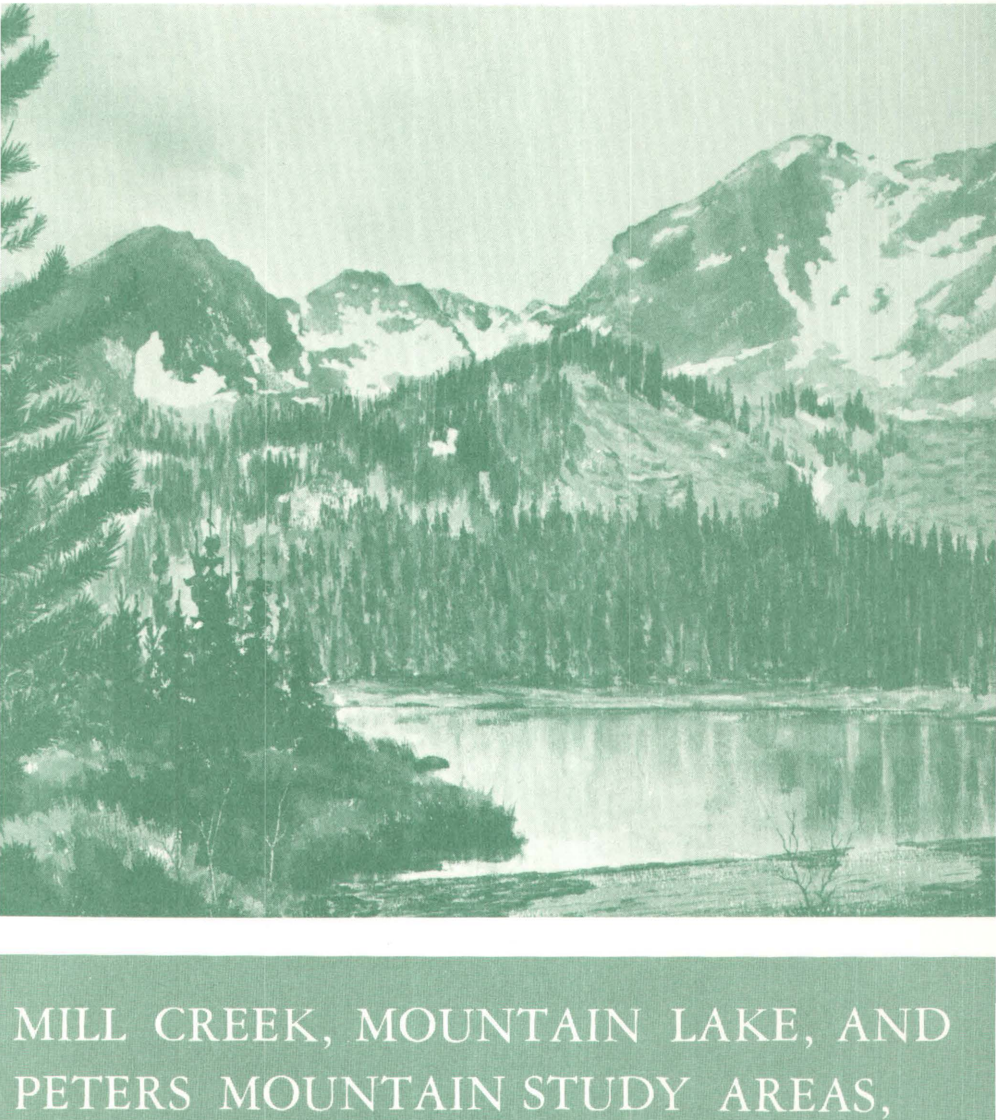
STUDIES RELATED TO WILDERNESS STUDY AREAS



MILL CREEK, MOUNTAIN LAKE, AND PETERS MOUNTAIN STUDY AREAS, VIRGINIA AND WEST VIRGINIA

GEOLOGICAL SURVEY BULLETIN 1510

Mineral Resources of the Mill Creek, Mountain Lake, and Peters Mountain Wilderness Study Areas, Craig and Giles Counties, Virginia, and Monroe County, West Virginia

By FRANK G. LESURE, U.S. GEOLOGICAL SURVEY,
and BRADFORD B. WILLIAMS *and* MAYNARD L. DUNN, JR.,
U.S. BUREAU OF MINES

With a section on OIL AND GAS POTENTIAL

By W. J. PERRY, JR., U.S. GEOLOGICAL SURVEY

STUDIES RELATED TO WILDERNESS—STUDY AREAS

GEOLOGICAL SURVEY BULLETIN 1510

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STUDIES RELATED TO WILDERNESS

STUDY AREAS

In accordance with the provisions of the Wilderness Act (Public Law 88-577, September 3, 1964) and the Joint Conference Report on Senate Bill 4, 88th Congress, and as specifically designated by PL 93-622, January 3, 1975, the U.S. Geological Survey and U.S. Bureau of Mines have been conducting mineral surveys of wilderness, wilderness study, and primitive areas. Studies and reports of all primitive areas have been completed. Areas officially designated as "wilderness," "wild," or "canoe" when the Act was passed were incorporated into the National Wilderness Preservation System, and some of them are presently being studied. For wilderness study areas, the mineral surveys constitute one aspect of the suitability studies. This report discusses the results of a mineral survey of some national forest lands in the Mill Creek, Mountain Lake, and Peters Mountain study areas, Virginia and West Virginia, that are being considered for wilderness designation (PL 93-622, January 3, 1975). The areas studied are in the Jefferson National Forest in Giles and Craig Counties, Va., and Monroe County, W. Va.

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ILLUSTRATIONS

[Plates are in pocket]

TABLES

CONVERSION FACTORS

Metric unit		Inch-Pound equivalent
Length		
millimeter (mm)	= 0.03937	inch (in)
meter (m)	= 3.28	feet (ft)
kilometer (km)	= .62	mile (mi)
Area		
square meter (m^2)	= 10.76	square feet (ft^2)
square kilometer (km^2)	= .386	square mile (mi^2)
hectare (ha)	= 2.47	acres
Volume		
cubic centimeter (cm^3)	= 0.061	cubic inch (in^3)
liter (L)	= 61.03	cubic inches
cubic meter (m^3)	= 35.31	cubic feet (ft^3)
cubic meter	= .00081	acre-foot (acre-ft)
cubic hectometer (hm^3)	= 810.7	acre-feet
liter	= 2.113	pints (pt)
liter	= 1.06	quarts (qt)
liter	= .26	gallon (gal)
cubic meter	= .00026	million gallons (Mgal or 10^6 gal)
cubic meter	= 6.290	barrels (bbl) (1 bbl=42 gal)
Weight		
gram (g)	= 0.035	ounce, avoirdupois (oz avdp)
gram	= .0022	pound, avoirdupois (lb avdp)
metric tons (t)	= 1.102	tons, short (2,000 lb)
metric tons	= 0.9842	ton, long (2,240 lb)
Specific combinations		
kilogram per square centimeter (kg/cm^2)	= 0.96	atmosphere (atm)
kilogram per square centimeter	= .98	bar (0.9869 atm)
cubic meter per second (m^3/s)	= 35.3	cubic feet per second (ft^3/s)

Metric unit		Inch-Pound equivalent
Specific combinations—Continued		
liter per second (L/s)	= .0353	cubic foot per second
cubic meter per second per square kilometer [$(m^3/s)/km^2$]	= 91.47	cubic feet per second per square mile [$(ft^3/s)/mi^2$]
meter per day (m/d)	= 3.28	feet per day (hydraulic conductivity) (ft/d)
meter per kilometer (m/km)	= 5.28	feet per mile (ft/mi)
kilometer per hour (km/h)	= .9113	foot per second (ft/s)
meter per second (m/s)	= 3.28	feet per second
meter squared per day (m^2/d)	= 10.764	feet squared per day (ft^2/d) (transmissivity)
cubic meter per second (m^3/s)	= 22.826	million gallons per day (Mgal/d)
cubic meter per minute (m^3/min)	= 264.2	gallons per minute (gal/min)
liter per second (L/s)	= 15.85	gallons per minute
liter per second per meter [(L/s)/m]	= 4.83	gallons per minute per foot [(gal/min)/ft]
kilometer per hour (km/h)	= .62	mile per hour (mi/h)
meter per second (m/s)	= 2.237	miles per hour
gram per cubic centimeter (g/cm^3)	= 62.43	pounds per cubic foot (lb/ft^3)
gram per square centimeter (g/cm^2)	= 2.048	pounds per square foot (lb/ft^2)
gram per square centimeter	= .0142	pound per square inch (lb/in^2)
Temperature		
degree Celsius (°C)	= 1.8	degrees Fahrenheit (°F)
degrees Celsius (temperature)	= [(1.8 × °C) + 32]	degrees Fahrenheit

MINERAL RESOURCES OF THE MILL CREEK, MOUNTAIN LAKE, AND PETERS MOUNTAIN WILDERNESS STUDY AREAS, CRAIG AND GILES COUNTIES, VIRGINIA, AND MONROE COUNTY, WEST VIRGINIA

By FRANK G. LESURE, U.S. Geological Survey, and
BRADFORD B. WILLIAMS and MAYNARD L. DUNN, JR.,
U.S. Bureau of Mines

SUMMARY

The Mill Creek, Mountain Lake, and Peters Mountain Wilderness Study Areas comprise about 8,200 ha[1] (hectares) of steep, wooded slopes in the Jefferson National Forest in west central Virginia and adjacent West Virginia (fig. 1). Mill Creek area contains 1,800 ha, and Peters Mountain area, about 1,600 ha in Giles County, Va. Mountain Lake area contains about 3,000 ha in Giles County, slightly more than 570 ha in Craig County, Va., and nearly 1,230 ha in Monroe County, W Va. A small part of each study area is privately owned – about 5 percent of Mill Creek, 20 percent of Mountain Lake, and 2 percent of Peters Mountain. The U.S. Forest Service owns the mineral rights on all the Government land except for about 162 ha in the Peters Mountain area. The three study areas are in the western part of the Valley and Ridge physiographic province and are therefore part of the folded Appalachians, which contain deformed sedimentary rocks of Paleozoic age. The same clastic marine and nonmarine sedimentary rock formations ranging in age from Late Ordovician to Middle Devonian are exposed throughout the region. Sandstones of the Juniata, Tuscarora, and Keefer Formations form cliffs, ridges, and steep dip slopes. The

[1] All measurements are given in SI units. See the table of SI units and inch-pound system equivalents.

distinctive hematitic sandstone beds of the Rose Hill Formation cover many dip slopes with red sandstone blocks. Other formations are less well exposed and form lower slopes and valleys.

The region is broken into structural blocks by several major thrust faults. Mill Creek area is a simple syncline between the Narrows Fault on the northwest and the Saltville Fault on the southeast. Peters Mountain area lies between the St. Clair Fault on the northwest and the Narrows Fault on the southeast. The mountain is the southeast-dipping limb of a truncated major anticline cut by three minor thrust faults and warped by several minor folds. Mountain Lake area, between the Saltville and St. Clair Faults, contains several low-plunging folds and is crossed by several minor thrust faults that may represent the Narrows Fault zone.

Mineral resources of the three study areas consist of large submarginal iron resources, large resources of common building stone suitable for crushed rock, and insignificant submarginal manganese resources. Deposits of limestone being mined nearby are in beds that are covered by more than 750 m of younger sediments within the study

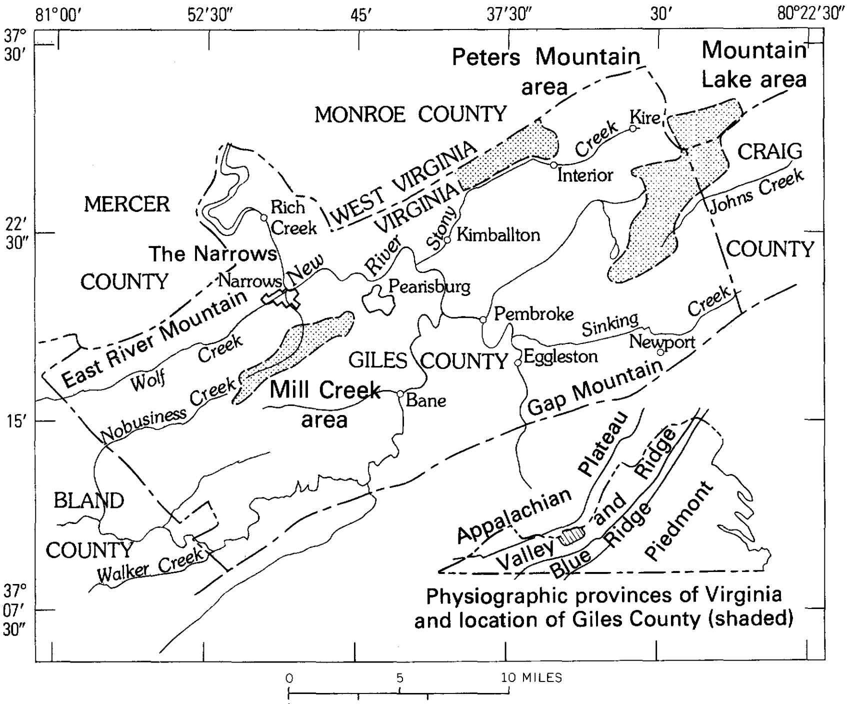

FIGURE 1.–Index map showing the location of the Mill Creek, Mountain Lake, and Peters Mountain Wilderness Study Areas (shaded).

areas. Potential resources of dimension stone and silica sandstone have no unique properties that differentiate them from similar materials more readily accessible outside the study areas. Shale suitable for brick is found mainly in the Johns Creek valley part of the Mountain Lake area. Better exposures are found outside that study area.

The red hematitic sandstone beds of the Rose Hill Formation of Silurian age are a low-grade iron resource in the three areas (figs. 2, 3).

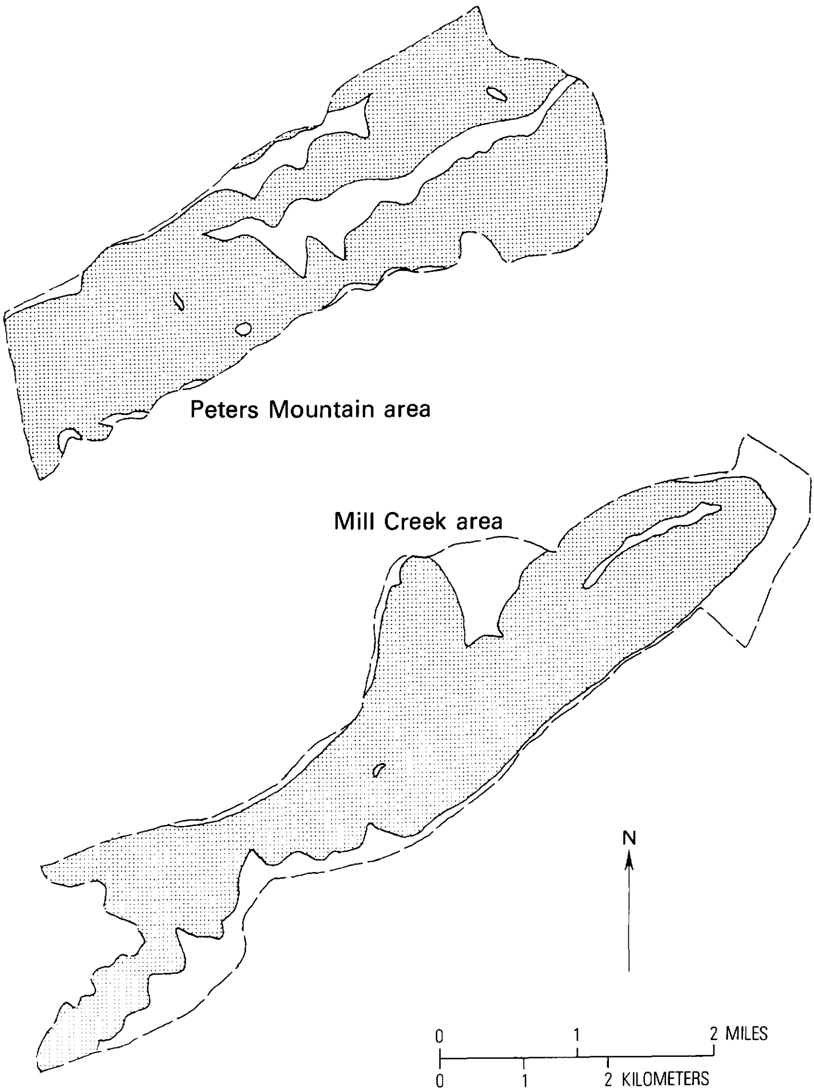

FIGURE 2.–Areas of iron resources (shaded) in Mill Creek and Peters Mountain Wilderness Study Areas. See figure 1 for location of study areas.

