Once-molten rock similar to basalt.
Granite	Quartz and feldspar with mica; occurs as crosscutting sheets and irregular masses.	White to pink.	Once-molten rock with high silica content.
Lamprophyre	Chiefly mica; occurs as crosscutting sheets.	Dark green.	Once-molten rock with low silica content.

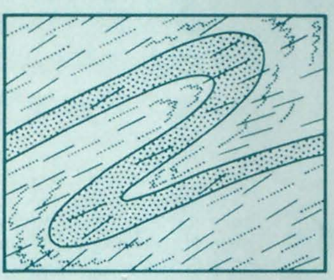
The shales and muddy sandstones were deposited on the bottom of an ancient ocean, probably in a deep trough near the coast of a rugged landmass. Farther east, near Chain Bridge, the metamorphosed shale and sandstone exposed in the sides of the valley at Great Falls grade into thick deposits of muddy sandstone containing jumbled pebbles and boulders of quartz, amphibolite, granite, and other rocks. These materials were deposited by huge submarine landslides that cascaded down the steep eastern side of the trough. The muddy sandstones at Great Falls were probably formed from thick slurries of mud and sand that moved downslope from the main slides and came to rest in the bottom of the trough. The shales at Great Falls were originally muddy sediments that were carried seaward by ocean currents and settled to the bottom during the quiet intervals between the slides. Soon after deposition of these sediments, molten lava was injected in thick sheets parallel to the layers of sandstone and shale and cooled to form the layers of basaltlike rock that later became amphibolite. The high landmass from which these sediments were eroded has long been obliterated, but it probably lay only a few miles to the east. It was made up largely of granitelike rocks similar to those exposed today near Baltimore which are about 1,100 million years old.

The exact time when the sediments were deposited is uncertain because no fossils have been found in them, but dating of a rare radioactive mineral (zircon) in the amphibolites shows that the amphibolites were intruded about 550 million years ago, and the sediments are probably about the same age.

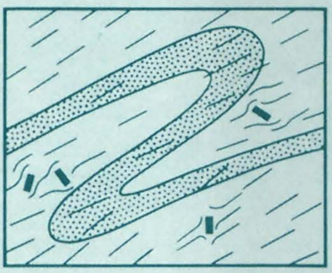
Since first formed, these rocks have undergone a full and varied history. As younger sediments accumulated above them, they became accordingly more deeply buried. They were later compressed, folded, metamorphosed, and finally intruded by granite. The different stages in this complex sequence of metamorphic events are outlined in the accompanying figure. The total thickness of sediment that accumulated can be inferred from laboratory experiments which show that a mineral (sillimanite) which grew in the schists when the granites were intruded requires a temperature of 1150°F and a pressure of 80,000 pounds per square inch to



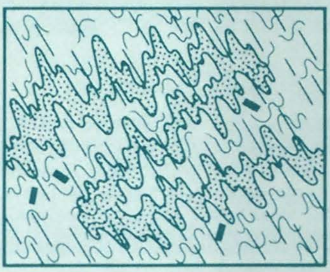
Sediments are deposited on the sea floor and eventually become layers of mudstone and muddy sandstone



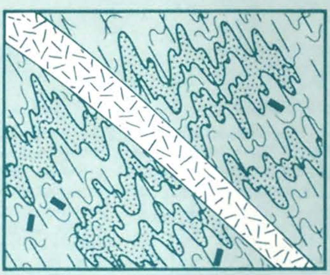
The layers of rock are folded and the mudstones recrystallize to form mica schists. The flakes of mica grow in parallel planes to form a new structure—schistosity—which cuts across the original layering



The growth of large crystals of kyanite and andalusite push the planes of schistosity aside