Mill Creek area contains an estimated 370 million metric tons of hematitic sandstone ranging in iron content from 15 to 20 percent, or 55–74 million metric tons of iron; Mountain Lake area contains an estimated 1,020 million metric tons of similar grade hematitic sandstone, or 153–204 million metric tons of iron; and Peters Mountain area contains 360 million metric tons of similar grade hematitic sandstone, or 55–72 million metric tons of iron. This low-grade iron resource is

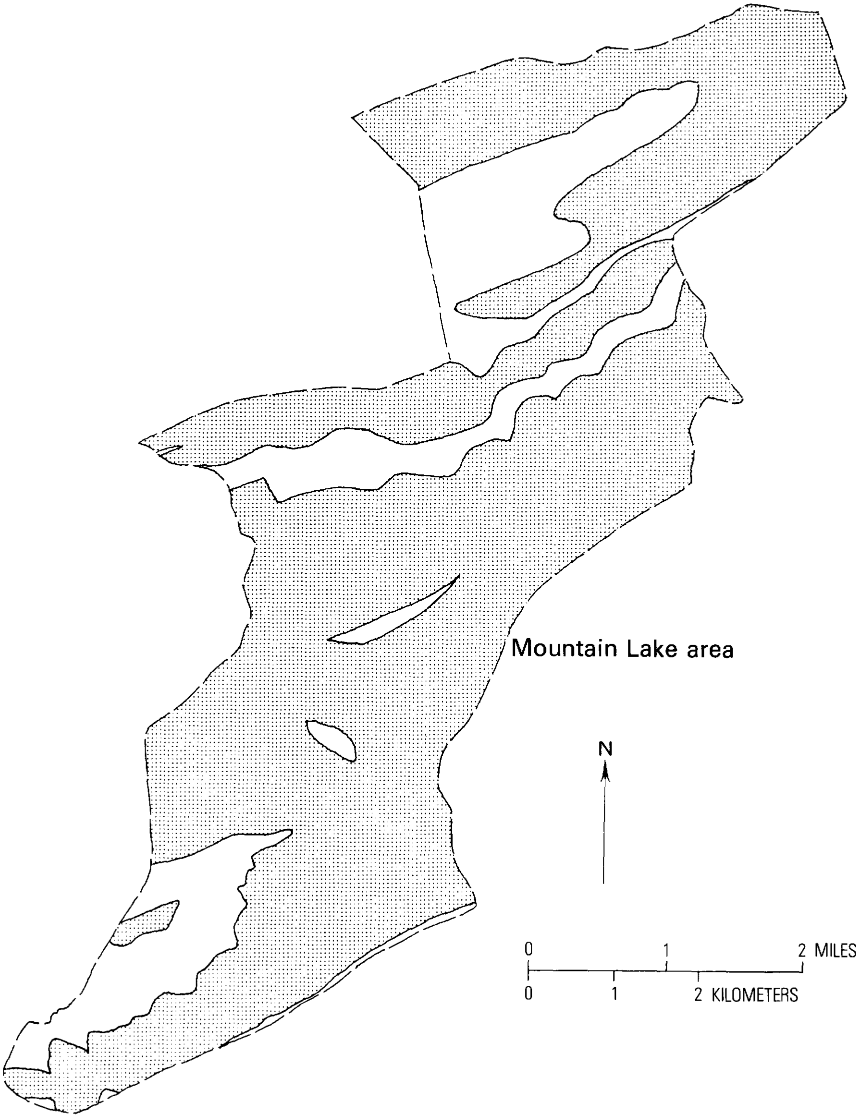

FIGURE 3.–Area of iron resources (shaded) in Mountain Lake Lake Wilderness Study Area. See figure 1 for location of study area.

contained in sandstone beds and lenses 1–10 m thick and as much as several kilometers long scattered throughout an interlayered series of shale and sandstone of lower grade that ranges in thickness from 45 to 60 m. The iron content ranges from 10 to 30 percent, and the phosphorus, from 0.05 to 0.8 percent. Mining or quarrying of hematitic sandstone in areas of outcrop would be relatively inexpensive, but beneficiation methods may not be adequate to permit economic production of acceptable iron-ore concentrates at existing prices.

Submarginal iron resources in the Rocky Gap Sandstone of Swartz (1929) of Devonian age are small in the three areas. Less than 100,000 t (metric tons) of limonite-cemented sandstone containing 15–20 percent iron may remain in the Chestnut Flat Mine area at the south end of Mill Creek area. Peters Mountain and Mountain Lake areas probably have even less potential for limonite deposits.

The sedimentary rocks in the three study areas have potential for natural gas but not for oil. Structural conditions appear unfavorable for gas accumulation below Mill Creek and Peters Mountain areas but are favorable below parts of Mountain Lake area. No drilling has been done on these structures.

INTRODUCTION

Mill Creek, Mountain Lake, and Peters Mountain are small wilderness study areas in the Jefferson National Forest in Virginia and West Virginia (fig. 1). Mill Creek contains about 1,800 ha[2] in Giles County, Va. The area is a synclinal upland forming the upper drainage basin of Mill Creek and its tributary Mercy Branch; it is bordered by Wolf Creek Mountain on the northwest and Pearis Mountain on the southeast. The southwest end is along Forest Service Road FS 199. The east end, called Angels Rest (fig. 4), is about 800 m from the city limits of Pearisburg, Va., the county seat of Giles County. The town of Narrows is 1.6 km northwest of the area. Altitudes range from 1,081 m above sea level on Wolf Creek Mountain, 1,107 m at Angels Rest, and 1,203 m on Pearis Mountain to less than 620 m at the Narrows Reservoir on Mill Creek. Generally, relief is moderate within the area, except where Mill Creek cuts across the structure and flows north to the New River (figs. 5, 6).

Mountain Lake study area covers about 4,800 ha from Johns Creek Mountain at the south to the old railroad grade along Potts Creek valley at the north. It includes parts of Salt Pond, Potts, and Little

[2] The acreages used in this report are estimated by planimetry of U.S. Forest Service boundary maps. Acreages given in Public Law 93-622 are Mill Creek, 4,000 acres (1,620 ha); Mountain Lake, 8,400 acres (3,400 ha); and Peters Mountain, 5,000 acres (2,023 ha).

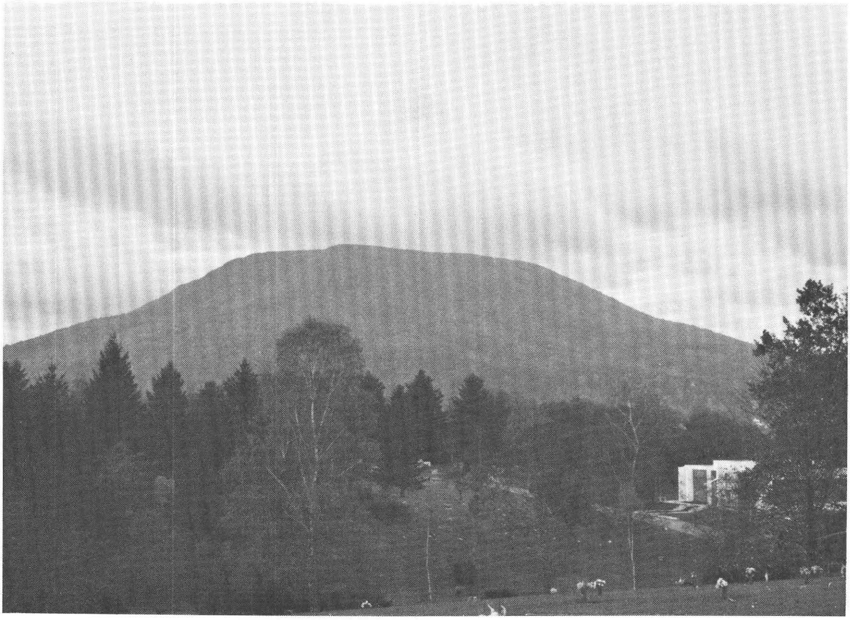

FIGURE 4.–View of Angels Rest, looking southwest from U.S. Highway 460 east of Pearisburg, Va.

Mountains and the upper end of Johns Creek valley (fig. 7) and lies along the divide between New River and James River drainages. About 1,230 ha of the area is in Monroe County, W. Va., 570 ha in Craig County, Va., and 3,000 ha in Giles County, Va. Altitudes range from a low of 640 m above sea level in Johns Creek valley to more than 1,250 m on Potts Mountain and 1,325 m on Bald Knob near the southwest end of Salt Pond Mountain.

Peters Mountain study area covers about 1,600 ha of National Forest land that includes several steep spurs along the southeast flank of Peters Mountain from Foster Knob at the southwest end near Olean to Huckleberry Ridge north of Interior at the northeast end, all in Giles County, Va. The southeast border is the paved road, Virginia State Road 635, along Stony Creek; the northwest border is the crest of Peters Mountain, which is the boundary between Monroe County, W. Va., and Giles County, Va. (fig. 8). Altitudes range from a high of 1,205 m on Peters Mountain to a low of 580 m on Stony Creek.

All three areas are heavily forested with second- or third-growth hardwoods. A few small stands of mature hemlock are preserved in Peters Mountain and Mountain Lake areas (fig. 9). Locally, the areas contain thick growths of rhododendron and mountain laurel. Access by trails and roads is fair to good for all three areas; the Appalachian Trail traverses the full length of Mill Creek area, most of Peters Mountain,

FIGURE 5.–Panoramic view of Mill Creek Wilderness Study Area, looking north from the fire tower on Flat Top Mountain, Giles County, Va.

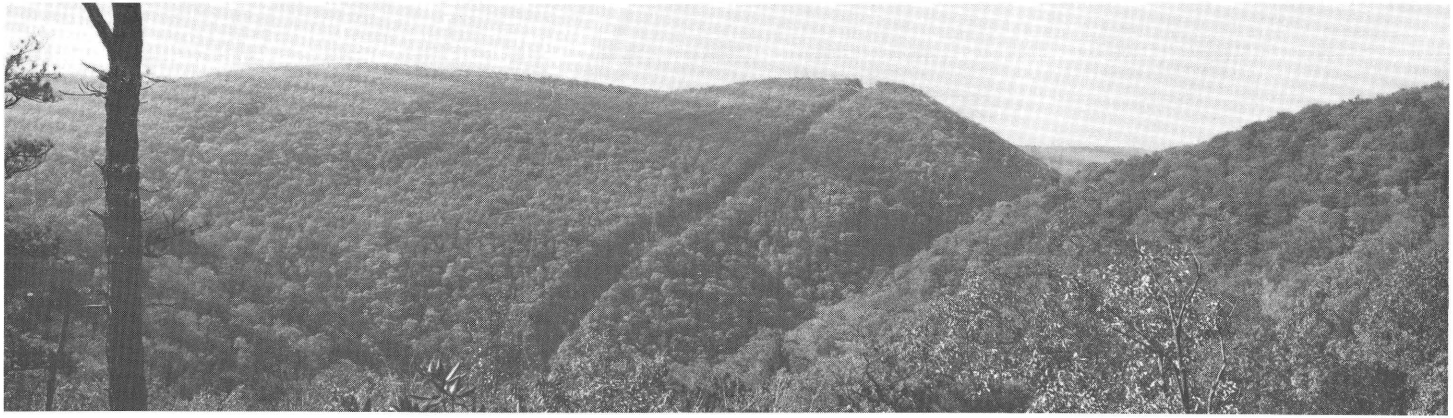

FIGURE 6.—Panoramic view of Wolf Creek Mountain and Mill Creek valley along the northern edge of Mill Creek Wilderness Study Area, showing one of the two powerlines that cross the study area.

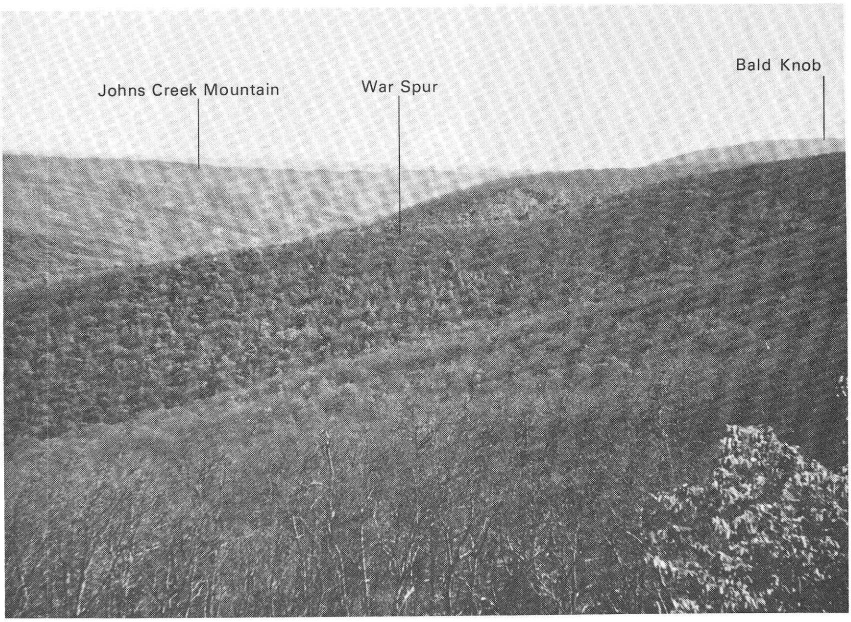

FIGURE 7.–View in the Mountain Lake Wilderness Study Area, looking southwest along the flank of Salt Pond Mountain toward War Spur in the distant center. Bald Knob is farther right. Johns Creek Mountain, the long ridge on the left, is mostly outside the study area.

and the north end of the Mountain Lake area. Mill Creek is crossed by two powerlines within a cutover right-of-way (fig. 6); Mountain Lake is crossed by one powerline.

PREVIOUS WORK

The earliest account of the geology of the three areas is that by W. B. Rogers (1836, p. 111–112), first State Geologist of Virginia, who mentioned the limestone valley below Angels Rest and Salt Pond Mountains and the sandstone debris on the slopes of Peters Mountain. He also (p. 113) gave a brief description of Mountain Lake. In later reports, Rogers (1838, p. 17–23; 1839, p. 7–9) detailed the general character of the Paleozoic sedimentary rocks in the Appalachian Valley; three of his cross sections, prepared then but not published until later (1884, pl. VII, sec. 13; pl. VIII, secs. 12, 14), were drawn through the general vicinity of the study areas. Section 12 is just northeast of Mountain Lake area, section 13 is between Peters Mountain and Mill Creek areas, and section 14 is southwest of Mill Creek. These sections are good generalizations of the complex geology in the area.

In 1881, C.R. Boyd (p. 134–150) published a brief account of the mineral resources of southwest Virginia, including Giles County.

FIGURE 8.—View of the northeast end of Peters Mountain Wilderness Study Area, looking from Interior, Va., northwest across the valley of Stony Creek toward Peters Mountain.

Stevenson (1887) made a reconnaissance of southwest Virginia and recorded some of the geology of Giles County (p. 87–95). Watson (1907, p. 447–448), Stose and Miser (1922, p. 118–127), and Ladd and Stead (1944) mapped minor deposits of iron and manganese in Giles County in the vicinity of the study areas; Hubbard and Croneis (1924) described the general geology of the county. Reger and Price (1926) mapped the geology of Monroe County, W. Va., which includes the north part of the Mountain Lake area. Butts (1933, 1940) compiled a reconnaissance geologic map and a detailed description of the rock units of the Appalachian Valley in Virginia, which includes the three study areas. Cooper (1944, p. 11–46) described the limestone and dolomite of the county, but these deposits are exposed outside the study areas.

Beginning in 1955, many students at Virginia Polytechnic Institute mapped small areas of Giles County for master's theses. A few of these are pertinent to the wilderness study areas. Eckroade (1962) studied a large area centered on Butt Mountain, including all the Peters Mountain and part of the Mountain Lake study areas. Whitman (1964) studied the geology of Pearis Mountain, which includes most of the Mill Creek study area.

In 1956, B. N. Cooper and several of his students at Virginia Polytechnic Institute (Cooper, 1958, 1960; Williams, 1957; Chauvin,

FIGURE 9.–View southwest up War Spur Branch in the Mountain Lake Wilderness Study Area, looking toward a small stand of virgin hemlock in the distant center.

1957) began a study of the economic potential of hematitic sandstone in the Rose Hill Formation in southwest Virginia. Cooper's work led to an exploration drilling program by Minerals Development Corp., Roanoke, Va., on a large area of National Forest that includes all the Mill Creek Wilderness Study Area. Results of this work prompted the U.S. Bureau of Mines to drill an area of hematitic sandstone in the Rose Hill Formation on Butt Mountain just west of Mountain Lake and to make detailed laboratory tests on the recovery of iron (Fish, 1967, p. 5).

In the early 1960's, W. A. Moon, Jr., compiled a geologic map of Giles County at a scale of 1:31,680. This map was not published but is on file at the Department of Geological Sciences, Virginia Polytechnic Institute and State University, Blacksburg, Va.

PRESENT WORK

The three areas were mapped and sampled in reconnaissance by U.S. Geological Survey (USGS) personnel during 3 weeks in April and May 1975 and 2 weeks in May 1976. For Mill Creek area, we used unpublished maps by Whitman (1964) and by the Minerals Development Corp. M. P. Foose, F. G. Lesure, P. L. Weis, and Helmuth Wedow, assisted by D. R. McQueen, checked formation contacts and collected 71 rock and

62 stream-sediment samples for chemical analyses in USGS laboratories in Reston, Va., and Denver, Colo.

In Peters Mountain area, the same personnel used an unpublished geologic map by Eckroade (1962), remapped parts of the area, and collected 43 stream-sediment and 73 rock samples. Because of major differences in interpretation of our reconnaissance mapping, Lesure, assisted by J.T. Hanley, spent several days field checking the area in April 1976. At the same time, J. P. D'Agostino and A. E. Grosz collected 48 soil samples.

Only part of the Mountain Lake area was covered by previous mapping. Eckroade's map (1962) covers some of the western edge, and the unpublished compilation by W. A. Moon of the geology of Giles County covers about half the area. Our fieldwork consisted of 6 days of reconnaissance mapping and geochemical sampling in April 1975 by the full field party and an additional 6 days of mapping by Lesure and Hanley in May 1976. We collected 122 rock samples and 98 stream-sediment samples in 1975.

Field investigation by B. B. Williams and M. L. Dunn, U.S. Bureau of Mines (USBM), entailed sampling rock units having mineral potential, at outcrop, if possible, or by a representative sample of float material. Workings at several mines and prospects within the study areas were mapped in conjunction with the sampling of ore material. Also, in their investigation of the areas' mineral potential, USBM personnel obtained leasing and prospecting information from the Bureau of Land Management, contacted Forest Service offices in Blacksburg and Roanoke, Va., visited mines and quarries outside the areas, and conversed with representatives of industry, State, and Federal agencies.

During field studies, 114 rock samples were collected by Williams and Dunn and were analyzed by the USBM, Reno Metallurgy Research Center, Nev. Limestone and silica sandstone tests were made on certain samples. The USBM, Tuscaloosa Metallurgy Research Center, Ala., evaluated ceramic properties of shale samples.

SURFACE AND MINERAL OWNERSHIP

Part of each study area is privately owned. Under Wilderness designation, these lands will remain in private hands provided that any activities on them are consistent with Wilderness management policy.

In the Mill Creek area, the Forest Service owns both surface and mineral rights for about 95 percent of the proposed wilderness (fig. 10). In the Mountain Lake area, about 20 percent of the proposed wilderness is privately owned (fig. 11). In Peters Mountain, only 2 percent of the surface rights are privately owned, but in two areas where the surface rights are held by the Forest Service, the mineral rights are

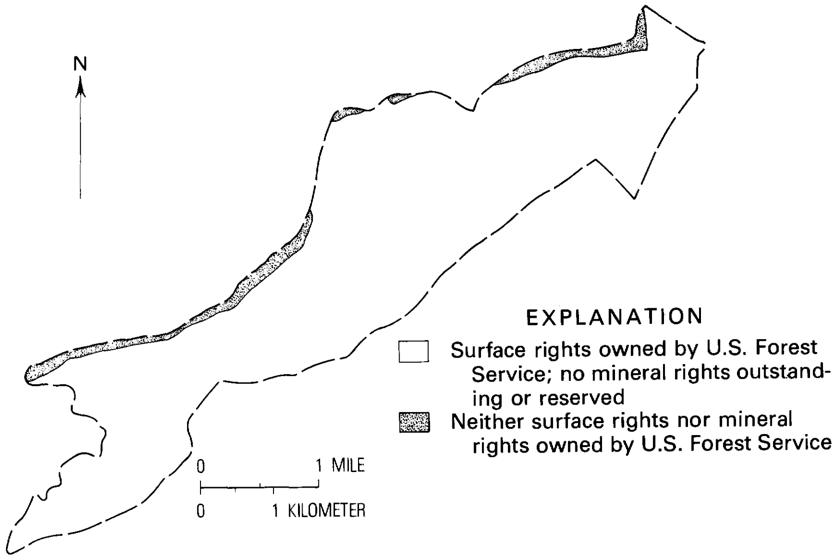

FIGURE 10.–Land ownership, Mill Creek Wilderness Study Area. See figure 1 for location of study area.

not. These are FS Tract J–892, 121 ha, and FS Tract J–557, one-half interest of 40.5 ha (fig. 12).

ACKNOWLEDGMENTS

Appreciation is extended to personnel of the U.S. Forest Service, Jefferson National Forest, for their assistance and cooperation, particularly Roger Eubanks. Dr. W. D. Lowry, Professor of Geology, Virginia Polytechnic Institute and State University, and Dr. J. L. Calver, former State Geologist, Virginia Division of Mineral Resources, provided valuable observations and material on mineral resources, including an unpublished geologic map of Giles County, Va., compiled by W. A. Moon, Jr. The Minerals Development Corp., Roanoke, Va., supplied copies of drill logs and maps of the Mill Creek area. Cooperation of local quarry operators and many local residents is greatly appreciated.

GEOLOGY

GEOLOGIC SETTING

The three study areas are in the western part of the Valley and Ridge physiographic province, which corresponds to the folded Appalachians (fig. 1). Here, Mississippian and older Paleozoic sedimentary rocks are exposed in northeast-trending anticlines and synclines separated into structural blocks by major thrust faults (pl. 1). The Mill Creek area is

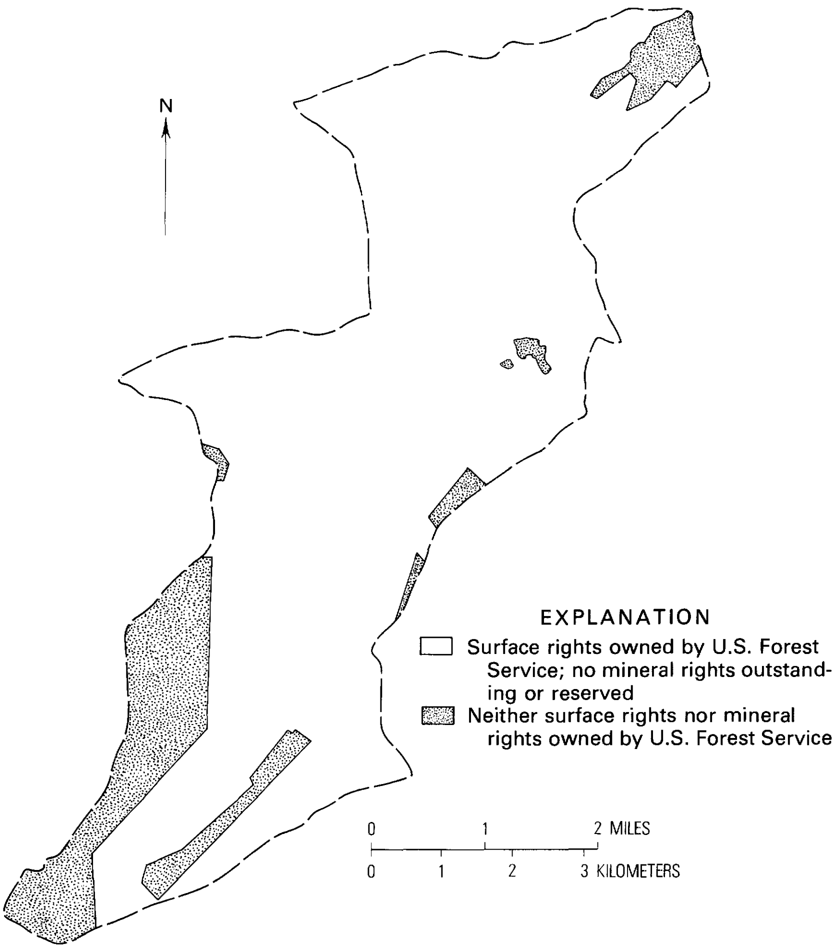

FIGURE 11.–Land ownership, Mountain Lake Wilderness Study Area. See figure 1 for location of study area.

between the Narrows Fault on the west and the Saltville Fault on the east. Peters Mountain, in the next block to the west, is between the Narrows Fault and the St. Clair Fault. Mountain Lake lies between the Saltville and St. Clair Faults. The Narrows Fault apparently dies out a few miles west of the Mountain Lake study area, but several minor thrusts possibly related to the Narrows Fault cross the north end of the study area.

Sedimentary rocks of Ordovician, Silurian, and Devonian age are exposed in all three areas (pls. 2–4). The youngest geologic units are minor deposits of alluvial clay, sand, and gravel of Quaternary age

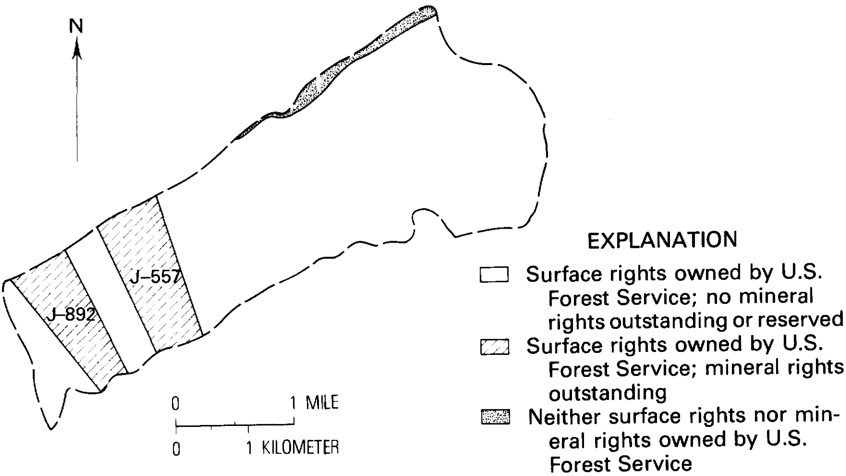

FIGURE 12.—Land ownership, Peters Mountain Wilderness Study Area. See figure 1 for location of study area.

along major streams and broad areas of alluvium and colluvium along the lower slopes of Salt Pond Mountain in Johns Creek valley, the eastern part of the Mountain Lake area.

STRATIGRAPHY

The same clastic marine and nonmarine sedimentary rock formations are exposed in the three study areas, and rock types in each formation are similar from one area to the next. An unconformity at the base of the Devonian System cuts across the Middle and Upper Silurian formations so that Rocky Gap Sandstone of Swartz (1929) (Lower Devonian) probably rests on Keefer Sandstone (Middle Silurian) in the Mill Creek area and on Tonoloway Limestone (Upper Silurian) or unidentified Upper Silurian sandstones in parts of the Peters Mountain and Mountain Lake areas.

The formations are fairly distinctive lithologic units, but some confusion is possible in the mapping of the major sandstone units, which include two dominantly red sandstone-shale sequences separated by a white quartzite and overlain by a second white quartzite. The lower red unit, the Juniata Formation, commonly contains fine-grained, light-reddish-brown sandstone beds and interbedded reddish-brown and greenish-gray shale. The overlying white quartzite, the Tuscarora, contains fine-grained pebble conglomerate in the lower part and fine- to medium-grained sandstone in the upper part. It is overlain by the second red unit, the Rose Hill Formation, which has beds of darker red, dense, hematitic sandstone. Iron content of the Rose Hill sandstone is much greater than that of the Juniata sandstone, but superficially, parts of the two formations look alike. A second white quartzite, the Keefer Sandstone, overlies the Rose Hill. The Keefer is generally finer grained than the Tuscarora, but fine-grained beds of one are indistinguishable from fine-grained beds of the other. In Peters Mountain and Mountain Lake areas, where thrust faults have cut out parts of the stratigraphic section, the Juniata is locally in contact with the Rose Hill, and the Tuscarora is in contact with the Keefer; the stratigraphic sequence is confusing and difficult to map. The geologic maps of these areas (pls. 3, 4) present our best interpretation of the structure and are based on reconnaissance mapping, photo interpretation, and previous geologic mapping. Additional mapping could improve many minor details.

ORDOVICIAN SYSTEM

MARTINSBURG SHALE

The Martinsburg Shale is a thick sequence of gray calcareous shale and thin-bedded light-gray limestone named from exposures near Martinsburg, W. Va., about 340 km northeast of Giles County (Geiger and Keith, 1891, p. 161). The formation is present but poorly exposed on the flanks of Pearis and Wolf Creek Mountains, mostly outside the boundaries of the Mill Creek area (pl. 2). Whitman (1964, p. 37) reported good exposures of the Martinsburg at the Narrows reservoir on Mill Creek. None of the formation is exposed in the Peters Mountain area, although several small streams have cut so deeply into the overlying Juniata Formation that the Martinsburg could be expected along the northeast flank of Peters Mountain (pl. 3). In the Mountain Lake area, the Martinsburg is present in the valley of White Rocks Branch, along the southeastern slopes of Johns Creek Mountain, and near Mountain Lake. The formation is generally poorly exposed; it forms steep slopes covered with sandstone blocks from the overlying Juniata and Tuscarora. Good exposures of the Martinsburg are found along the roadcut on U.S. Highway 460 at the Narrows, the gap cut by the New River through Peters-East River Mountain.

The Martinsburg is about 550 m thick near the Mill Creek area (Whitman, 1964, p. 38) and 450–550 m thick in the Mountain Lake area.

The Martinsburg is generally considered to be Middle and Late Ordovician in age. It is overlain conformably by the Juniata Formation. The upper part of the Martinsburg becomes sandy and grades into the Juniata. On the geologic maps, the contact is drawn approximately; it is placed at the base of the more prominent sandstone beds of the Juniata Formation.

JUNIATA FORMATION

The Juniata Formation of Late Ordovician age is an interlayered sequence of fine-grained sandstone and shale beds. The sandstone beds are generally pale red or grayish red and crossbedded. They break into thin slabby blocks. The shales are reddish or light greenish gray and poorly exposed. Darton and Taff (1896, p. 2; Clark, 1897, p. 180–181) named the formation for exposures along the Juniata River in Pennsylvania, and the rocks have been traced continuously along strike through western Maryland, eastern West Virginia, and western Virginia.

Juniata sandstone is moderately well exposed in the three study areas. The sandstone forms steep slopes and, in places, minor cliffs below the more resistant Tuscarora Quartzite. The boundary of Mill Creek area closely parallels the Juniata-Tuscarora contact along Pearis Mountain and is mostly above the contact on Wolf Creek Mountain, so that Juniata exposures are outside the study area.

The formation is well exposed along the west side of the top of Peters Mountain, generally outside that study area, and along two thrust faults on the east slope of the mountain within the study area.

In the Mountain Lake area, the Juniata is exposed in three erosional windows through the Tuscarora Quartzite along a dip slope on the east side of Salt Pond Mountain. Juniata sandstone is poorly exposed along a thrust fault in War Spur Branch and better exposed where it is brought up along the thrust fault on the east flank of Potts Mountain. Good exposures are also present on the west flank of Potts Mountain and on the east side of Little Mountain at the north end of the study area.

The sandstone members in the Juniata Formation are mostly very fine grained. Quartz is the principal mineral, but minor amounts of feldspar, some zircon, and rare opaque minerals are present. The sandstone is generally light grayish red, pale red, or pale yellowish brown. Locally, beds of light-gray to white quartzite, a meter or two thick, are interbedded with the more common reddish-brown sandstone. Much of the sandstone is crossbedded; cross beds are thin, 1–15 cm, and in layers 30–60 cm thick. The sandstone breaks readily into thin slabby blocks and forms rubble that conceals outcrops.

The interbedded shale is reddish brown or greenish gray. Reddish-brown layers are commonly mottled with greenish-gray areas. The shale is not well exposed except along roadcuts.

The Juniata Formation ranges in thickness from 60 to 120 m. Whitman (1964, p. 85–87) measured one section of 93 m on Pearis Mountain and one of 96 m in Mill Creek; Eckroade (1962, p. 42–43) measured a section of 57 m on Salt Pond Mountain and reported a thickness of 120 m at the west end of Butt Mountain. Butts (1940, p. 207) measured 60 m along U.S. Highway 460 at the Narrows of the New River.

The iron content of the Juniata red sandstone ranges from 0.1 percent to as much as 5 percent but is commonly about 1 or 2 percent

TABLE 1.—*Range and median values for 41 elements in rock and stream-sediment samples*
24 elements in soil samples from

[All analyses of rock and stream sediment samples are by semiquantitative spectrographic methods by Leung Mei, quantitative spectrographic methods by J. M. Motooka for all elements except zinc, which is by atomic absorption determination; >, greater than upper limit of determination; N, not detected. Elements looked for spec- parentheses, in parts per million: Au (10), Bi (4), Cd (10), Dy (6), Er (4), Ge (3), Hf (21), Ir (6), Os (6), Pd (0.6), Pt (6), looked for in soils but not found and their lower limit of determination, in parentheses, in parts per million: As

Elements	Average sandstone [1]	Juniata Formation Sandstone (20 samples) Low	High	Median	Tuscarora Sandstone Quartzite (72 samples) Low	High	Median
Si	36.8	>34	>34	>34	>34	>34	>34
Al	2.5	.18	7.5	1.5	.031	1.7	.31
Fe	.98	.11	5.0	1.5	.064	11	.48
Mg	.7	.013	.88	.12	.0039	.097	.019
Ca	3.91	.009	.15	.03	.0039	.076	.016
Na	.33	<.004	>.31	.0062	<.0046	.021	<.0046
K	1.07	.076	>1.4	.68	<.068	1.0	.12
Ti	.15	.023	.77	.22	.018	.27	.074
P	.017	<.068	.11	.07	.068	.33	<.068
Mn	.05	.002	.58	.011	.0012	7.1	.0064
							Parts
Ag	0.0x[2]	<0.4	<0.4	<0.4	<0.4	6	<0.4
As	1	<68	<68	<68	<68	93	<68
B	20–30	31	190	70	13	190	70
Ba	300	11	350	150	12	980	54
Be	2	<1	2	<1	<1	7	<1
Ce	92	<43	110	46	<43	270	<43
Co	.3	<1	14	2	<1	420	<1
Cr	10–20	3	57	19	2	33	11
Cu	10–20	<1	220	6	<1	930	1
Eu	1.6	<1	1	<1	<1	12	<1
Ga	12	<2	15	3	<2	7	<2
Gd	10	<14	20	<14	<4	68	<4
Ho	2	<3	<3	<3	<10	22	<10
In	.0x[2]	<4	5	<4	<4	<4	<4
La	30	<4	52	14	<4	100	13
Lu	1.2	<3	4	<3	<3	5	<3
Mo	.2	<1	<1	<1	<1	33	<1
Nb	.0x[2]	<10	16	<10	<10	20	<10
Nd	37	<68	100	<68	<68	190	<68
Ni	2	1	45	11	1	>1,000	4
Pb	9	<6	33	<6	<6	350	<6
Pr	8.8	<3	7	<3	<3	21	<3
Sc	1	<1	11	2	<1	8	1
Sm	10	<4	7	<4	<4	71	<4
Sr	20	4	130	24	2	180	6
Th	1.7	<21	25	<21	<21	40	<21
V	10–20	3	60	23	1	110	7
Y	40	3	56	18	2	540	11
Yb	4	<1	5	2	.2	35	1
Zn	16	<14	24	<14	<14	780	<14
Zr	200–250	120	1,400	360	<46	2,400	772

See footnotes at end of table.