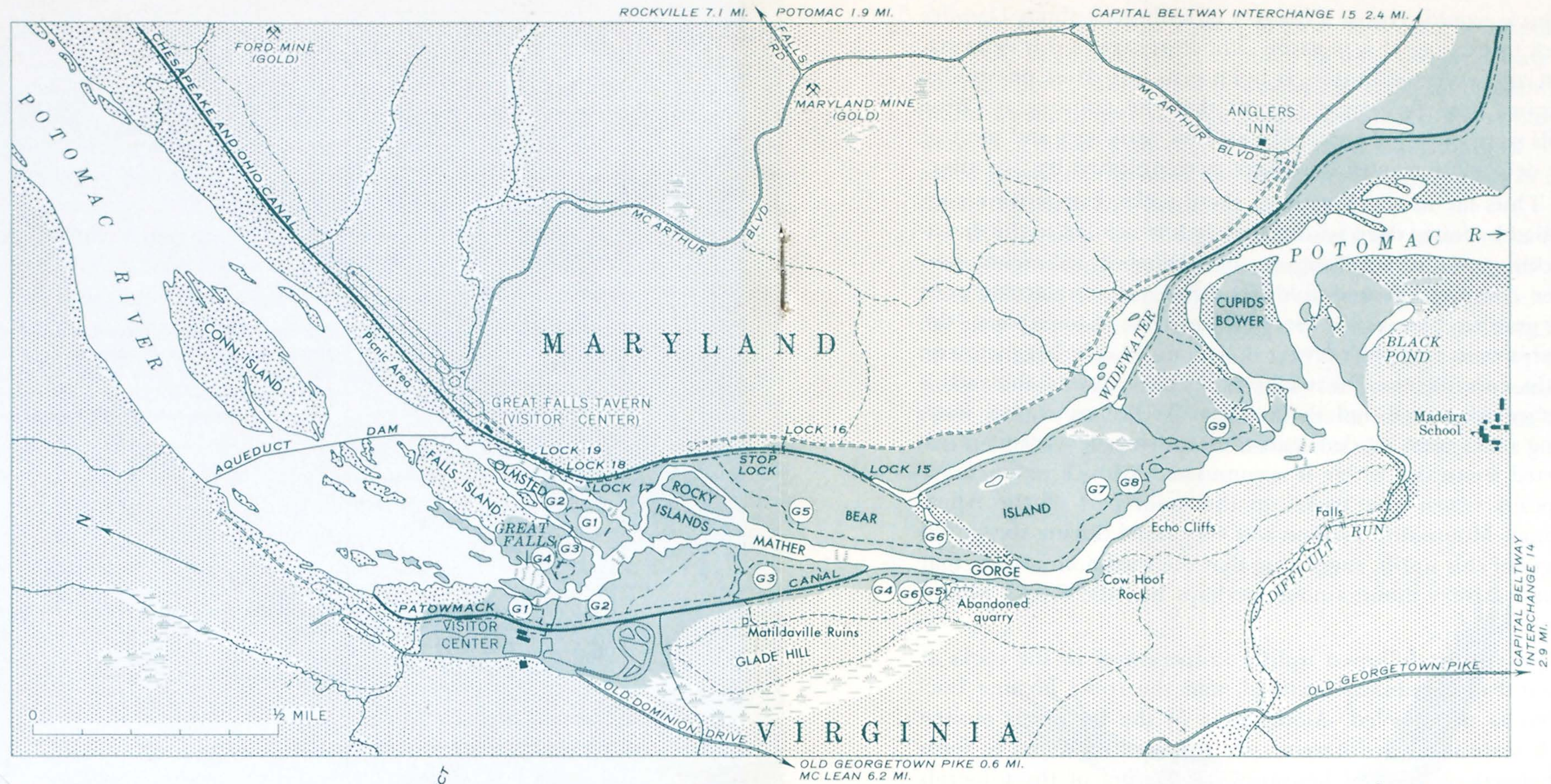


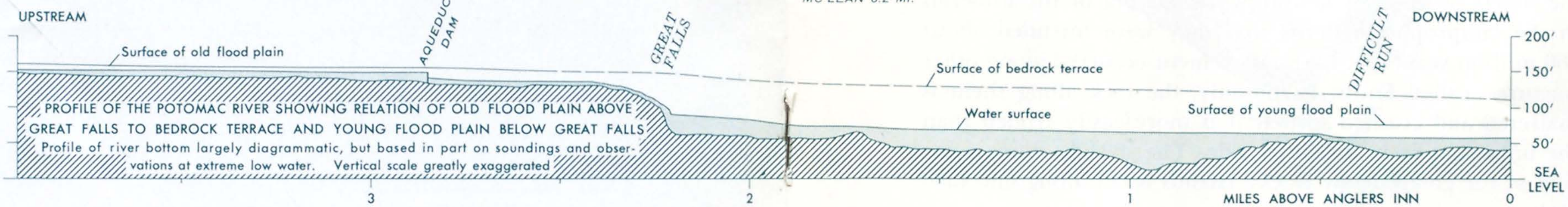
The layers are folded again, and new planes of schistosity are formed at angles to the first



Rocks are fractured and molten material wells up along the cracks to form granite intrusions. Kyanite and andalusite are altered to sillimanite

STRUCTURAL AND METAMORPHIC HISTORY
OF CRYSTALLINE ROCKS





MAP EXPLANATION

Old flood plains

Flood plains of the river and its tributaries above Great Falls and of the Difficult Run above its falls. These flood plains occupy valley bottoms that were not deepened during the cutting of the gorge. They are underlain by silt, sand, and gravel deposited by floods that still cover these areas every few years

Young flood plains

Flood plains of the river above Great Falls. These flood plains have formed since the cutting of the gorge and the development of Great Falls. They are underlain by materials similar to those of the old flood plains and are also covered by floods every few years

Bedrock terrace

Areas of bare rock and rock thinly veneered with sand and gravel. These areas are remnants of the old valley floor scoured bare during cutting of the gorge. The upper surface corresponds in altitude and age to the valley floor occupied by the old flood plain above Great Falls

Piedmont uplands

Well-drained uplands underlain by thick clayey soils and deeply decayed crystalline rocks similar to the fresh rocks exposed along the river and on the bedrock terrace. Exposures of fresh rock are very rare, except on steep hillsides at the edge of the river valley

Swamps

In the uplands swamps generally occur at the edge of flats bordering small streams; on the bedrock terrace they occupy depressions between bedrock ribs and knobs. The large swamp west of Glade Hill occupies an old channel of the river that was abandoned as the gorge was cut

G8 Self-guiding trail showing numbered stops

Other trails

TRAIL MAP OF THE GREAT FALLS AREA SHOWING LANDSCAPE SUBDIVISIONS

form; it would require a blanket of sediments about 11 miles thick to produce this pressure. The exact age of this deformation and recrystallization is unknown, but dates on similar granites near Baltimore suggest that the granites at Great Falls were intruded about 425 million years ago, and most of the deformation must have been accomplished by that time.

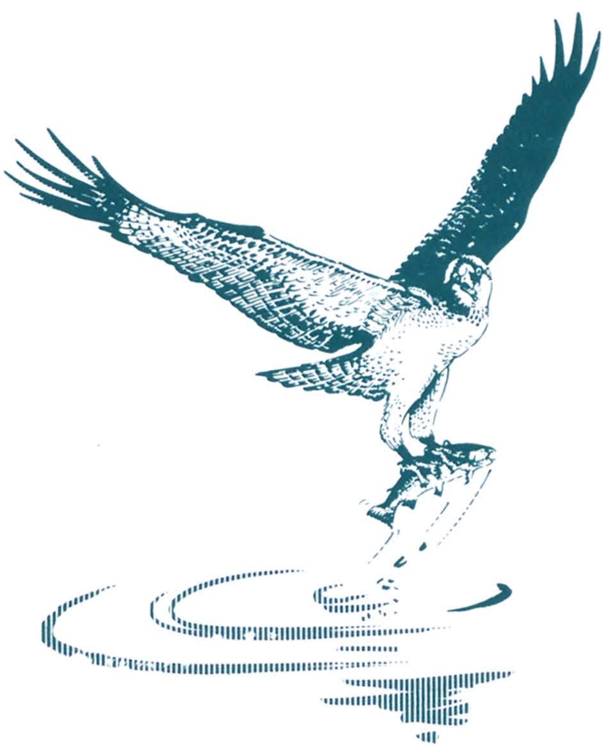
Thus far in the history of these rocks, events were controlled by forces deep within the earth which led to the downbuckling of the sea floor, accumulation of sediments, and later compression and folding. After the emplacement of the granite, however, a fundamental change took place; the earth's crust stopped moving down, and slowly began to rise again, carrying the Great Falls rocks back toward the earth's surface where we find them today. As the crust rose, overlying rocks were eroded, and the resulting debris was transported westward, where it accumulated as thick sedimentary deposits which now make up the main part of the Appalachian Mountains. Erosion was very rapid during the initial stages of this uplift, suggesting that the Piedmont area at that time was very mountainous, perhaps like the Rocky Mountains today.