(table 1). The ranges shown in table 1 for 40 other elements do not suggest any uncommon concentrations when compared with those for the average sandstone.

from Mill Creek, Mountain Lake, and Peters Mountain Wilderness Study areas and for Mountain Lake and Peters Mountain area

Norma Rait, and J. D. Fletcher, U.S. Geological Survey laboratories, Reston, Va.; analyses of soils are by semi-
methods by C. A. Curtis in U.S. Geological Survey laboratories, Denver, Colo. Symbols used: <, less than lower limit of
trographically in rock and stream sediments but not found, except as noted, and their lower limit of determination, in
Re (10), Rh (0.6), Ru (0.6), Sb (68), Sn (14), Ta (460), Tb (10), Te (460), Tl (4), Tm (3), U (140), and W (10). Elements
(200), Au (10), Cd (20), Sb (100), Sn (10), and W (50)]

Rose Hill Formation			Keefer Sandstone			Rocky Gap Sandstone of Swartz (1929)		
Hematitic sandstone (68 samples)			Quartzite (51 samples)			Limonitic sandstone (31 samples)		
Low	High	Median	Low	High	Median	Low	High	Median
Percent								
8.0	>34	>34	14	>34	>34	3.8	>34	21
.43	3.2	1.0	<.031	2.3	.2	.22	2.4	.7
4.8	>23	>23	.18	23.0	.7	1.0	>23	>23
.028	.34	.093	.0064	1.0	.022	.0021	.091	.013
<.014	1.1	.10	.0046	.073	.012	<.0006	.19	.026
<.0046	.044	<.0046	<.0046	.031	<.0046	<.0046	<.0046	<.0046
<.068	.7	.43	<.068	.99	<.068	<.068	>1.40	<.068
.042	.26	.12	.011	.41	.055	<.0003	.11	.020
<.068	1.7	<.068	<.068	.70	<.068	<.068	1.3	<.068
.0038	.33	.01	.0006	4.9	.0089	<.0068	16	.021
per million								
<0.4	0.9	<0.4	<0.4	4	<0.4	<0.4	4	<0.4
<68	84	<68	<68	<68	<68	<68	280	<68
<14	160	72	19	320	95	<14	75	<14
25	640	150	6	1,700	40	<14	>2,100	110
<1	10	2	<1	20	<1	<1	29	4
<43	500	200	<43	320	<43	<43	390	<43
<1	21	2	<1	780	<1	<1	870	12
<14	51	30	2	34	8	6	78	18
<1	200	3	<1	150	<1	9	530	46
<1	7	1	<1	3	<1	<1	7	<1
<2	23	11	<2	8	<2	<2	46	10
<4	63	<14	<4	46	<4	<4	36	<4
<3	21	<10	<3	<10	<3	<3	8	<3
<4	<4	<4	<4	7	<4	<4	7	<4
<4	94	48	<4	47	5	<4	90	<4
<3	4	<3	<3	5	<3	<3	<3	<3
<1	13	<1	<1	3	<1	<1	29	<1
<10	20	12	<10	26	<10	<10	20	<10
<68	220	<68	<68	160	<68	<68	<68	<68
2	52	11	1	360	4	2	360	86
<6	650	16	<6	210	10	11	1,000	35
6	20	13	<3	16	<3	<3	22	6
5	17	11	<1	10	1	<1	34	5
<4	60	9	<1	19	<4	<4	19	<4
20	330	150	1	160	5	2	100	8
<21	130	51	<21	32	<21	<21	110	<21
21	130	85	2	39	6	10	580	50
13	380	63	2	100	9	5	170	13
1	72	4	.2	9	1	1	10	1
<14	1,000	50	<14	1,700	<14	110	4,600	580
280	2,300	810	100	>2,100	820	17	600	140

The Juniata Formation is overlain conformably by the Tuscarora Quartzite of Early Silurian age. The contact is sharp and easily mapped. Basal Tuscarora is generally a pebble conglomerate and is much

TABLE 1.—*Range and median values for 41 elements in rock and stream-sediment samples*
24 elements in soil samples from Mountain

Elements	Stream sediments					
	Mills Creek area (62 samples)			Mountain Lake area (98 samples)		
	Low	High	Median	Low	High	Median
Si	34	>34	>34	9	>34	<34
Al	.06	5.1	1.3	.06	6.1	1.3
Fe	.2	5.1	1.5	.14	5.3	1.5
Mg	.007	.9	.15	.01	1.3	.1
Ca	.003	2.6	.03	.01	1.7	.06
Na	<.004	>.3	.01	<.004	>.3	.02
K	<.06	>1.4	.3	<.06	>1.4	.5
Ti	.02	.5	.15	.01	.6	.13
P	<.06	.2	.07	<.06	.17	.07
Mn	.001	.15	.025	.003	.32	.07
						Parts
Ag	<0.04	0.9	<0.4	<0.4	0.7	<0.4
As	<68	<68	<68	<68	<68	<68
B	3	210	65	4	150	66
Ba	13	410	110	30	600	160
Be	<1	4	1	<1	11	1
Ce	<43	110	55	<43	100	<43
Co	<1	30	5	<1	50	10
Cr	1	52	17	3	59	18
Cu	<1	32	6	<1	100	15
Eu	<1	2	<1	<1	1.7	<1
Ga	<2	16	3	2	16	3
Gd	<14	19	<14	<14	20	<14
Ho	<3	<3	<3	<3	<3	<3
In	<4	<4	<4	<4	5	<4
La	<4	54	18	<4	50	17
Lu	<3	4	<3	<3	<3	<3
Mo	<1	1	<1	<1	12	<1
Nb	<10	17	10	<10	22	<10
Nd	<68	130	<68	<68	120	<68
Ni	<1	38	4	<1	100	12
Pb	<6	78	14	<6	140	21
Pr	<3	9	3	<3	7	<3
Sc	1	12	3	<1	17	3
Sm	<4	7	<4	<4	7	<4
Sr	2	150	17	3	160	18
Th	<21	53	<21	<21	53	<21
V	5	75	29	8	180	33
Y	5	100	22	2	120	20
Yb	.3	8	2	<.15	11	2
Zn	<14	140	<14	<14	300	24
Zr	93	>2,100	360	64	2,400	280

[1] Pettijohn (1963, p. S11) and Turekian and Wedepohl (1961, table 2).
[2] Order of magnitude estimated by Turekian and Wedepohl (1961, table 2).

more resistant to weathering than is the Juniata. Locally, beds of white quartzite in the Juniata 15 m or more below the top of the formation *from Mill Creek, Mountain Lake, and Peters Mountain Wilderness Study areas and for Lake and Peters Mountain area*–Continued

			Soil					
Peters Mountain area (43 samples)			Mountain Lake area (50 samples)			Peters Mountain area (48 samples)		
Low	High	Median	Low	High	Median	Low	High	Median
Percent								
23	>34	>34	---------	---------	---------	---------	---------	---------
.06	5.6	1.3	---------	---------	---------	---------	---------	---------
.25	14	1.6	.15	5	1.5	.3	7	1.0
.009	.88	.09	.03	.5	.1	.03	.3	.1
.008	.92	.04	N	.1	<.05	N	.1	.05
<.004	.26	.01	---------	---------	---------	---------	---------	---------
<.06	>1.4	.4	---------	---------	---------	---------	---------	---------
.03	.6	.11	.15	1.0	.5	.1	.7	.5
<.06	.14	.06	---------	---------	---------	---------	---------	---------
.001	.41	.035	.001	.5	.015	.002	.5	.03
per million								
<0.4	0.6	<0.4	N	2	N	N	0.7	N
<68	<68	<68	N	N	N	N	N	N
38	110	71	20	150	70	15	100	70
20	440	150	N	1,500	150	N	5,000	150
<1	9	2	N	5	<1	N	3	1.0
<43	170	54	---------	---------	---------	---------	---------	---------
<1	140	11	N	20	<5	N	30	<5
2	48	16	<10	70	20	<10	50	20
<1	90	13	N	70	5	N	20	5
<1	2	<1	---------	---------	---------	---------	---------	---------
<2	15	3	---------	---------	---------	---------	---------	---------
<14	14	<14	---------	---------	---------	---------	---------	---------
<3	<3	<3	---------	---------	---------	---------	---------	---------
<4	<4	<4	---------	---------	---------	---------	---------	---------
<4	48	16	N	150	20	N	50	<20
<3	3	<3	---------	---------	---------	---------	---------	---------
<1	2	<1	N	50	N	N	7	N
<10	18	<10	N	20	<20	N	20	<20
<68	160	<68	---------	---------	---------	---------	---------	---------
1	81	10	<5	70	7	<5	50	10
<6	140	16	N	100	<10	N	30	10
<3	9	<3	---------	---------	---------	---------	---------	---------
<1	12	3	<5	15	7	N	10	7
<4	8	<4	---------	---------	---------	---------	---------	---------
2	130	16	N	200	<100	N	200	N
<21	48	<21	---------	---------	---------	---------	---------	---------
3	85	29	10	500	50	10	150	30
4	60	22	10	70	30	N	50	20
.7	5	2	---------	---------	---------	---------	---------	---------
14	700	<14	15	200	30	10	300	50
110	>2,100	450	100	1,000	500	700	1,000	500

may be mistaken for the Tuscarora or even the Keefer Sandstone. Such beds are generally thin and do not persist for more than a few thousand meters along strike. Careful mapping and observation may be necessary to distinguish Juniata red sandstone from the younger Rose Hill red hematitic sandstone. Stratigraphic position and differences in iron content are helpful guides.

SILURIAN SYSTEM

TUSCARORA QUARTZITE

The thick hard beds of Tuscarora Quartzite are well exposed along high ridges, steep slopes, and prominent knobs in all three study areas (fig. 13). This distinctive ridge-maker was named for exposures on Tuscarora Mountain in Pennsylvania by Darton and Taff (1896, p. 2), and it forms many of the highest ridges in the folded Appalachians from Pennsylvania to Tennessee.

In the Mill Creek area, the Tuscarora outcrop is a cliff that nearly encircles the study area. In the Peters Mountain area, a Tuscarora cliff forms the northwest boundary of the study area along Peters Mountain, and thrust faults repeat the formation in narrow belts through the center of the area. Small patches of this quartzite are exposed in an anticline along Stony Creek and Virginia State Road 635.

The largest outcrop area of the Tuscarora is on Salt Pond Mountain in the Mountain Lake study area, where the southeast side of the mountain is a dip slope of quartzite; this slope is broken by three small streams that expose the underlying Juniata Formation below spectacular cliffs of Tuscarora Quartzite, such as Bear Cliffs (pl. 4). To the north, straight, narrow outcrops of the Tuscarora are present where the formation dips steeply, as along the flank of Potts Mountain, and sinuous narrow exposure patterns form along plunging folds, such as those between White Rocks and Little Mountain. In the three areas, the highest peaks are formed by the resistant beds of the Tuscarora, although the quartzite is generally overlain by a thin remnant of the younger Rose Hill Formation. In some places, this remnant is merely a few feet of flaggy hematitic sandstone boulders and cobbles.

The Tuscarora is probably 40 m thick in the Mill Creek area (Whitman, 1964, p. 41). Butts (1940, p. 235) reported 30 m of Tuscarora in the Narrows of the New River. Eckroade (1962, p. 35) reported that the Tuscarora ranges in thickness from 15 m near the Cascades, 3 km west of Mountain Lake, to 42 m on the west end of Butt Mountain and to 36 m along Stony Creek near Peters Mountain area.

The lower part of the Tuscarora is a fine- to coarse-grained quartzitic sandstone, generally conglomeratic. White spheroidal pebbles of quartz, 6–50 mm long, are common in lenses of conglomerate or in thin layers only a few pebbles thick. The formation becomes finer grained toward the top and locally contains minor shaly beds. Bedding is thin, 2–10 cm, to massive, 1–2 m. Locally, the rock is crossbedded, especially in the conglomeratic layers. The quartzite is generally white to light gray, but red and purple iron stains are common on most outcrops. A silica cement makes the quartzite hard and resistant to weathering.

In general, the Tuscarora is a clean quartzite and contains only minor amounts of trace elements (table 1). Some of it is probably pure enough to be used as low-quality glass sand. In a few places, it has been impregnated with iron or manganese oxides (table 2). One manganese prospect found during the course of field mapping on Johns Creek Mountain (pl. 4) is in an area of low-dipping Tuscarora, where metallic elements have accumulated in the sandstone and have replaced sand grains and silica cement.

The Tuscarora weathers into large blocks and boulders that choke drainages and mantle colluvial slopes.

The formation is overlain conformably by red hematitic sandstone and shale of the Rose Hill Formation. The contact is sharp and easily mapped.

ROSE HILL FORMATION

Red hematitic sandstone of the Rose Hill Formation is the most distinctive and widespread rock type throughout the three study areas. These sandstone beds contain from 5 to more than 33 percent iron and are a significant submarginal iron resource. Wide areas of dip slope on the Rose Hill Formation in the three areas could be easily mined if an economical method of concentrating the iron could be devised and if the need to use such low-grade materials existed. This iron-rich rock has been correlated with the Clinton Group (Formation) of New York and has been called Clinton-type iron ore, or red ore. Some thin beds rich in fossil material and iron are known as fossil ores and contain more iron. Iron ores mined near Birmingham, Ala., are of this type (Wright and others, 1968, p. 405–411).

The Rose Hill Formation was named by Swartz (1923, p. 28) from exposures on Rose Hill, Cumberland, Md. The formation can be traced south from Maryland into West Virginia, and only minor variations in the proportions of sandstone and shale are found. The red beds are its most distinctive characteristic. Rocks we mapped as Rose Hill were included in the Cacapon Sandstone Member of the Clinton Formation by Butts (1940, p. 237–250).

In Giles County, the Rose Hill Formation is an interlayered sequence of red and greenish-gray sandstone and shale. Most common is dark grayish-red, very fine to coarse-grained quartzitic sandstone, well cemented with hematite. Some minor granule and fine-grained pebble

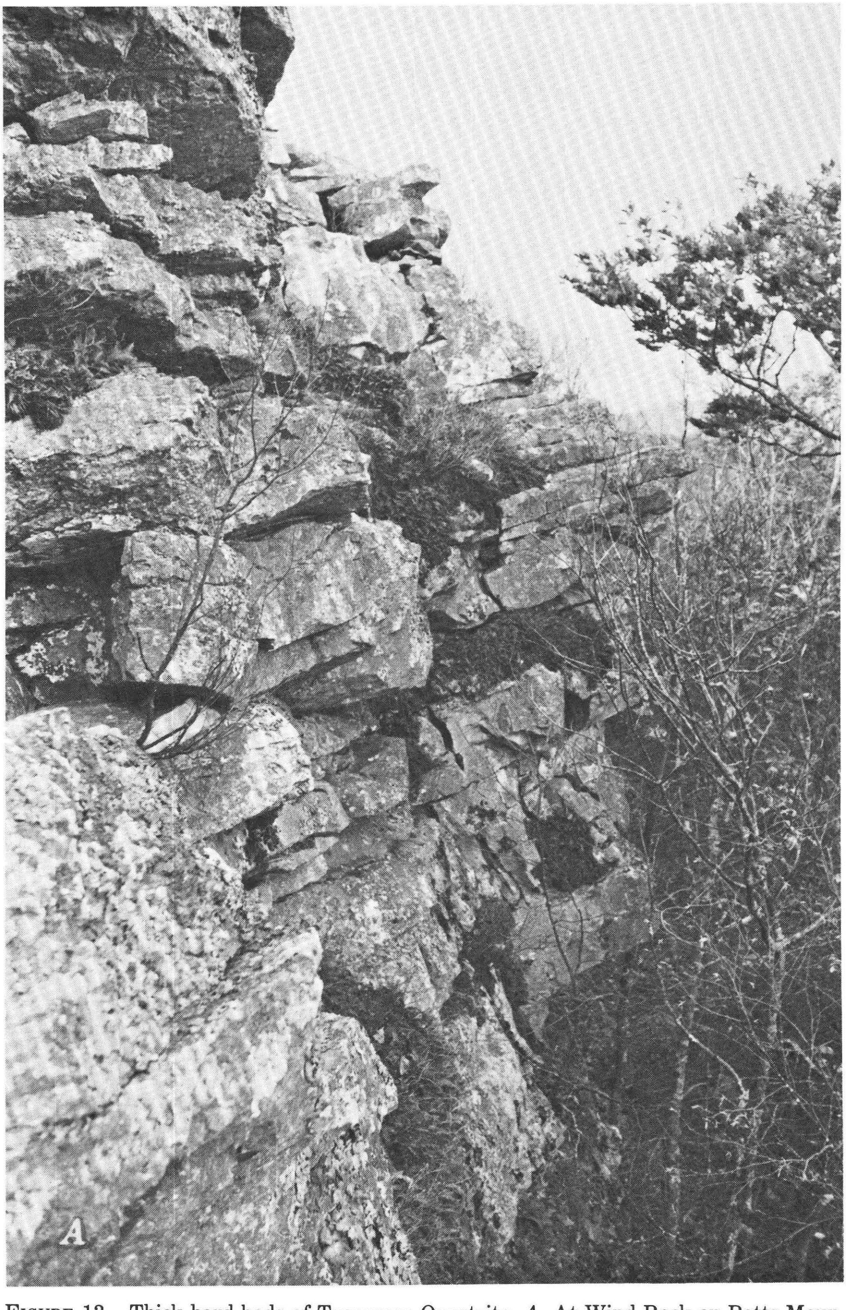

FIGURE 13.–Thick hard beds of Tuscarora Quartzite. *A*, At Wind Rock on Potts Mountain, Mountain Lake Wilderness Study Area, looking southwest along strike. The cliff is about 7 m high. *B*, Along Stony Creek near the south end of Peters Mountain Wilderness Study Area.

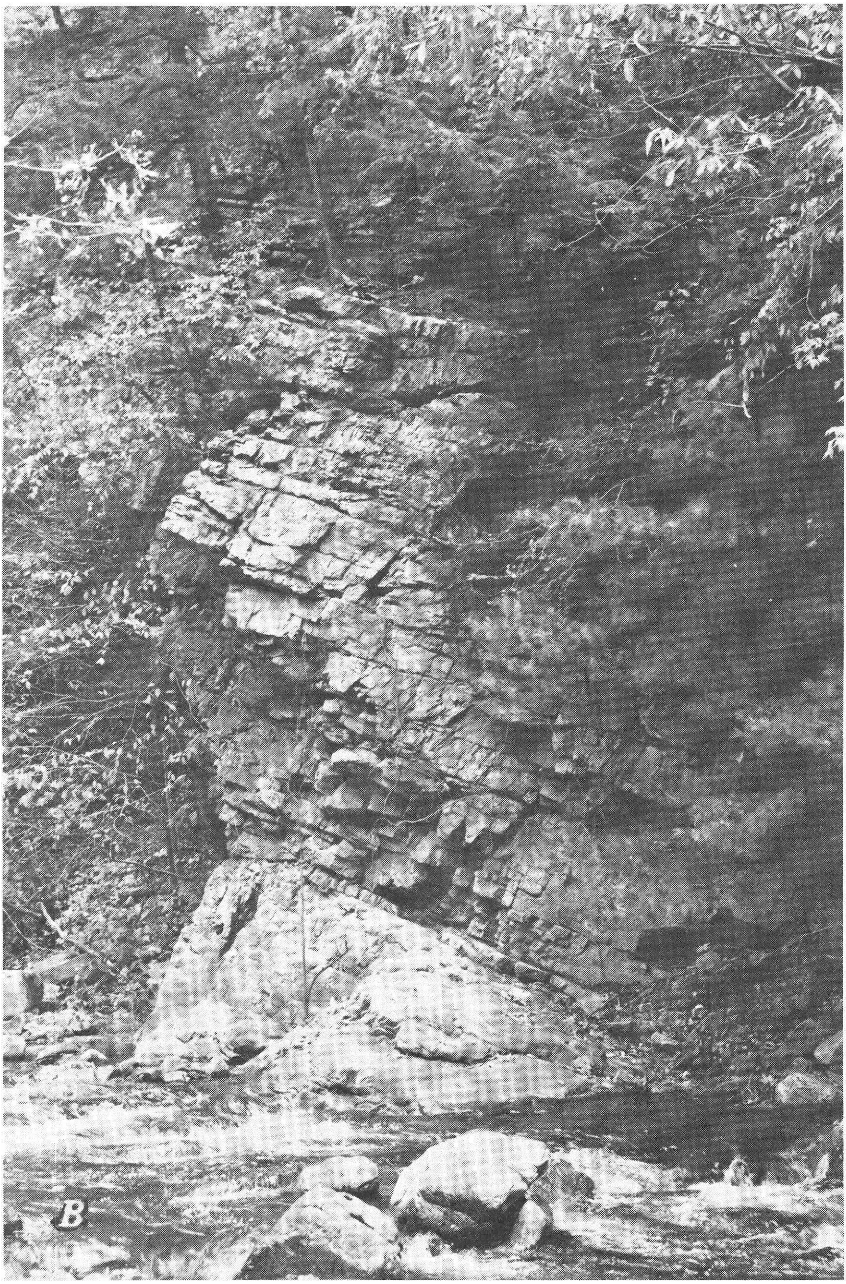

FIGURE 13.–Continued.

TABLE 2.—*Analyses of iron- and manganese-rich rock samples from the Mill Creek, Peters Mountain, and Mountain Lake Wilderness Study Areas, collected by the U.S. Geological Survey*

[For sample locations, see pls. 2-4. Emission spectrographic analyses by Leung Mei and Norma Rait, U.S. Geological Survey, Reston Va. >, greater than; <, less than; sp gr, specific gravity. The standard deviation of any single value should be taken as +50 percent and -33 percent; iron content shown in brackets was determined by Hezekiah Smith, U.S. Geological Survey, Reston, Va., using colorimetric methods]

Sample	Percent			Parts per million							Sample description
	Al	Fe	P	Ag	Co	Cu	Mn	Ni	Pb	Zn	
					Tuscorora Quartzite						
VML 143___	1	8	<0.06	<0.4	1	1	180	3	16	<14	Composite sample of iron-cemented cobbles of quartzite in layer 30-60 cm thick.
VML 147___	<.06	11	.39	6	300	77	49,000	380	<6	560	Composite sample of iron-manganese-cemented sandstone; old prospect.
VML 148___	1.7	1	.18	<3	340	270	71,000	700	<6	780	Composite sample of manganese-cemented sandstone; old prospect.
VML 151___	1.6	9	<.06	<.4	1	<1	71	6	13	<14	Chip sample, 45-cm layer, iron-cemented sandstone; top of formation.
VML 419___	.44	9	.22	<.4	1	6	290	12	160	24	Iron-cemented brecciated sandstone.
VML 438___	1.1	.48	.10	3	420	230	59,000	260	23	540	Manganese-cemented brecciated sandstone.
					Rose Hill Formation						
VMC 004___	1	>23	<0.06	<0.4	1	3	59	5	26	120	Hematitic sandstone near base of formation; sp gr, 3.12.
VMC 006___	1	15	<.06	<.4	3	30	77	14	12	32	60-cm-thick ledge, hematitic sandstone, 3 m above base of formation; sp gr, 2.90.
VMC 008___	0.63	24 [28.5]	<.06	<.4	1	44	49	4	27	100	Chip sample, 4.8-m section, hematitic sandstone; sp gr, 2.96.

VMC 009___	.61	20	<.06	<.4	<1	46	100	4	15	84	Hematitic sandstone above sample 008; sp gr, 2.86.
VMC 021___	1.1	>23	<.06	<.4	3	2	120	19	27	110	Hematitic sandstone near base of formation; sp gr, 3.11.
VMC 022___	.96	13 [10.2]	.33	<.4	2	<1	51	7	10	<14	Chip sample, 1.2 m, hematitic sandstone.
VMC 031___	1.1	25	<.06	<.4	3	<1	60	20	16	23	Chip sample, 30 cm, hematitic sandstone; sp gr, 2.99.
VMC 102___	1.2	27 [18.5]	<.06	<.4	2	39	60	11	19	32	Chip sample, 1.5 m, hematitic sandstone, near top of formation; sp gr, 2.98.
VMC 104___	1.3	18	<.06	<.4	1	64	61	6	18	70	Chip sample, 1.5 m, hematitic sandstone; sp gr, 2.74.
VMC 110___	.95	>23 [20.5]	.56	<.4	2	27	58	7	18	81	Chip sample, 3 m, hematitic sandstone, 6 m above base of formation; sp gr, 2.92.
VMC 111___	.83	19	<.06	<.4	1	36	70	5	13	<14	Chip sample, 60 cm, hematitic sandstone, shale chips; sp gr, 2.81.
VMC 115___	1.4	>23	1.7	.5	11	200	360	52	37	210	Composite sample, float from 2-m zone limonite in sandstone; sp gr, 3.32.
VMC 117___	1.1	>23	<.06	<.4	1	100	100	6	21	42	Chip sample, 1.5 m, hematitic sandstone; sp gr, 2.89.
VMC 120___	1	24 [23.4]	<.06	.5	21	18	3,300	11	14	81	Chip sample, 1.5 m, hematitic sandstone near top of formation; sp gr, 3.1.
VMC 207___	1.3	11	<.06	<.4	4	34	100	16	7	<14	Hematitic sandstone; sp gr, 2.76.
VMC 305___	.98	>23	<.06	<.4	1	32	42	4	24	57	Hematitic sandstone; sp gr, 3.13.
VMC 403___	1	>23	<.06	<.4	5	92	110	17	47	83	Composite, float, hematitic sandstone; sp gr, 3.16.
VMC 406___	.69	15	<.06	<.4	2	81	59	9	18	<14	Hematitic sandstone; sp gr, 2.63.
VMC 412___	.91	21	<.06	<.4	3	85	92	13	14	80	Hematitic sandstone, 2-3 m below top of formation.

TABLE 2.–*Analyses of iron- and manganese-rich rock samples from the Mill Creek, Peters Mountain, and Mountain Lake Wilderness Study Areas, collected by the U.S. Geological Survey*–Continued

Sample	Percent			Parts per million							Sample description
	Al	Fe	P	Ag	Co	Cu	Mn	Ni	Pb	Zn	
Rose Hill Formation–Continued											
VPM 002	.78	23	<.06	<.4	<1	<1	120	9	14	20	Hematitic sandstone; sp gr, 2.9.
VPM 007	1.3	15 [10.0]	.31	<.4	3	<1	270	11	14	21	Chip sample, 60 cm, hematitic sandstone, lower part of formation; sp gr, 2.85.
VPM 011	2.2	>23 [20.3]	.57	<.4	4	<1	130	16	20	53	Chip sample, 30 cm, hematitic sandstone, lower part of formation; sp gr, 3.02.
VPM 012	.69	>23 [18.4]	.57	<.4	1	<1	89	6	15	24	Chip sample, 60 cm, hematitic sandstone; sp gr, 2.85.
VPM 016	1.3	19	.40	<.4	4	<1	110	14	14	20	Hematitic sandstone; sp gr, 2.91.
VPM 017	.83	>23	<.06	<.4	1	<1	73	8	18	42	Chip sample, 1 m, hematitic sandstone; sp gr, 2.94.
VPM 019	1.3	25	.54	<.4	3	<1	260	16	19	39	Chip sample, hematitic sandstone near base of formation; sp gr, 2.93.
VPM 022	1.2	>23	.48	<.4	4	6	150	22	17	48	Chip sample, 60 cm, hematitic sandstone; sp gr, 2.9.
VPM 030	.61	20	<.06	<.4	<1	<1	38	5	13	24	Chip sample, 60 cm, hematitic sandstone; sp gr, 2.96.
VPM 104	.98	16	<.06	<.4	2	<1	130	10	16	29	Chip sample, 3 m, hematitic sandstone; sp gr, 2.79.
VPM 116	1.2	>23 [23.3]	<.06	<.4	1	<1	110	9	19	55	Chip sample, 2 m, hematitic sandstone; sp gr, 2.94.
VPM 124	.87	18 [15.7]	<.06	<.4	1	<1	61	9	<6	76	Chip sample, 2 m, hematitic sandstone; sp gr, 2.99.
VPM 125	1.6	25 [18.4]	.49	<.4	2	<1	410	9	22	42	Chip sample, 1 m, hematitic sandstone; sp gr, 2.96.
VPM 215	1.7	18	<.06	<.4	3	<1	110	14	14	31	Chip sample, 3 m, hematitic sandstone; sp gr, 2.87.

VPM 217___	2.0	23	.63	<.4	4	<1	320	11	18	37	Grab sample, hematitic sandstone; sp gr, 2.93.
VPM 220___	1.2	18	.37	<.4	6	<1	130	26	12	30	Chip sample, 7 m, hematitic sandstone; sp gr, 2.89.
VPM 400___	.73	20	<.06	<.4	2	7	100	6	15	74	Hematitic sandstone; sp gr, 2.95.
VPM 401___	.94	14	.33	<.4	3	1	81	51	12	<14	Hematitic sandstone; sp gr, 2.89.
VPM 404___	2.1	16	<.06	<.4	3	3	75	18	11	33	Hematitic sandstone; sp gr, 2.84.
VPM 412___	1.3	25	<.06	<.4	5	1	84	20	16	44	Hematitic sandstone; sp gr, 2.90.
VPM 423___	1.3	>23	<.06	<.4	4	<1	370	14	15	94	Composite, float, hematitic sandstone; sp gr, 2.87.
VML 013___	1.1	>23 [29.7]	<.06	<.4	2	1	140	15	23	130	Chip sample, 1.5 m, hematitic sandstone; sp gr, 3.07.
VML 017___	3	18	<.06	<.4	8	<1	220	28	15	37	Chip sample, 60 cm, hematitic sandstone; sp gr, 2.88.
VML 019___	1.4	23	.67	<.4	1	<1	140	9	20	86	Hematitic sandstone.
VML 100___	1.1	16 [11.9]	<.06	<.4	1	3	160	10	12	18	Chip sample, 2 m, hematitic sandstone; sp gr, 2.87.
VML 102___	1	20	<.06	<.4	3	<1	120	10	16	33	Chip sample, 1 m, hematitic sandstone; sp gr, 2.85.
VML 109___	.9	>23	<.06	<.4	2	6	85	13	18	100	Chip sample, 1 m, hematitic sandstone; sp gr, 3.04.
VML 115___	.77	25 [19.8]	.48	<.4	1	2	57	9	16	46	Chip sample, 2 m, hematitic sandstone; sp gr, 3.12.
VML 126___	.68	>23	.51	<.4	3	<1	100	25	16	74	Chip sample, 1 m, hematitic sandstone; sp gr, 3.07.
VML 135___	.89	>23	.61	<.4	9	2	260	25	21	120	Chip sample, 2 m, hematitic sandstone; sp gr, 3.12.
VML 145___	.83	>23	<.06	<.4	4	1	320	13	26	49	Chip sample, 1 m, hematitic sandstone; sp gr, 3.07.
VML 149___	1.6	25 [22.4]	<.06	<.4	5	47	540	18	35	88	Chip sample, 2 m, hematitic sandstone; sp gr, 3.02.
VML 210___	1	>23	.57	.5	2	7	87	8	20	60	Hematitic sandstone; sp gr, 3.02.

TABLE 2.—*Analyses of iron- and manganese-rich rock samples from the Mill Creek, Peters Mountain, and Mountain Lake Wilderness Study Areas, collected by the U.S. Geological Survey*—Continued

Sample	Percent			Parts per million							Sample description
	Al	Fe	P	Ag	Co	Cu	Mn	Ni	Pb	Zn	
					Rose Hill Formation—Continued						
VML 222	1.4	16	<.06	<.4	1	<1	83	3	9	<14	Hematitic sandstone; sp gr, 2.75.
VML 302	1.1	>23	.62	.9	2	9	100	14	650	1,000	Hematitic sandstone, near base of formation.
VML 312	1.5	>23	<.06	<.4	4	27	82	14	20	69	Do.
VML 401	1.1	>23	<.06	<.4	1	6	100	6	29	44	Hematitic sandstone; sp gr, 3.01.
VML 402	.86	>23	.97	<.4	3	16	230	21	13	130	Limonitic and hematitic sandstone; sp gr, 3.32.
VML 405	3.2	>23	<.06	<.4	3	4	330	13	15	68	Hematitic sandstone, near base of formation; sp gr, 3.09.
VML 414	1	25	.46	<.4	2	4	93	19	33	53	Hematitic sandstone; sp gr, 2.88.
VML 417	.85	10	.14	<.4	<1	1	100	2	<6	<14	Hematitic sandstone; sp gr, 2.7B.
VML 423	1.2	>23	<.06	<.4	5	10	1,000	15	26	130	Hematitic sandstone.
VML 440	1.5	>23	.62	<.4	3	1	680	10	39	68	Do.
VML 444	1.2	>23	<.06	<.4	4	3	610	10	28	120	Do.
VML 452	.43	21	<.06	<.4	1	51	81	6	14	81	Do.
VML 502	1.2	26	.45	<.4	2	6	99	9	18	93	Chip sample, 1 m, hematitic sandstone; sp gr, 3.02.
					Keefer Sandstone						
VMC 112	0.63	18	0.68	<0.4	7	130	600	37	110	100	Chip sample, 1.5 m, limonite-cemented brecciated sandstone.
VPM 205	1	23	.7	<.4	35	101	2,300	110	130	1,500	Composite sample, iron-cemented sandstone from dump.