As erosion followed uplift, temperatures in the rocks at Great Falls gradually declined, and the rocks became fractured as they cooled. Along some of the fractures, molten rock material of a different type rose and solidified to form the sheets or dikes of lamprophyre. Dating of the minerals in the lamprophyres shows that they were intruded about 360 million years ago. Later, movement occurred along other fractures, called faults. Commonly, the rock along them is shattered and crushed so that it is more easily eroded than the unbroken rocks on either side. The straight narrow section of the gorge below Rocky Islands is cut along one such fault.

Along other parallel faults, hot solutions from below deposited thick veins of white quartz. Some of these veins carry small amounts of native gold which was mined sporadically in the area from 1867 until as recently as 1941. Many of these faults and quartz veins have the same orientation as faults of Triassic age (about 200 million years old) a few miles to the west, and the faults at Great Falls may be of the same age.

The Triassic faults appear to have developed in response to a final stage of uplift, a regional arching and stretching of the Piedmont rocks, which produced a series of fault-bounded basins by subsidence of keystone-shaped blocks. These basins were then filled with the red shales and sandstones of Triassic age which crop out a few miles west of Great Falls in the Leesburg Basin and Frederick Valley.

At this stage in the geologic story, we have come full circle; the record of the rocks merges with the origin of the river and the development of its valley. But the chronicle of the river and the rocks is told best not by words and sketches on a printed page, but by the face of the land and by the rocks themselves. To read the story for yourself, you are invited to take one or more of the trails maintained by the National Park Service on either side of the river.



Trail log—Great Falls, Virginia

FLOOD-PLAIN TREES

sycamore

boxelder

This walking tour is designed to acquaint you with the important geological features that can be seen from the park trails. To help you find the stops that are indicated, small light-colored oval signs have been placed in strategic places to point your way. At each stop there will be similar signs that have the stop number on it. Length 2.14 miles.

Mileage

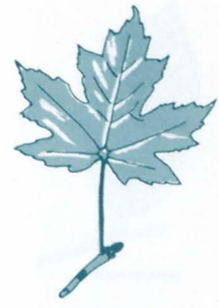
0.00 Leave south entrance of Visitor Center. Cross old Patowmack Canal and walk to nearest overlook at the brink of the falls.

0.12 (About 250 paces.) Stop G1. *A closeup of Great Falls.* The total drop of the river here from the uppermost rapids to the channel below this overlook is about 40 feet; the cascade directly in front of you is 16 feet high. The narrowest part of the channel below the falls here is 75 feet wide at normal stages of the river. The foam commonly seen below the falls is detergent suds – evidence of water pollution from towns and cities upstream.

The rock here is metagraywacke, a type of metamorphosed sandstone. The conspicuous layers in this outcrop are the original layers or beds in which the sand was deposited on the sea bottom but which were turned on edge as the rocks were folded. The sand grains in some of the layers are as large as B-B's, but most of the sand is much finer. The same layers are plainly visible in the rocky islands in the middle of the falls. Note how the river channels follow the rock layers.

Notice also the straight fractures or joints that cut across the rock layers. These joints formed as the rocks were uplifted and cooled. The most conspicuous joints are nearly vertical and perpendicular to the rock layers. These joints break the rock into blocks, making it easier for the river to quarry away the resistant layers. Each of the cascades in the falls marks a place where the river passes over a group of joints.

Return to path along old Patowmack Canal, turn left and walk south (downstream).



silver maple

0.27 (About 320 paces.) Marker here shows level of 1936, 1942, and 1937 floods. In 1936 the water in the middle of the river was more than 80 feet deep. Turn left here and walk about 50 feet to overlook.

0.28 (About 20 paces.) Stop G2. *Vista of the falls and view of the old riverbed.* The level surface on which you stand was part of the bed of the river before the gorge was cut and the falls were formed. From here you can trace the surface upstream and see that it becomes the present riverbed a few hundred yards above the falls.

Notice the nearly right-angle turn in the river at this point. Above this point the river is following the rock layers; here it turns to follow a zone of weakness caused by closely spaced joints like those visible at Stop G1.

green ash

Return to path along Patowmack Canal and continue south (downstream).

0.42 (About 300 paces.) Large outcrop of rock in the trail. This rock is mica schist containing lenses and pods of white quartz. Notice how the layers are crumpled and folded. This occurred during metamorphism that converted the rock from shale to schist.

This surface is part of the old riverbed. The exposed rock was rounded and smoothed by the river.

Continue along same path.