VML 009____	2.4	>23	<.06	.8	1	48	160	9	>1,000	190	Bedded(?) limonite.
VML 010____	.86	5	<.06	1	22	2	16,000	22	10	58	Iron- and manganese-cemented sandstone.
VML 424____	.24	7	.2	<.4	11	34	910	30	53	140	Brecciated sandstone.
VML 425____	1.4	1	.12	4.8	780	150	49,000	360	210	1,700	Iron- and manganese-cemented sandstone.
Tonoloway Limestone (?)											
VPM 111____	0.96	>23	0.69	<0.4	18	41	1,700	170	42	1,300	Limonite replacing thin-bedded limestone.
Rocky Gap Sandstone of Swartz (1929)											
VMC 001____	0.77	>23	<0.06	<0.4	8	14	100	120	423	450	Chip sample, 5 m, iron-rich sandstone, upper part of formation.
VMC 002____	.79	20	<.06	<.4	6	14	100	65	32	410	Chip sample, 5 m, iron-rich sandstone, lower part of formation; sp gr, 2.60.
VMC 100____	1.6	>23	<.06	<.4	14	51	300	86	110	450	Chip sample, 5 m, iron-rich sandstone.
VMC 119____	.22	>23	<.06	<.4	<1	53	88	10	35	190	Chip sample, 1.5 m, iron-cemented sandstone; sp gr, 2.81.
VMC 200____	1.2	>23	<.06	<.4	10	100	<68	100	85	460	Iron-cemented sandstone.
VMC 300____	2.4	>23	<.06	<.4	94	250	320	120	130	590	Do.
VMC 301____	.93	>23	<.06	.5	34	80	200	150	51	580	Chip sample, 2.5 m, iron-cemented sandstone; sp gr, 2.71
VMC 312____	1.8	>23	.9	.8	8	31	210	36	440	140	Iron-cemented sandstone.
VMC 400____	1.7	>23	<.06	<.4	21	50	300	78	58	420	Iron-cemented friable sandstone.

TABLE 2.—*Analyses of iron- and manganese-rich rock samples from the Mill Creek, Peters Mountain, and Mountain Lake Wilderness Study Areas, collected by the U.S. Geological Survey*—Continued

Sample	Percent			Parts per million							Sample description
	Al	Fe	P	Ag	Co	Cu	Mn	Ni	Pb	Zn	
Rocky Gap Sandstone of Swartz (1929)—Continued											
VMC 401	.95	>23	<.06	.6	2	9	52	22	45	280	Iron-cemented friable sandstone.
VPM 003	.92	>23	1.2	<.4	41	87	580	320	30	2,000	Do.
VPM 004	.19	>23	.5	.8	23	17	4,100	68	20	280	Do.
VPM 028	.7	25	.7	<.4	23	51	150	180	18	1,100	Iron-cemented friable sandstone; sp gr, 2.60.
VPM 033	.93	>23	.7	<.4	1	46	47	22	20	210	Chip sample, 2 m iron-cemented sandstone.
VPM 109	.68	21	<.06	<.4	1	47	100	26	34	250	Chip sample, 7 m, iron-cemented sandstone.
VPM 127	.72	13	<.06	<.4	1	25	300	12	21	110	Chip sample, 1 m, iron-cemented friable sandstone.
VPM 203	.39	17	<.06	<.4	1	24	240	15	11	260	Chip sample, 4 m, iron-cemented sandstone.
VPM 204	.51	>23	<.06	.4	6	24	120	97	33	1,100	Chip sample, iron-cemented sandstone.

VML 107	.24	>23	<.06	.5	15	10	190	360	21	890	Chip sample, 2 m, iron-cemented sandstone.
VML 112	.32	>23	.86	<.4	40	36	1,800	350	33	930	Do.
VML 132	.58	13	.41	<.4	30	59	210	250	14	870	Chip sample, 1 m, iron-cemented sandstone.
VML 234	.5	10	.44	<.4	<1	18	120	2	14	250	Iron-cemented sandstone.
VML 301	.24	16	1.1	<.4	12	11	1,600	72	21	910	Iron-cemented sandstone; sp gr, 2.68.
VML 409	.66	20	<.06	2.5	35	32	30,000	14	110	700	Iron-cemented friable sandstone.
VML 426	1.5	2	.13	4.3	870	130	160,000	420	1,000	4,600	Manganese-cemented sandstone.
VML 428	.34	23	.67	<.4	9	33	320	100	92	880	Iron-cemented sandstone.
VML 429	.74	>23	1.3	<.4	18	30	470	240	85	2,500	Limonite-cemented brecciated sandstone.
VML 450	1.4	>23	1	<.4	12	73	430	70	62	1,600	Iron-cemented sandstone.
VML 453	.50	20	.7	<.4	17	96	170	160	310	1,800	Do.
Huntersville Chert of Price (1929)											
VPM 110	1.4	18	0.4	<0.4	4	51	180	34	75	295	Iron-cemented brecciated chert.
VPM 126	.3	13	.3	<.4	9	82	290	83	27	630	Chip sample, 60 cm, iron-cemented brecciated chert.

conglomerate is present locally. The hematitic sandstone commonly contains clay galls or elliptical chips of pale-red shale. Most of the sandstone is thinly crossbedded; some is ripple marked. The sandstone is well exposed, but interlayered shale is poorly exposed. The shale in intervening areas is covered by abundant flat slabby cobbles and boulders of sandstone (fig. 14).

In the Mill Creek area, at least two zones of thick hematitic sandstone were indicated by drilling, and Whitman (1964, p. 44) recognized four zones in his mapping. Correlation of individual zones between drill holes is uncertain, probably because the hematitic sandstone beds are lenticular and randomly spaced in the formation. The amount of sandstone probably ranges from about one-fourth to one-third of the formation, but it appears to be greater because of the large quantities of sandstone debris that cover the less resistant shale.

The hematitic sandstone is dense, heavy, and well cemented. The specific gravity of collected samples ranges from 2.63 to 3.32 and averages 2.94. The specific gravity of nonhematitic sandstone ranges from 1.65 to 2.63 and should average about 2.50. The median value for the iron content in 68 samples of hematitic sandstone is greater than 23 percent (table 1). Some of these iron-rich sandstones also contain more copper, lead, and zinc than does average sandstone (tables 1, 2), but these amounts are not important economically. In addition to these elements, amounts of cerium, niobium, strontium, thorium, and zirconium are also slightly greater than the average for sandstone (table 1).

Whitman (1964, p. 88–91) reported the thickness of the Rose Hill Formation in the Mill Creek area to be 79–82 m, but drilling by Minerals Development Corp., Roanoke, Va., in that area did not reveal more than 45 m of the Rose Hill. Butts (1940, p. 242) reported 48 m at the Narrows, but Chauvin (1957, p. 17–18) measured 57 m along U.S. Highway 460 at the Narrows, perhaps along a newer roadcut than the exposure Butts measured. Fish (1967, p. 7) reported that the thickness on Butt Mountain ranges from 45 to 60 m, which agrees with Eckroade's estimates of 48 m on Johns Creek Mountain and 63 m on White Rock Mountain (1962, p. 15).

The Rose Hill is overlain conformably by the Keefer Sandstone. The contact is sharp and generally easily mappable.

KEEFER SANDSTONE

The Keefer Sandstone is a ridge-making white quartzite similar to the Tuscarora but not as coarse grained. The lower part of the formation is moderately well exposed in the three study areas. It generally forms knobs and spurs that are slightly lower than those formed by the Tuscarora.

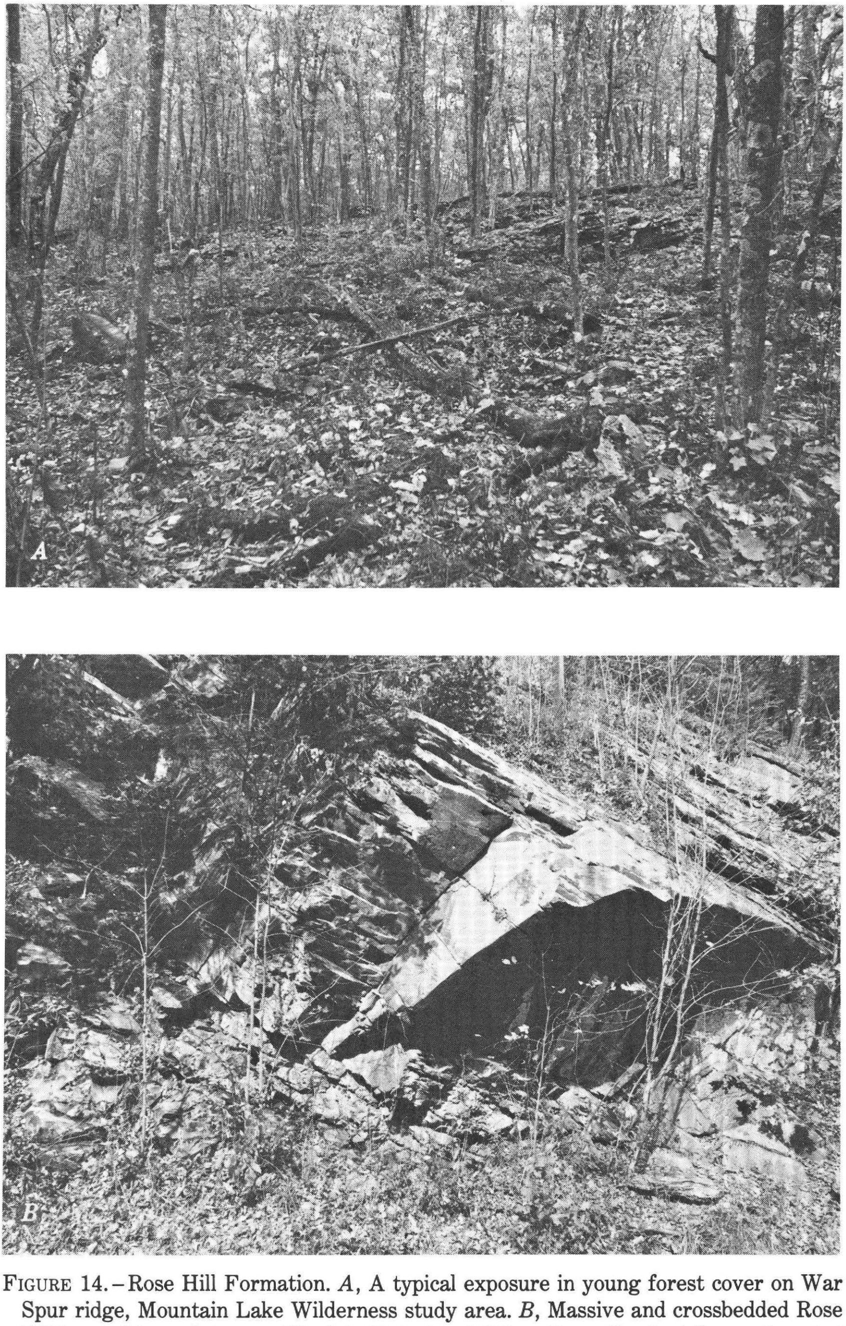

FIGURE 14.–Rose Hill Formation. *A*, A typical exposure in young forest cover on War Spur ridge, Mountain Lake Wilderness study area. *B*, Massive and crossbedded Rose Hill hematitic sandstone on Virginia State Road 635 up Stony Creek at the south end of Peters Mountain Wilderness Study Area.

The Keefer Sandstone was named by Stose and Swartz (1912, p. 5) for exposures on Keefer Mountain in Maryland. What has been generally called Keefer Sandstone in this part of Virginia (Butts, 1940, p. 245–247; Lesure, 1957, p. 37–39; Spencer, 1970, p. 71–73) is much thicker and may include beds both older and younger than the Keefer type section (Woodward, 1941, p. 94–95; Cooper, 1944a, p. 119; Folk, 1960, p. 45). For this and other reasons, some recent workers prefer to use the term "Keefer" Sandstone to indicate the difference between type Keefer and this expanded unit (Dennison, 1970, p. 9; Diecchio, 1973, p. 16–17). In this report we will continue to use the term Keefer, without quotation marks, for the expanded unit.

Much of the lower part of the Keefer Sandstone is a white, fine- to medium-grained quartzite. Weathered surfaces may be stained red, brown, or black by iron oxides. Unweathered Keefer exposed in a recent roadcut along U.S. Highway 460 at Gap Mountain contains disseminated grains of pyrite, and some of the iron stain on weathered Keefer may be caused by oxidation of pyrite. Bedding in the formation ranges from thin, 1–3 cm, to massive, 0.5–1 m. Crossbedding is common. *Scolithus* tubes, thin vertical markings in sandstone that apparently represent animal burrows, are common locally.

The quartzitic sandstone of the lower part of the Keefer Sandstone grades upward into friable, white to light-tan or orange sandstone that is poorly exposed. This rock may have had a carbonate cement when fresh, but weathered outcrops now contain varying amounts of iron oxides. This poorly exposed part of what we mapped as Keefer may correlate with formations generally younger than type Keefer, such as the Williamsport Sandstone or the Wills Creek Shale.

The Keefer Sandstone is 30–33 m thick in the Mill Creek area (Whitman, 1964, p. 48), 47 m along U.S. Highway 460 at the Narrows (Butts, 1940, p. 239), and about 45 m thick in the Peters Mountain and Mountain Lake areas (Eckroade, 1962, p. 17).

The Keefer is overlain in the Mill Creek area by the Rocky Gap Sandstone of Swartz (1929). In the Peters Mountain and Mountain Lake areas, the Keefer is apparently overlain by the Tonoloway Limestone, which is not exposed. The covered interval between the well-exposed uppermost quartzite layers of the Keefer and Swartz's Rocky Gap Sandstone include an unknown thickness of friable sandstones of the upper part of the Keefer and probably 15–20 m of Tonoloway Limestone. The contact shown on the geologic maps has been drawn at the base of recognizable Rocky Gap.

The ranges in trace-element content in 51 samples of Keefer Sandstone are given in table 1. One sample from Mill Creek (VMC 112), one from Peters Mountain (VPM 205), and three from Mountain Lake (VML 009, 010, 424) contain large amounts of iron (table 2). These samples are from brecciated sandstone cemented by secondary iron oxides and do not represent significant potential sources of iron.

TONOLOWAY LIMESTONE

The Tonoloway Limestone is a thin-layered gray shaly limestone named for exposures on Tonoloway Ridge in western Maryland (Ulrich, 1911, pl. 28; Stose and Swartz, 1912, p. 7). The only exposures of the Tonoloway near the areas studied are those along Stony Creek north of Interior and outside the Peters Mountain study area. Eckroade (1962, p. 19) measured 23 m of the Tonoloway along Stony Creek and estimated a thickness of 15 m elsewhere in the vicinity of Peters Mountain and Mountain Lake areas.

The Tonoloway was not mapped separately because it is not exposed. We have no firm evidence that Tonoloway is present in the Mill Creek area. It may have been removed by erosion before deposition of Swartz's Rocky Gap (Lower Devonian). One sample of banded limonite from the Peters Mountain area (table 2) may represent thin-layered Tonoloway Limestone replaced by iron oxides.

DEVONIAN SYSTEM

ROCKY GAP SANDSTONE OF SWARTZ (1929)

The three study areas contain a few isolated exposures of an iron-stained and locally iron-cemented coarse, friable sandstone that is correlated with the Lower Devonian Rocky Gap Sandstone of Swartz (1929, p. 83–84). The type locality of this formation is 3 km east of Rocky Gap in Bland County, Va., about 24 km southwest of Narrows.

The formation is a friable to well-cemented, medium- to coarse-grained quartz sandstone. Iron oxides and hydroxides are the principal cement in outcrop, but calcium carbonate is probably the principal cement where the rock is not weathered. Impressions of various marine fossils, including crinoids and brachiopods, are common. The sandstone is about 15 m thick in the Mill Creek area (Whitman, 1964, p. 49) and 18-25 m thick in the Peters Mountain and Mountain Lake areas (Eckroade, 1962, p. 21).

In Mill Creek, the Rocky Gap is exposed in two old iron-manganese workings along the west edge of the study area and one small isolated outcrop 1.5 km to the east. In Peters Mountain, the sandstone is exposed on two small knobs at the west end of the area and more extensively at the east end of Huckleberry Ridge and on the small knobs along the lower part of Dismal Branch. The iron workings west of Dismal Branch are partly in the Rocky Gap but mostly in the interval normally occupied by the Tonoloway Limestone and the upper part of the Keefer Sandstone. In Mountain Lake area, the Rocky Gap is poorly exposed along the base of Potts, Salt Pond, and Johns Creek Mountains. The sandstone forms small triangular knobs, sometimes called flat irons, along the lower flanks of the high ridges.

Trace-element contents of 31 samples of weathered Rocky Gap Sandstone are summarized in table 1. Selected elements for the more iron-rich samples are given in table 2. The high values for zinc in many of the iron-rich samples may be typical for this type of iron deposit. Zinc has been reported as a minor constituent of similar supergene iron ores found in the Lower Devonian at the Longdale Mine, Alleghany County, Va., about 88 km northeast of the study areas (Firmstone, 1879, p. 93–99). The zinc may have accumulated with iron and manganese during weathering or may be an original part of the calcareous sandstone. The overlying black shale contains minor concentrations of zinc in calcareous concretions that would supply the metal to ground solutions during weathering. Fresh calcareous sandstones of the Lower Devonian that crop out about 5 km east-northeast of White Sulphur Springs, Greenbrier County, W. Va., 48 km northeast of Peters Mountain study area, contain as much as several percent zinc locally. These sandstones are similar to the Rocky Gap Sandstone and may be partly correlative.