persimmon

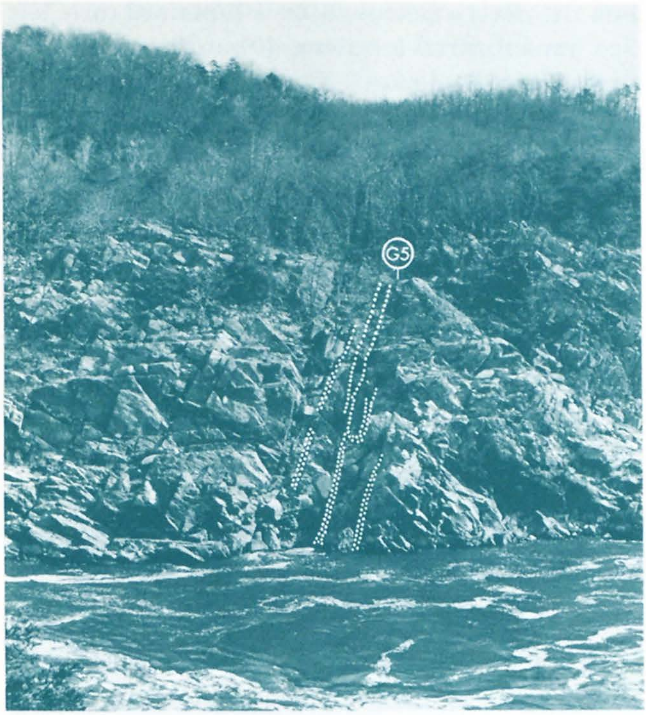
0.61 (About 400 paces.) Trail intersection at wooden bridge over old canal bed. Turn left off main trail. Walk about 125 yards and turn right on steep side trail leading down into small stream valley. Go about 10 yards upstream and cross creek. The narrow valley that you face in crossing the stream was man made, an early attempt to provide an outlet for the Patowmack Canal. The main valley was cut along a series of thin lamprophyre dikes, several of which are exposed in a small waterfall about 15 yards farther upstream. Scramble up steep trail on south side of valley. About 30 yards after crossing stream, turn right and follow trail south (downstream).

0.75 (About 300 paces.) Stop G3. *The Mather Gorge.* The cliff below is about 65 feet high. The river here is about 220 feet wide and is 25 feet deep at normal stages of the river.

Sight along the flat rock face toward the Maryland shore. You can see a series of deep vertical clefts in the cliff face which are dikes of lamprophyre. They look as though they should project across the river to about this point, but the extension of them on this side of the river is about 80 feet upstream. This offset is caused by a fault that lies beneath the river. The straight steep-sided gorge here has been cut by the river in the crushed and broken rock along the fault. The fault zone is more easily eroded than the solid rocks on either side.

American hornbeam

The rock here is mica schist. About 25 feet to the north (upstream) is a vein of



Lamprophyre dikes (indicated by white dots) on the Maryland side of the river as seen from Stop G3 on the Virginia side. Location of Stop G5 on the Maryland side is also shown.

quartz more than a foot thick. Gold was mined from similar veins at several nearby places on the Maryland side of the river.

river birch

0.88 (About 275 paces.) Follow narrow but distinct trail downstream along brink of gorge past river-smoothed outcrops of mica schist.

At the junction of two trails, continue on 40 yards where a twin-trunked tree is living testimony of the flood of 1889 (the year of the Johnstown flood). The single inclined trunk grew vertically but was felled. The vertical trunks started to grow when the parent tree was felled. Their age tells us that the tree was felled in 1889 by a flood as large as that in 1936.

Retrace steps to trail junction, turn left on crosstrail for about 40 yards to main trail along Patowmack Canal. Turn left (downstream).

post oak

0.92 Ruins of lift lock on the Patowmack Canal. The lock is built chiefly of reddish-brown sandstone of Triassic age that was quarried near Seneca, 8 miles upstream from Great Falls, and carried downriver by boat. The same "Seneca Stone" was used in many of the older buildings in downtown Washington.

At trail fork at lower end of lock follow right (upper) branch of trail.

River-worn pebbles wedged in a rock cranny more than 50 feet above the normal water level.

Beyond the trail entering on the left and to the next stop, you pass through a red oak and post oak forest, typical of the ancient riverbed which is now a bedrock terrace some 60 feet above the river. Also growing here are Virginia pine, cedar, pignut hickory, white oak, and chestnut oak. This type of forest is present on the flat surface above the cliffs across the river.

red oak

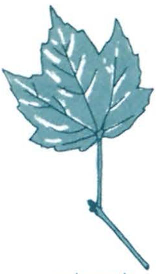
1.08 (About 350 paces.) Stop G4. *Potholes.* Here are several unusually good examples of potholes — circular holes ground in the rock by pebbles and boulders churned by the river when it was at this level. (See page 34, Stop G2, Maryland trail log, for a discussion of the formation of these holes.) Some of the pebbles left by the river can still be seen in the potholes and wedged in crannies in the rock outcrops. The small pond to the west, between here and the steep hill, was once a side channel of the river.

Leave trail and walk over to edge of the gorge. Large potholes can be seen at the present river level and many smaller ones at the top of the cliffs on the Maryland side.

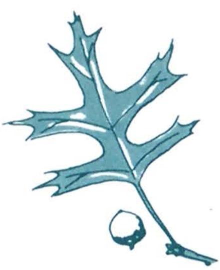
pignut hickory

Looking upstream you can see evidence of the effect of flooding on plant life. Near the tops of the cliffs the rocks are rough and sharp and are covered by several species of gray lichens. Some are leaflike, others are tight crusts cemented to the rock. The large ones that look like warty, gray potato chips are *Umbilicaria.* The light-gray, spreading ones are *Parmelia conspersa.* The gray crust that requires close examination to see is *Lecanora cinera.* The lichens are alive. If watered they turn soft and green in 5 to 10 minutes. Floods reach these levels only rarely, perhaps once every 10 to 20 years.

SWAMP TREES



red maple



pin oak

About 20 to 30 feet below the cliff edge is an irregular band marked by dark-olive-green patches of moss *(Grimmia laevigata)*. This species is common on many kinds of rocks in the Great Smoky Mountains and southern Blue Ridge; here it is growing at its northernmost limit. This zone is flooded about once every 2 years. Below the moss and extending down to 10 or 20 feet above normal water level, the rocks have a yellowish cast which is due to yellow and orange lichens *(Candelariella vitellina)*. This zone is flooded several times each year.

Near the base of the cliffs, just above normal water level, the rocks are covered with a metallic purplish-black coating that consists of iron and manganese oxides.

Return to trail and continue south (downstream).

1.15 (About 150 paces.) Stop G5. *A geological puzzle*. Along the trail are many rounded pebbles, cobbles, and boulders left behind by the river when it flowed at this level. This boulder, 5 feet in diameter and estimated to weigh over 6 tons, is the granddaddy of them all! It is composed of a dark, heavy igneous rock called diabase, and the nearest outcrop of such rock is near Blockhouse Point, more than 7 miles upstream. This boulder is far too large to have been moved by even the most violent flood. Could it have floated in an ice jam or in a tangle of logs?

Continue downstream about 20 yards, turn right on faint trail leading up steep hill. Scramble to top of hill and follow trail to the right, skirting brink of abandoned stone quarry on the left. Follow this trail for about 100 yards, then turn right again on main horse trail.

Virginia pines are growing on disturbed ground along the edge of the quarry. Beyond and along the trail the forest consists primarily of oak species — white, black, scarlet, southern red, and chestnut oaks. Note that post oak is not present, and red oak and pignut hickories are rare. This forest is typical of a well-drained upland.

sourgum

1.30 (About 320 paces.) Stop G6. *An ancient gravel deposit.* The ground here is littered with gravel and large rounded boulders, part of a river deposit even more ancient than those along the trail below. This deposit lies almost 120 feet above the present level of the river and must have been deposited during a very early stage of the cutting of the valley, perhaps 2 to 3 million years ago.

Notice the deep gullies that run parallel to the trail. The trail here follows part of the old road to Matildaville. Like many heavily traveled dirt roads in the Piedmont, this one was subject to severe erosion. Water ran down the ruts left by wagon wheels, eroding gullies in the deep clay soil. When the ruts became too deep, it was easier to move the road to one side than repair the gullies. In some places this happened several times, leaving a series of parallel gullies.

swamp
white oak

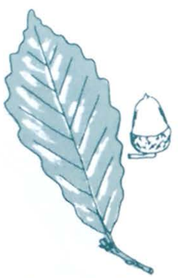
Follow trail north (upstream).

1.41 (About 230 paces.) Deep gullies crossing road were probably caused by drainage from old field, now completely overgrown.

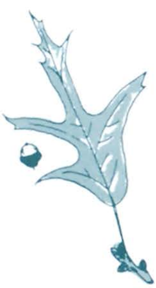
willow oak

The old field to the west is marked not only by a wire fence embedded in tree trunks, but also by the presence of Virginia pine. The pines are dying and falling, thus permitting the hardwood trees — oaks — to grow more rapidly. In and along the gullies, yellow poplar, a valuable timber tree, is pre-

yellow poplar



chestnut oak



southern red oak

dominant. This species is common in places where soil was severely eroded in the past.

The forest from near the base of the hill to the Patowmack Canal is typical of areas that had heavy land use. Black locust with short stout spines, elm, and boxelder are common. The tree bristling with many-branched thorns is honey locust found only here. Many cultivated plants such as daffodils, day lilies, privet, and others indicate human activity.

1.64 (About 500 paces.) Chimney and ruins of buildings at Matildaville. Turn right and follow trail back to path along old Patowmack Canal. Turn left and return to Visitor Center.

2.14 (About 1,060 paces.) Visitor Center.

Trail log—Great Falls, Maryland

This walking tour is designed to acquaint you with the important geological features that can be seen from the park trails. To help you find the stops that are indicated, small light-colored oval signs have been placed in strategic places to point your way. At each stop there will be similar signs that have the stop number on it. Length 1 mile. Optional Bear Island trail 3.5 miles.

Mileage

0.00 Leave Great Falls Tavern Visitor Center, cross C. and O. Canal. Turn left (downstream) on towpath. The low dam across the river diverts about 2,500 gallons of water per second into an underground aqueduct which empties into Dalecarlia Reservoir 9 miles away. The water is then used by the District of Columbia and nearby suburbs.

The reddish rock used in the canal locks is sandstone of Triassic age that was quarried near Seneca, 9 miles above Great Falls. This "Seneca Stone" was used in the construction of many of the older buildings in Washington.

0.27 (About 570 paces.) Trail junction 80 yards beyond lower end of Lock 18. Turn right on the Great Falls Trail.

white oak

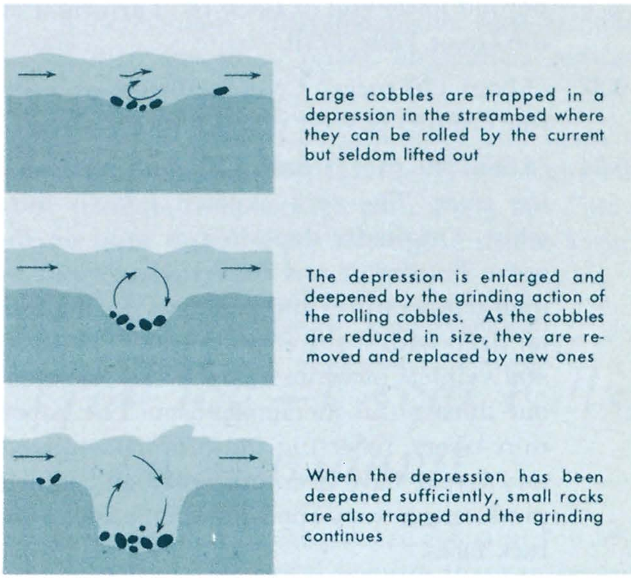
0.32 (About 110 paces.) Cross footbridge over narrow channel of river onto Olmsted Island.

0.34 (About 40 paces.) Stop G1. *The rocks and the river.* The rock exposed here is mica schist. Originally deposited as mud on the ocean bottom, it was converted to schist by high temperatures and pressures during burial deep within the earth's crust. The knots and veinlets of white quartz were "sweated" out during this metamorphism. The paper-thin layers, reflecting the original sedimentary layers, have been crumpled and folded, producing a wavy appearance on some of the rock faces.

Many small trees in this vicinity have been overturned by floods. Notice how the vertical stems (really branches) have sprouted from the prostrate trunks. To determine the time of the floods, a tree was cored at the base of the stem and the rings counted. Most of these trees were damaged during the 1936 flood.

scarlet oak

0.37 (About 60 paces.) Stop G2. *Part of the former riverbed.* The large circular holes in the rock are potholes. They were ground in the rocks by pebbles and cobbles churned in rapids when this area was part of the river bottom. All of the rocks exposed in this area were smoothed and polished by the river at that time. Although an occasional flood still reaches this level, the potholes and water-smoothed rocks date from a much earlier stage, prior to the cutting of the gorge and formation of the falls. From here to the overlook at the falls you will be walking over part of this ancient riverbed.