An unconformity separates the Rocky Gap from the underlying Middle and Upper Silurian formations. The exact correlation of the Rocky Gap with a more complete section of Lower Devonian rocks exposed near Clifton Forge, Va., is not known. The Rocky Gap Sandstone is overlain by the Huntersville Chert of Price (1929, p. 236), which is also considered to be Early Devonian in age.

HUNTERSVILLE CHERT OF PRICE (1929)

In the Mill Creek and Peters Mountain areas, many of the small outcrops of Rocky Gap Sandstone are covered with fragments of white chert that may be the Huntersville Chert, named by Price (1929, p. 236) from exposures near Huntersville, Pocahontas County, W. Va. No more than a few meters of chert are preserved in these areas, and no chert beds in place were found. Eckroade (1962, p. 21) estimated an average thickness of 20 m for the formation along Peters Mountain north of Interior. Some chert was also seen in the soil above Rocky Gap exposures in Johns Creek valley, but no thicknesses could be measured. The impression from reconnaissance mapping in that area was one of very little chert; the overlying black Millboro Shale appears nearly in contact with the Rocky Gap Sandstone.

Only three samples of weathered Huntersville Chert were analyzed. All contain more zinc and iron than does average sedimentary rock. The iron is probably the result of supergene processes, and the zinc may be, too.

The Huntersville Chert is overlain by the Millboro Shale (Middle and Upper Devonian).

MILLBORO SHALE

In Johns Creek valley and the valley of Crosier Branch north of Potts Mountain, the Huntersville Chert and Rocky Gap Sandstone are overlain by a thick mass of dark-gray to black shale. This rock was named Millboro Shale by Butts (1940, p. 308) for exposures near Millboro Springs, Bath County, Va., more than 105 km northeast of Mountain Lake area. The shale is well exposed in several small roadside quarries west of Waiteville in the valley of South Fork of Potts Creek (pl. 4). Locally, it contains abundant fine-grained pyrite crystals. In the study area, the shale occurs as black to cream-colored chips in the soil and is exposed in a few outcrops along small streams. No section of the Millboro was measured in the vicinity of the study areas, but the formation may be several hundred meters thick. The black shale grades upward into the dark-gray to greenish-gray shale and sandstone of the overlying Brallier Shale. This contact is not well exposed, and we made no attempt to map it during our reconnaissance.

BRALLIER SHALE

The youngest rocks in any of the study areas are a thick series of dark shale and very fine grained sandstone poorly exposed along steep slopes and small streams in Johns Creek valley. These rocks are correlated with the Brallier Shale of Late Devonian age. Butts (1918, p. 523–524) named the formation for exposures near Brallier Station, Bedford County, Pa., and traced it the full length of the Valley and Ridge province in Virginia (1940, p. 318).

Butts reported a thickness of more than 900 m on Brushy Mountain in Bland County, Va., southwest of the Mountain Lake study area (1940, p. 318). In the study area, where the top of the formation is not present, the Brallier Shale may be as thick as 100 m. Many of the small hills in the Johns Creek valley are capped with colluvial-alluvial gravels, but the slopes are covered with shale chips of the Brallier.

QUATERNARY SYSTEM

QUATERNARY DEPOSITS

Many of the streams in the study areas have minor deposits of alluvium along their lower reaches, and some have extensive boulder fields of colluvium-alluvium in the upper reaches. Some of these areas are large enough to map in Peters Mountain and Mountain Lake areas. A continuous sheet of colluvial gravel conceals bedrock in the upper part of Johns Creek, mainly along the lower slope of Salt Pond Mountain (pl. 4). This gravel is thin and probably does not average more than 1 or 2 m in thickness. Boulders of Tuscarora Quartzite and hematitic sandstone of the Rose Hill Formation are the most common ingredients. Just east of Saltpeter Branch on the side of War Spur ridge is an area of jumbled blocks and boulders that may be a large landslide mass. Smaller areas of talus are common near cliffs of Tuscarora and Keefer but were not mapped.

STRUCTURE

Structurally, the three areas are part of the folded Appalachians. They lie along major folds that extend for tens of kilometers along the regional northeast strike (pl. 1).

Mill Creek is part of a relatively simple syncline, the Pearisburg or Butt Mountain Syncline, which extends from Salt Pond Mountain in the Mountain Lake area to and beyond Tazewell, about 74 km southwest of Pearisburg. The formations dip 5°–30° toward the axis of the syncline, which is along Mill Creek and Mercy Branch. The axis apparently plunges gently to the southwest.

Peters Mountain is the southeast limb of a large anticline that has been cut by the St. Clair Fault to the west. The southeast-dipping limb is also cut by three smaller thrust faults and contains several minor anticlines and synclines. Axes of all the minor folds trend northeast; they plunge gently southwest in the western part of the area and northeast in the eastern part.

The Mountain Lake area contains several northeast-plunging folds cut by at least five thrust faults. At the southern end of the area, the valley of Johns Creek is a large northeast-plunging syncline that continues for at least 48 km to the northeast beyond the study area. Flanking this syncline to the north is the Salt Pond or Bane Anticline, which extends 24 km or more southwest of the area. This anticline is cut off by the thrust fault along War Spur Branch. A smaller anticline north of War Spur dies out in the flank of a larger fold that is in turn cut off by the thrust fault on the flank of Potts Mountain. Another large fold along White Rocks Creek splits into several minor northeast-plunging folds between Potts Mountain and Little Mountain. These folds are asymmetric and have gently dipping southeast limbs and steep or overturned northwest limbs.

The structure of all three areas is related to the late Paleozoic deformation of the Appalachian region and is a product of lateral compression. The small thrust faults in the Peters Mountain and Mountain Lake areas probably merge into the St. Clair and Narrows Faults at depth. Total amount of horizontal movement produced by folding and faulting is unknown, but according to the cross-sectional model on plate 1, the horizontal movement must have been more than 30 km.

GEOCHEMICAL SURVEY

A reconnaissance geochemical survey was made of each area to test for indistinct or unexposed mineral deposits that might be recognized by their geochemical halos. Similar geochemical surveys based on trace-element analyses have been credited with the discovery of many types of mineral deposits (Hawkes and Webb, 1962). No metallic mineral deposits other than iron and manganese are known in the sequence of rocks exposed in the three study areas, and no evidence of any other deposit was found in the geochemical studies, which included analyses of stream-sediment, rock, and soil samples.

Most of the small drainage basins in each study area and many of those adjacent to the areas were sampled by collecting a few handfuls of the finest sediment available. After drying in the laboratory, the samples were sieved, and the minus 80-mesh fraction was used for analyses.

The rock samples consist of a few small chips taken from beds of one lithology and known thickness. The samples are representative of the major rock types exposed in the study areas. The Juniata and Rose Hill Formations contain interbedded shales that are not well exposed and were not sampled. The Tonoloway Limestone also was not sampled because of a lack of exposures. The hematitic sandstones of the Rose Hill Formation, the limonitic sandstones of the Rocky Gap and Keefer Sandstones, and a few manganese-cemented sandstones in the Tuscarora Quartzite represent subeconomic resources of iron and manganese (table 2). No other obviously mineralized rock was found. The soil samples, from five areas in Mountain Lake and from one area in Peters Mountain, are from the A_2 or upper B soil zones, just below the dark organically rich surface soil or A_1 zone.

All stream-sediment and rock samples were scanned spectrographically for 64 elements and were analyzed chemically for gold in the USGS laboratories at Reston, Va. Soil samples were scanned spectrographically for 30 elements and were analyzed chemically for zinc in the USGS laboratories at Denver, Colo. The complete analytical data are given in Mei and Lesure (1978), Mei and others (1978), Rait and Lesure (1978), and Motooka and others (1978).

RESULTS

The analytical data indicate areas rich in iron and manganese; they do not indicate any other well-defined anomalous areas obviously related to mineralized rock. Some of the rock samples rich in iron or manganese tend to contain more barium, cobalt, copper, nickel, silver, and zinc (table 2); however, these are common geochemical associations formed during weathering and do not suggest the presence of economically valuable deposits of these elements in clastic sedimentary rocks. Histograms showing the distribution of zinc in stream sediments in each area (pl. 5) suggest a bimodal distribution. Other elements for which tests were made seem to have a normal or background distribution in the stream sediments.

In the Mill Creek area, the streams containing 70 ppm (parts per million) zinc or more are all outside the study area (pl. 5). These streams drain areas underlain mostly by Ordovician carbonate rocks that are not found within the study area. Such limestone and dolomite commonly contain traces of zinc.

In Peters Mountain, most of the streams containing 70 ppm or more zinc are clustered at the east end of the study area (pl. 5). The stream containing 700 ppm zinc (VPM 207) drains an area that includes the Interior iron mine. Sediment in this stream is heavily contaminated with fines from iron-ore mining. The limonite from the Interior Mine contains as much as 1,500 ppm zinc; hence, the high-zinc content of the stream-sediment sample is explained. Three other streams in the Peters Mountain area that have sediment containing 100 ppm zinc also drain areas having limonite-cemented Rocky Gap Sandstone.

In the Mountain Lake area, most of the stream sediments containing 100 ppm or more zinc are in Johns Creek valley. These streams drain areas that have outcrops of limonite-cemented sandstone (pl. 5).

In order to evaluate further the stream-sediment data, we collected soil samples in six areas that have drainage basins containing anomalous zinc. Forty of the soil samples are from areas underlain by Keefer Sandstone, 29 are from areas underlain by Rocky Gap Sandstone or Huntersville Chert, and 26 are from areas underlain by Millboro Shale. A summary of the range and median values for 24 elements in the soils shows no uncommon values for most elements (table 1). The median value of zinc in soil from Peters Mountain area is 50 ppm, and that from Mountain Lake is 30 ppm.

Only a few soils from each lithologic unit contain 100 ppm or more zinc. These samples are generally from areas near exposures of limonite-cemented Rocky Gap or Keefer Sandstone.

A few soil samples from areas underlain by Rocky Gap Sandstone or Huntersville Chert contain more barium than does soil derived from the other formations. The nearby limonite deposits also tend to have more barium than does unaltered sandstone.

The large zinc and barium contents of only a few soil samples do not appear to have any economic significance. Both elements are present in normal amounts in unweathered parts of these formations nearby and were probably concentrated locally during the deep weathering that produced the small deposits of limonite.

MINERAL RESOURCES

Mineral resources of the three study areas include both metallic and nonmetallic materials. Iron and manganese are the only identified metallic resources of any importance in the region; the three areas contain large submarginal resources of iron but only insignificant resources of manganese. Limestone, silica sandstone, shale, dimension stone, common building stone, and sand and gravel are the nonmetallic resources. With the exception of the limestone, they are not considered to be important economically. Limestone and dolomite are currently being produced from large quarries and underground workings outside the three study areas.

MINES AND PROSPECTS

Prospecting for iron and manganese was intense throughout the entire region in the late 19th and early 20th centuries (pl. 1). Mill Creek area has one small abandoned iron mine, the Chestnut Flat Mine, and a small unnamed iron prospect. The entire study area was included in three Bureau of Land Management drilling permits, BLM–A–050368, 051840, and 051841, issued in 1961 to the Minerals Development Corp., Roanoke, Va., for the exploration of iron deposits. Mountain Lake area has a small manganese prospect, the Denison(?), and several unnamed iron prospects. Peters Mountain has one abandoned iron mine, the Interior Mine, and one manganese prospect, the Simpkins. All these mine and prospect workings have been overgrown by vegetation for many years.

IRON RESOURCES

Two types of submarginal iron resources are present in the three study areas. The most extensive and most important as a resource are hematitic sandstone beds of the Rose Hill Formation. Of less importance are the limonite deposits, or brown ores, found in the Rocky Gap Sandstone and locally in the underlying Tonoloway Limestone and Keefer Sandstone.

HEMATITE DEPOSITS

Deposits of hematite, an iron oxide mineral (Fe_2O_3) are widely distributed in sedimentary rocks of Silurian age from central New York to Alabama. They have been called Clinton iron ores or Clinton-type ores after typical exposures near Clinton, Oneida County, N.Y. These deposits were mined extensively near Birmingham, Ala., and to a lesser extent in Georgia, Tennessee, and New York. Small amounts were also mined in Pennsylvania, Maryland, Virginia, and West Virginia (Wright and others, 1968, p. 409).

The hematite in the Clinton-type iron ores is generally in three forms: (1) as flattened flaxseedlike particles, called oolites; (2) as replacements of fossil remains that preserve the shape of the original calcareous shells; and (3) as cementing material surrounding original sand grains, oolites, and fossils (Wright and others, 1968, p. 407). The principal ores are thus either oolitic or fossil, and some are combinations of the two types.

The unweathered ore is hard and calcareous; the weathered ore is soft and less calcareous. Iron content of the hard ore ranges from 20 to 47 percent, and calcium carbonate content, from 10 to 50 percent. In the soft or leached ore, iron content ranges from 40 to 60 percent, and calcium carbonate is generally less than 1 percent (Whitlow, 1962). The ore-grade material is commonly enclosed in or grades into hematitic sandstone or shale. Hematitic sandstone associated with the oolitic and fossil ores of the Birmingham, Ala., district contains 15–30 percent iron and less than 10 percent calcium carbonate (Crane, 1926, p. 31).

The Clinton-type iron ores and associated hematitic sandstone are a primary type of iron deposit. The iron was precipitated from sea water and concentrated as the sediments were deposited. In the Birmingham area, the oolitic and fossil ores were probably deposited as lagoonal sediments, and the hematitic sandstone, as a barrier island (Sheldon, 1970, p. 110). In the Giles County, Va., area the Rose Hill Formation was also probably deposited in a shallow-marine environment (Diecchio, 1973, p. 57–62). The mineral hematite formed in the sediments during compaction and lithification of the rocks. The primary deposition of the iron as a component of the sediments is of significance because it suggests that the iron content of an ore bed or hematitic sandstone bed will be fairly consistent throughout the bed and will persist to depth.

Oolitic and fossil ore beds have been found in the Rose Hill Formation in Lee and Wise Counties in the far southwestern part of Virginia and near Iron Gate and Low Moor in Alleghany County, about 65 km northeast of Giles County (Gooch, 1954, p. 4; Lesure, 1957, p. 121). These ore beds were never important economically. The fossil ore beds near Low Moor and Iron Gate are generally less than 0.5 m thick (Harder, 1909, p. 230); ore beds in the Birmingham, Ala., district are 2–7 m thick. Grimsley (1909, p. 260–268) reported Clinton-type ore on Potts, Little or Middle, and Peters Mountains in Monroe County, W. Va.

No oolitic or fossil ore beds were found in the Rose Hill Formation in the three study areas, but hematitic sandstones similar to those associated with the ore beds in Alabama are common. These sandstones are not of sufficient grade to be currently considered hematitic iron ore; however, they commonly contain 15–30 percent iron and represent a significant identified conditional or submarginal iron resource.[3]

RECENT EXPLORATION

Drilling permits were granted in 1961 by the Bureau of Land Management to the Minerals Development Corp., Roanoke, Va., to explore, by drilling, a deposit believed at that time to contain more than 272 million metric tons of hematitic sandstone that can be quarried in the Rose Hill Formation on Pearis and Wolf Creek Mountains. During the 1-year program, 10 holes totaling 348.4 m were drilled within the Mill Creek study-area boundary (pl. 2). Drill cores were logged by the company, and chemical analyses of iron and phosphate were made on 62 samples by commercial assayers (table 3).

The results were interpreted by the company to indicate essentially two hematitic sandstone zones. Any correlation of sandstone units between drill holes is, however, only approximate because of the lack of a good key horizon cut by all holes. On the basis of his field mapping in the Mill Creek area, Whitman (1964, p. 43–46) described four hematitic sandstone zones. The lowest is near the bottom of the formation and is about 9 m thick; the second is 27–33 m above the base of the formation and is 2–3 m thick; the third is 36–45 m above the base of the formation and is 12 m thick; the fourth is near the top of the formation and is only 1.2 m thick. Outcrops in the area are not continuous enough to permit mapping of these zones in detail. Our samples come from a zone near the top, one or more zones within the formation, and a zone near the bottom. Most probably, the hematitic sandstone zones are only approximately correlative from area to area. The sandstones are probably overlapping lenses that represent a shifting back and forth of a depositional environment in a relatively shallow sea.

In conjunction with the core drilling, the Minerals Development Corp. mined "two bulk samples weighing 9 short tons" (8.2 t) from the Rose Hill Formation on Mercy Branch for metallurgical testing. The prospect site was not positively identified in field investigations conducted for this report. Test results from these samples, together with data obtained from the drilling program, were the basis for estimating the average iron content of the hematitic sandstone to be between 22 and 23 percent. Exploration in this area, however, was terminated because the formation contained a much greater proportion of shale waste material than had been expected.

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[3] Identified resources are specific bodies of mineral-bearing rock whose existence and location are known. Their extent and grade may or may not be evaluated. Conditional resources are that part of the identified resources not profitably or technologically minable at present; they may eventually become minable when conditions of economics or technology are met. Submarginal resources are that part of conditional resources that would require a substantially higher price (more than 1.5 times the price at the time of determination) or a major cost-reducing advance in technology (Brobst and Pratt, 1973, p. 3-4).