Stages in the cutting of a pothole.


black oak

0.54 (About 360 paces.) Stop G3. *A relict of the river.* This boulder, about 2 feet in diameter, is composed of coarse-grained white quartzite of a type that is found at Harpers Ferry and at Point of Rocks. It must have been carried downstream at least 25 miles when the river flowed at this level. Many other pebbles and boulders scattered throughout this area were transported from sources many miles upstream.

0.57 (About 60 paces.) Stop G4. *A closeup view of Great Falls.* The total drop here at normal stages of the river is about 40 feet. The highest cascades are about 16 feet. The distance from here to the overlooks on the Virginia shore is about 500 feet. In the narrowest part of the channel below the falls the river is about 75 feet wide at normal stages, but at higher stages it floods to the base of the cliff below you. About once every 2 years floods cover this overlook to depths of 1 to 2 feet.

Some of the scattered shrubs growing among the rocks below are sycamore and river birch that normally grow to be large trees. Here they are kept small and shrubby by frequent flood damage. The detergent suds commonly seen in the river just below the falls are evidence of pollution from towns and cities upstream.

Notice the broad flat surface at the top of the cliffs on the Virginia side. This is part of the same ancient riverbed across which you have been walking. This ancient riverbed, which lies 40 to 50 feet higher than the river below the falls, can be traced upstream to the present level of the river above the falls. The river occupied this bed before the gorge was cut and the falls were formed (see pages 12–13).

The forest on the old riverbed downriver from the falls is different from that on the same surface upriver from the falls. This trail passed through a red oak and post oak forest with pine, juniper, pignut hickory, and a few other species. Upriver, this surface supports a sycamore and ash forest with river birch, silver maple, boxelder, and cottonwood. Red and post oaks are not present.

SHRUBS AND SMALL TREES

pawpaw

spice bush

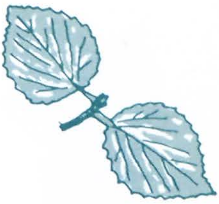
Folded metagraywacke layer in mica schist near stop G4. The folds shown in the photograph and the schistosity that cuts across the folded sedimentary layering (bedding) were formed during the second period of folding. An older schistosity formed during an earlier episode of folding lies parallel to the bedding.

Although it is not obvious from the photograph, the sand grains in the metagraywacke are larger and more conspicuous near the bottom of the layer. The bottom of the layer is quite distinct, but the top is indefinite — the metagraywacke passes gradually into the overlying schist without a clean break.

These features suggest that the metagraywacke bed was deposited by an underwater avalanche of sand and mud that cascaded down a steep submarine slope and moved as a slurry across the sea bottom. When the soupy mixture came to rest, the larger sand grains settled out first, forming the coarse bottom part of the layer, while the finer sand settled much more slowly and was mixed with more and more mud, giving rise to the gradational upper contact of the layer. Many of the metagraywacke layers in the Great Falls area display these same features and were presumably deposited in the same way.

maple-leaf viburnum

The rocks here are chiefly metagraywacke (a type of metamorphosed sandstone). On the outcrop directly east of you is an 8-inch-thick layer of metagraywacke interlayered with mica schist. Some of the larger original sand grains are visible in the lower part of the layer. When these layers were deposited, they lay nearly horizontal on the sea bottom, but they were crumpled into folds at the time the rocks were deeply buried and metamorphosed. The many knots and layers of white quartz were sweated out of the rocks during metamorphism and outline some of these folds. Notice the schistosity cutting across the layers.



southern arrowroot

The straight fractures or joints displayed in the rocky islands in the river were formed when the rocks were uplifted. The most conspicuous joints are nearly vertical and perpendicular to the folded rock layers. Notice how these structures control the details of the falls. The several river channels tend to closely parallel the rock layers, and the cascades or steps occur where the channels cross a closely spaced group of joints.

Continue along trail for about 30 yards to lower overlook. Note conspicuous folds in rock layers to the right 15 feet beyond the lower overlook guardrail.

American holly (evergreen)

0.66 (About 190 paces.) Trail intersection. Turn right and return along trail to towpath.

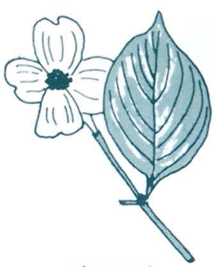
0.91 (About 530 paces.) C. and O. Canal towpath. From this point you may turn left and return the 0.27 mile to the starting point. The remainder of the hike is over rough secondary trails suitable for experienced hikers only. If you elect to continue, turn right along the towpath to the Bear Island ("Billy Goat") Trail.

Trail log—Bear Island (optional)

chinquapin

0.19 (About 400 paces.) The towpath passes high above an intermittent river channel encircling Rocky Islands. Nearly dry in the low-water stages of summer and fall, this channel is often filled to a depth of 40 feet by winter and spring floods. Notice the small shrubs growing in rocks at the bottom of the channel. These are sycamore, river birch, and ash that normally grow to be large trees, but here they are kept small by the frequent battering of flood torrents.

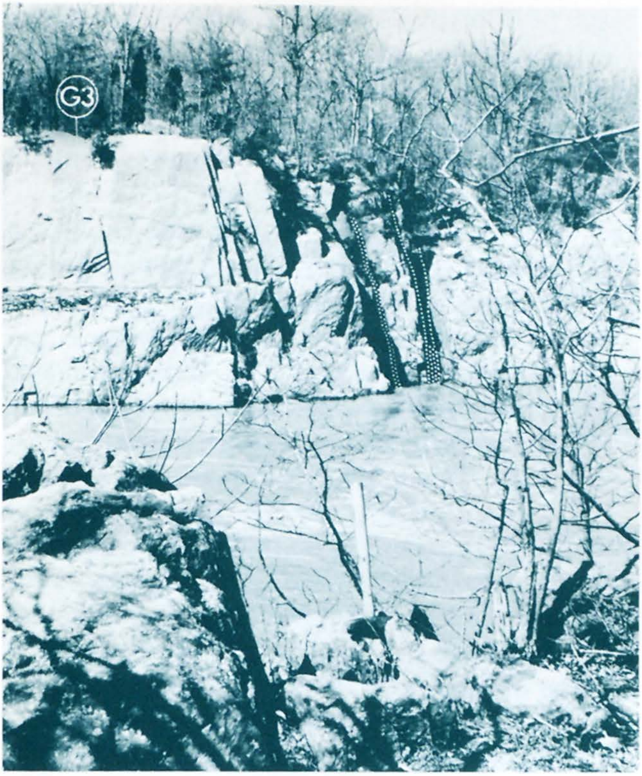
0.28 (About 190 paces.) Trail junction; follow marked trail to right along west side of Bear Island. Towpath straight ahead follows C. and O. Canal 1.6 miles to Widewater and MacArthur Blvd. Along the trail and to your right are many bent trees that were felled by the March 1936 flood which was 10–15 feet deep along the trail.



dogwood

The prominent levee constructed of rock debris to the left of the trail was designed to divert floodwaters from the canal bed and return them to the main channel of the Potomac.

0.49 (About 440 paces.) Stop G5. Trail crosses a narrow valley cut along easily eroded dikes of lamprophyre. Turn right and follow valley for 70 feet to the overlook at outcrop of dark-green lamprophyre. Across the river, diagonally upstream, notice a series of vertical clefts in the steep rock wall of the gorge.



Lamprophyre dikes (indicated by white dots) on the Virginia side of the river as seen from Stop G5 on the Maryland side. Location of Stop G3 on the Virginia side is also shown. Hammer (in foreground) rests on an outcrop of dike.

fringetree

mountain-laurel (evergreen)

These clefts are the continuation of the lamprophyre dikes on which you are standing. Notice that they are not directly on the trend of the narrow valley projected across the river, but are about 80 feet upstream from where you would expect to find them. The rocks on the two sides of the river have slid past each other along a major fracture, called a fault, which lies beneath the river at this point. The straight steep-sided gorge that stretches downstream is cut in the crushed and broken rocks along the fault. This fault zone is more easily eroded than the solid rocks on either side.

The trail between Stops G5 and G6 passes in and out of a red oak and post oak forest typical of this bedrock terrace. Other trees are white and chestnut oaks, pignut hickory, Virginia pine, and redcedar which is used to make cedar chests.

blackjack oak

0.81 (About 680 paces.) Stop G6. For about 150 yards, the trail weaves among ribs and knobs of quartzose mica schist along the top of the present river gorge. Many large potholes can be seen along the trail. The prominent bench at this elevation — best seen on the other side of the gorge — is a bedrock terrace which marks the ancient riverbed before the gorge was eroded (see p. 12). The potholes were cut by the grinding action of rocks trapped by current eddies. (See page 34, Stop G2, Maryland trail log.) One contains a large boulder of rusty-brown diabase; the nearest outcrop of diabase along the river is near Blockhouse Point, more than 7 miles upstream, and this boulder must have been carried at least that far by the river.

red cedar

This stop also provides an excellent view of this part of Mather Gorge which is a remarkably straight steep-sided gorge cut in the crushed rocks along the fault. On the walls of the gorge, horizontal color bands produced by different species of lichens and by chemical staining reflect different levels of flooding. (See page 29, Stop G4, Virginia trail log.)

0.96 (About 320 paces.) Trail crosses a small valley eroded along a fracture zone. Rocks in brook bed are heavily stained with iron, probably from sulfides deposited long ago by solutions percolating along the fracture zone, then dissolved by the brook as it cuts its way down into the crushed rocks, and then reprecipitated. The white-barked trees are sycamore growing with ash, elm, and box-elder on fine soil deposited on flood plains by high water. A little-used trail turns left along east side of brook, and leads 0.25 mile to C. and O. Canal and another 0.96 mile back to Great Falls Tavern Visitor Center.

Continue across valley and up cleft in rock slabs.

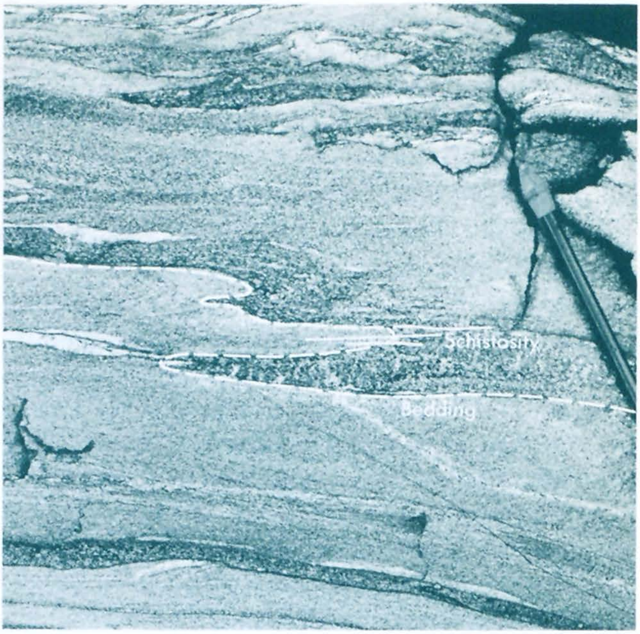
1.21 (About 530 paces.) Stop G7. Straight ahead, a prominent plug of light-colored granite and several smaller granite dikes intrude a thick sheet of dark-green amphibolite which is rusty brown on weathered surfaces. The amphibolite was formed by the metamorphism of basaltlike rock. The dark stubby crystals visible on weathered surfaces of the amphibolite are clusters of hornblende replacing crystals of pyroxene in the original rock.

black walnut

Just upstream from the amphibolite, numerous beds of metagraywacke 1 to 8 inches thick and a 5-foot sheet of amphibolite are interlayered with mica schist. These rocks display many of the details of the folding and metamorphism outlined earlier. Most rocks display a prominent schistosity parallel to the layering; a few contain the early folds which produced the schistosity. Hornblende clusters in the amphibolite are strung out parallel to the schistosity, showing that the amphibolite must have been intruded and metamorphosed before the folding.

elm

The rocks are cut by many thin veinlets of quartz, most of which are intricately folded (as shown in photograph), and must have formed prior to the folds and the schistosity. But the small veins and irregular pods of light-colored coarse-grained granite cut across the schistosity, showing that the granite must have been intruded after the folding. Several of the mica schist layers contain



Early folds in metagraywacke at Stop G7. Schistosity cuts across bedding in the noses of the folds, but everywhere else the two are parallel.

honeylocust

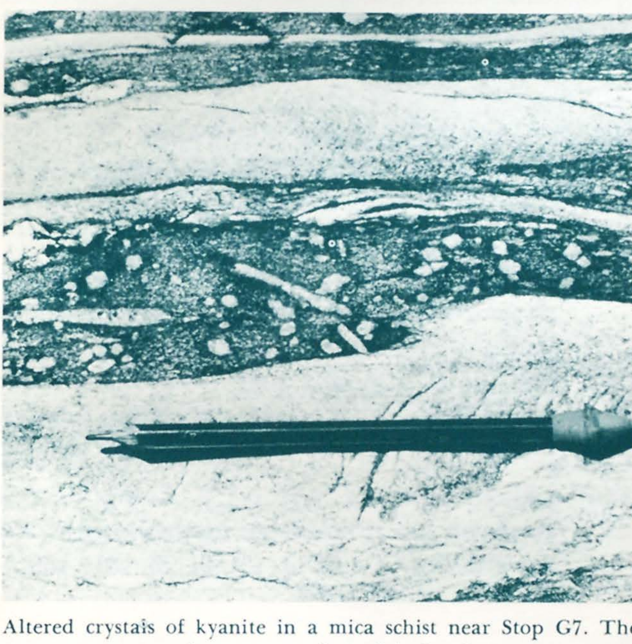
elongated 2-inch crystals of light-colored kyanite; they too must have formed after the folding, because they clearly pushed the schistosity aside as they grew.

Return to the trail, and continue southeastward (downstream).

1.34 (About 275 paces.) Stop G8. This outcrop shows a good example of one of the late folds (see page 19), in which the early schistosity, parallel to the metagraywacke layers, is bent, and a second, weaker schistosity has formed at an angle to the first.

From here the trail descends into a small valley which follows the sinuous form of a folded amphibolite sheet, more easily eroded than the schists and metagraywackes on either side (see p. 45). This fold is a larger scale example of the late folds, like the small one on page 44.

Intricately folded veinlet of quartz cutting across layers in mica schist near Stop G7.



Altered crystals of kyanite in a mica schist near Stop G7. The crystals are as much as 2 inches long.

black locust

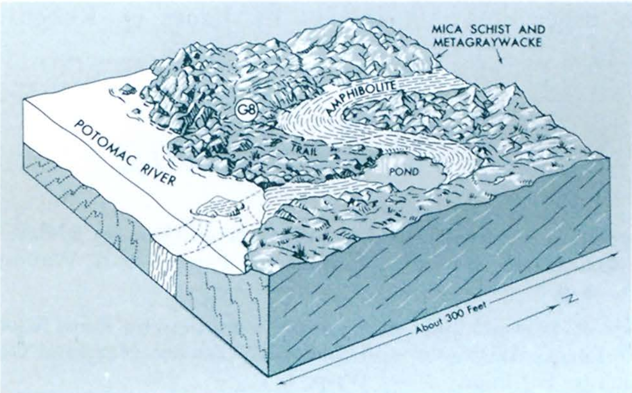
Late fold in interlayered mica schist and metagraywacke at Stop G8. An old schistosity lies parallel to the bedding; the new schistosity, formed during development of this fold, cuts across the bedding in the hinge of the fold. Details of fold partly obscured by lichen growth (light gray in photograph)

poison-sumac

Across the pond from the trail, sycamore, boxelder, ash, and silver maple trees are growing on fine soil deposited by the Potomac River during high water.

1.49 (About 320 paces.) The trail crosses a small stream on a plank bridge. Side trails on both banks of the stream turn left to Widewater and the C. and O. Canal. Continue straight ahead over low rock ledge, following marked trail.

1.67 (About 380 paces.) Stop G9. After the trail drops off a bedrock ridge it turns northward toward the C. and O. Canal. Shortly there-after it dips into a valley containing an elongated pond to your left. This part of the trail is impassable during floods because water flows from the river northward. Note the flood debris that litters the valley bottom, and that is caught on the south sides of shrubs and tree trunks. Many trunks lean to the north, showing that high water flows from the river to your right and sweeps around the hill in front of you.



Block diagram showing folded amphibolite at Stop G8.

sugar maple

After the trail passes over the hill it again dips into a narrow valley which is the extension of the valley at Stop G9. Note here that flood debris on shrubs and trees and leaning trunks show that high water flowed from your left to the river on your right.

1.92 (About 530 paces.) Trail emerges on the C. and O. Canal at Widewater. Follow towpath to the left 1.55 miles to return to Great Falls Tavern Visitor Center. To the right, the towpath leads 0.51 mile to parking lot at MacArthur Boulevard.

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Drawings by J. R. Stacy of the Geological Survey; photographs on pages ii, 4, 10, and 14 by James Q. Reber of Bethesda, Md.

Suggested reading

Botanical evidence of floods and flood-plain deposition, by Robert S. Sigafoos: U.S. Geological Survey Professional Paper 485–A, Washington, 1964, 35 p.

The geology of Howard and Montgomery Counties, by Ernst Cloos, C. A. Hopson, G. W. Fisher, and Emery T. Cleaves: Maryland Geological Survey, Baltimore, 1964, 373 p.

Crystalline rocks of the Potomac River Gorge near Washington, D. C., by John C. Reed, Jr. and Janice Jolly: U.S. Geological Survey Professional Paper 414–H, Washington, 1963.

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