TABLE 3.—*Partial chemical analyses of composite samples from drill core, Mill Creek Wilderness Study Area*

[Data from Minerals Development Corp., Roanoke, Va.]

Hole No.	Sample interval (feet [1])	Analyses (percent) Fe	P	Hole No.	Sample interval (feet [1])	Analyses (percent) Fe	P
T2-1a	46.8- 57.3	8.6	0.17	T5-14a	98.1-101.6	10.14	.146
	59.7- 61.8	9.1	.13		107.0-127.5	13.52	.166
	63.8- 77.7	13.6	.18		153.8-157.6	20.54	.354
	107.6-118.7	20.1	.32		164.1-169.6	15.29	.125
	118.7-119.2	6.7	.18		171.0-175.3	26.88	.644
	119.2-124.0	17.7	.38	T6-15a	4.0- 10.0	8.91	.073
	124.0-125.6	20.8	.436		15.4- 20.5	13.29	.115
	125.6-130.7	12.0	.20		20.8- 25.0	16.70	.139
	130.7-135.3	15.5	.28		26.5- 30.0	15.56	.109
	135.3-135.9	16.6	.28		61.1- 66.1	22.85	.121
	135.9-140.4	23.7	.48		67.1- 67.5	24.15	.135
T2-2a	8.8- 19.5	10.6	.14		71.9- 75.2	24.45	.190
	19.5- 32.3	13.5	.15		80.1- 80.8	15.07	.189
	75.2- 80.0	23.0	.32		82.9- 85.6	17.51	.312
	84.2- 86.9	21.9	.32		92.9- 93.8	27.07	1.569
	98.0- 99.8	32.4	.76	T6-17a	3.0- 7.2	11.20	.042
T5-10a	5.5- 15.0	28.85	.293		8.5- 12.5	16.80	.040
	20.5- 37.9	17.51	.095		48.0- 49.5	18.75	.221
T6-12a	4.0- 14.0	12.57	.079		49.5- 55.3	19.88	.232
	14.0- 16.5	16.60	.133		60.0- 64.5	30.03	.437
	49.7- 56.5	24.02	.323		72.5- 75.9	25.16	.372
	57.5- 59.4	20.63	.120	T2-18a	4.0- 9.2	10.47	.018
	62.3- 65.9	27.40	.321		9.2- 13.7	10.98	.108
	73.2- 77.5	28.53	.461		13.7- 21.0	8.55	.136
	83.6- 83.9	28.88	.842		23.5- 37.0	8.23	.140
	125.9-127.6	10.80	.124		38.0- 41.0	15.98	.118
T5-13a	5.0- 11.0	24.48	.108		74.0- 79.9	15.98	.122
	13.5- 16.9	28.69	.193		81.4- 88.5	15.01	.128
	23.1- 26.7	24.48	.201		88.5- 95.8	16.30	.110
	83.0- 94.1	18.96	.129	T2-19a	2.0- 10.8	21.78	.085
					10.8- 13.9	16.88	.179
					17.0- 19.9	32.95	.386

[1] To convert footage to meters, multiply by 0.3048.

THICKNESS AND DISTRIBUTION

Much of the hematitic sandstone in the Rose Hill Formation is in crossbedded units 0.3–2 m thick; the median value is 1 m. Some lenses are 3–8 m thick, but many of the thicker lenses contain minor shale beds. One prominent sandstone unit drilled by the USBM on Butt Mountain, 3–8 km west of Mountain Lake, was intersected in eight out of nine holes (Fish, 1967, p. 14–15). It ranges in thickness from 1.5 to 9 m and extends for nearly 5 km along the mountain top. Other hematitic units are smaller lenses. Some fairly thick beds intersected in one hole are not present in adjacent holes only 1 km away (Fish, 1967, p. 14).

Chauvin (1957, p. 30) estimated that about 24 percent of the Rose Hill Formation in a well-exposed section along U.S. Highway 460 in the Narrows of the New River was hematitic sandstone. Drilling by the Minerals Development Corp. in the Mill Creek area indicates that roughly 30 percent of that part of the formation drilled in 10 holes was hematitic sandstone. The drilling by the USBM on Butt Mountain indicates that 15–45 percent of the formation may be hematitic sandstone (Fish, 1967, p. 15).

GRADE

The weighted average of the iron content for 99 m of hematitic sandstone from 10 drill holes sampled by Minerals Development Corp. in the Mill Creek area is 17 percent Fe (iron). The "upper zone" has an average of 6 m of hematitic sandstone and an iron content of 14 percent; the "lower zone" has an average of 4.5 m of sandstone and an iron content of 20.7 percent. Similarly, a weighted average of 17.5 percent Fe was obtained for 75 m of hematitic sandstone in USBM drill core from Butt Mountain; nine samples of float from the same area have an average content of 18.1 percent Fe (Fish, 1967, p. 10–13).

We collected 105 samples of hematitic sandstone from outcrops and float of the Rose Hill Formation in the three areas and one sample from a roadcut on U.S. Highway 460 on Gap Mountain just east of Giles County (tables 2 and 4). Ninety-six samples contain 10 percent Fe or more; 44 contain more than 23 percent Fe. Sixty-two had detectable phosphorus, but the spectrographic method used for analysis of the USGS samples may not be sensitive enough for phosphorus determinations in rock with a high iron content. Sixty-five of the USGS samples represent about 66 m of ferruginous material in outcrop and float and have a weighted average of 20.5 percent Fe. The USBM collected 21 samples of thicker sections of rock; these represent 145 m of hematitic sandstone that has an average of 14.1 percent Fe. In addition, 17 "character" samples of float collected by the USBM averaged 16.3 percent Fe. The differences between the reported compositions of the sample suites are due in part to sampling and analytical techniques.

The average specific gravity of samples tested is 2.94; the range in specific gravity is 2.63–3.32.

RESOURCE CALCULATIONS

A rough calculation of the submarginal iron-resource potential in the three study areas can be made on the basis of the total area of exposed Rose Hill Formation, total area where the formation is covered by as much as 60 m of younger sedimentary rocks, and total area where the formation is covered by more than 60 m of younger sediments (pl. 6). For thickness, we assume an average of 9 m of hematitic sandstone within the 45–60 m of total Rose Hill Formation. This reasonable figure makes allowance for removal by erosion of part of the formation in areas of outcrop. The average thickness of hematitic sandstone containing at least 10 percent Fe in holes drilled by Minerals Development Corp. is 9 m; in the holes drilled by the USBM on Butt Mountain, thickness is 11 m.

To determine the resources, we multiply the volume in cubic meters by an average specific gravity of 2.94 and get the weight of hematitic

TABLE 4.—*Analyses, in percent, of iron- and manganese-rich rock samples from the Mill Creek, Peters Mountain, and Mountain Lake Wilderness Study Areas, collected by the U.S. Bureau of Mines*

[For sample localities, see fig. 13 and 17 and pls. 2–4. All analyses were performed by U.S. Bureau of Mines, Reno Metallurgy Research Center, Nev. Samples are random chips taken every 5–15 cm through the interval noted. Where no interval is noted, samples are representative grab samples of either float or dump material. Elements tested for spectrographically but not detected include As, Au, Ba, Bi, Cd, Ga, Hf, In, La, Li, P, Pt, Re, Sb, Sn, Ta, and Zn. Exceptions are listed in the footnotes at the end of table. Symbols used: >, greater than upper limit of determination; <, less than lower limit of determination; N, not detected and hence may occur only in amounts less than the lower detection limit; ____, analysis not performed]

Sample	General spectrographic analyses								Atomic absorption		X-ray fluorescence	Neutron activation	Sample interval (meters)	Sample description
	Al	Ag	Co	Cu	Fe	Mn	Ni	Pb	Fe	Mn	P	SiO_2		
Mill Creek area														
VMC 601 ______	0.3	N	N	<0.002	>4	0.005	<0.002	<0.01	29.9	0.0215	____	54	4.3	Devonian Rocky Gap Sandstone of Swartz (1929), opencut.
VMC 602 ______	.1	N	N	<.002	4	.004	.002	<.01	23.2	.0150	____	57	2.3	Do.
VMC 603 ______	.2	N	N	<.002	2	.003	<.002	<.01	13.1	.0110	____	84	3.4	Do.
VMC 604 ______	.05	N	N	<.002	>4	.004	.003	N	54.9	.0205	0.03	4	0.2	Goethite vein.
VMC 605 ______	.3	N	N	<.002	>4	.03	.003	<.01	25.3	.0400	.33	62	2.7	Devonian Rocky Gap Sandstone of Swartz (1929), mineralized.
VMC 606 ______	.8	N	N	<.002	>4	.09	<.002	N	11.3	____	.14	81	6.9	Silurian Rose Hill Formation.
VMC 608 ______	.2	N	N	<.002	>4	.004	<.002	<.01	25.6	.0180	____	62	12.2	Devonian Rocky Gap Sandstone of Swartz (1929), opencut.
VMC 609 ______	.1	N	N	<.002	>4	<.003	N	<.01	33.9	.0055	____	5		Composite hematitic vein material.
VMC 610 ______	.8	N	N	<.002	3	.005	.002	<.01	21.4	.0270	____	60		Dump material, opencut.
VMC 611 ______	.8	N	N	<.002	>4	.01	<.002	<.01	14.9	.0270	____	68	2.3	Prospect pit.
VMC 612 ______	.3	N	N	<.002	>4	.004	.002	<.01	17.1	.0110	____	70	2.6	Devonian Rocky Gap Sandstone of Swartz (1929), boxwork.
VMC 613 ______	.5	N	N	<.002	>4	.01	<.002	N	11.3	____	.07	23	8.9	Silurian Rose Hill Formation.
VMC 614 [1] _____	.3	N	N	<.002	>4	.3	<.002	N	37.5	.79	.89	26		Silurian Rose Hill Formation, mineralized.
VMC 615 ______	.6	N	N	<.002	>4	.03	<.002	<.01	9.8	____	.13	81		Silurian Rose Hill Formation.
VMC 618 ______	.8	N	N	<.002	>4	.06	<.002	<.01	15.9	____	.14	70		Do.
VMC 619 ______	.4	N	N	<.002	4	.003	.003	N	12.5	____	.10	78	3.9	Do.
VMC 621 ______	.4	N	N	<.002	>4	.004	<.002	N	11.6	____	.18	82	2.4	Do.
VMC 622 ______	.4	N	N	<.002	>4	.02	<.002	N	21.4	____	.26	68		Do.
VMC 625 ______	.5	N	N	<.002	>4	.01	N	N	15.9	____	.08	____		Do.
VMC 626 ______	.9	N	N	<.002	>4	.03	<.002	N	5.2	____	.08	91	8.2	Do.
VMC 628 [1] _____	.6	N	N	<.002	>4	.03	<.002	<.01	42.7	.0720	____	21		Dump material, prospect pit.
VMC 630 ______	.3	N	N	<.002	>4	.003	<.002	N	25	____	.15	62		Silurian Rose Hill Formation.
VMC 631 ______	.5	N	N	<.002	>4	<.003	<.002	N	19.8	____	.12	68	0.9	Do.
VMC 635 ______	.4	N	N	<.002	>4	.003	<.002	N	24.1	____	.18	66	6.1	Do.
VMC 636 ______	.6	N	N	<.002	>4	.01	<.002	N	9.8	____	.07	86	6.3	Do.

VMC 639	.6	N	<.003	.003	>20	.07	<.003	<.09	17.0	.04	____	____	2	Devonian Rocky Gap Sandstone of Swartz (1929).
VMC 640	.6	N	.003	.003	>20	<.002	<.003	<.09	15.9	.02	____	____	2	Do.
Peters Mountain area														
VPM 604	0.5	<0.001	N	<0.002	0.7	0.010	<0.002	N	2.2	____	0.02	93	14.9	Silurian Rose Hill Formation.
VPM 605	.4	<.001	N	<.002	>4	1	<.002	N	6.5	____	.02	83	6.5	Do.
VPM 608	.4	N	N	<.002	>4	.01	.004	N	11.3	.0310	____	75	4.0	Devonian Rocky Gap Sandstone of Swartz (1929).
VPM 609	.4	N	N	<.002	>4	.01	<.002	N	13.4	____	.14	78		Silurian Rose Hill Formation.
VPM 610	.3	N	N	<.002	>4	.01	<.002	N	11.5	____	.14	80		Do.
VPM 612	.5	<.001	N	<.002	>4	.003	<.002	N	14.9	____	.16	72	13.0	Do.
VPM 613	.5	<.001	N	<.002	>4	.004	<.002	N	14.6	____	.12	76	4.9	Do.
VPM 614	.8	<.001	N	<.002	>4	.003	<.002	N	16.6	____	.12	75	3.9	Do.
VPM 617	.4	<.001	N	<.002	>4	.003	<.002	N	16.1	____	.12	75		Do.
VPM 618	.5	<.001	N	<.002	>4	.003	<.002	N	11.2	____	.07	83		Do.
VPM 621	.8	<.001	N	<.002	>4	.01	<.002	N	18.6	____	.18	70	15.2	Do.
VPM 622	.5	<.001	N	<.002	>4	.006	<.002	N	14.9	____	.29	72	7.5	Do.
VPM 623	.1	<.001	N	<.002	>4	<.003	<.002	N	11.3	.007	____	83	3.0	Devonian Rocky Gap Sandstone of Swartz (1929).
VPM 626	.4	N	N	<.002	>4	.3	.003	<.01	29	.79	____	43		Dump material, mine pit.
VPM 627	.4	N	N	<.002	>4	.3	.008	.02	37.4	.89	____	29		Do.
VPM 628	.4	N	N	<.002	>4	.01	.004	<.01	31.5	.13	____	25		Do.
VPM 629	.4	N	N	<.002	>4	.03	.004	<.01	36.8	.17	.42	29		Composite vein material, mine pit.
VPM 630	.2	N	N	<.002	>4	.2	<.002	<.01	40.1	.79	.28	22		Composite vein material, prospect pit.
VPM 631	.08	<.001	N	<.002	>4	.01	<.002	N	17.8	.026	____	72	12.8	Devonian Rocky Gap Sandstone of Swartz (1929).
VPM 632	.4	N	N	<.002	>4	.01	<.002	<.01	40.3	.26	____	28		Devonian Rocky Gap Sandstone of Swartz (1929), float material.
VPM 633	.3	.002	N	<.002	>4	<.003	<.002	N	12.1	.0075	____	74	1.2	Devonian Rocky Gap Sandstone of Swartz (1929).
VPM 634	.3	<.001	N	<.002	>4	<.003	<.002	N	18.9	.0055	____	68	.9	Do.
VPM 635	.05	<.001	N	<.002	>4	.006	<.002	N	17.4	.024	____	67	18.9	Do.
VPM 636	.3	N	N	<.002	>4	.006	<.002	N	13.6	____	.12	75	8.8	Silurian Rose Hill Formation.
VPM 637	.4	N	N	<.002	>4	.006	<.002	N	15.2	____	.12	72		Do.
VPM 638	3	.002	.2	.06	1	>20	.06	<.02	1.4	11.1	____	____		Silurian Keefer Sandstone, dump material.
Mountain Lake area														
VML 604	0.5	<0.001	N	<0.002	>4	0.006	<0.002	N	15.2	____	0.20	____	7.9	Silurian Rose Hill Formation.
VML 606	.6	<.001	N	<.002	>4	.04	<.002	<0.01	8.2	.0910	.06	81	.9	Prospect pit.
VML 607	.1	<.001	.004	<.002	>4	.06	.004	<.01	7.7	____	.08	85		Silurian Rose Hill Formation.
VML 609	.95	<.001	N	<.002	>4	.03	<.002	N	5	.0740	____	91	.9	Silurian Keefer Sandstone, mineralized zone.
VML 610 [2]	.3	N	.007	<.002	1	>3	.002	<.01	2.6	.18	____	79		Silurian Keefer Sandstone, nodular float material.

TABLE 4.—*Analyses, in percent, of iron- and manganese-rich rock samples from the Mill Creek, Peters Mountain, and Mountain Lake Wilderness Study Areas, collected by the U.S. Bureau of Mines*—Continued

Sample	General spectrographic analyses								Atomic absorption		X-ray fluo-rescence	Neutron acti-vation	Sample interval (meters)	Sample description
	Al	Ag	Co	Cu	Fe	Mn	Ni	Pb	Fe	Mn	P	SiO_2		
Mountain Lake area—Continued														
VML 612	.5	<.001	N	<.002	>4	.008	<.002	N	11.5	----	.13	74	6.6	Silurian Rose Hill Formation.
VML 613	.5	<.001	N	<.002	>4	.009	<.002	N	10.9	----	.14	74		Do.
VML 614	.5	<.001	N	<.002	>4	.014	<.002	N	12.2	----	.08	81		Do.
VML 615	.5	<.001	N	<.002	>4	.02	<.002	N	15	----	.08	72	15.2	Do.
VML 616 [3]	.4	<.001	N	<.002	>4	.01	.004	N	14.2	.0190	----	70	3	Devonian Rocky Gap Sandstone of Swartz (1929).
VML 618 [3]	.2	<.001	N	<.002	>4	.008	.006	N	15.6	.0275	----	71	6.1	Devonian Rocky Gap Sandstone of Swartz (1929) (?).
VML 621	.5	<.001	N	<.002	>4	.01	<.002	N	12.6	----	.14	69		Silurian Rose Hill Formation.
VML 622	.65	<.001	N	<.002	>4	.01	<.002	N	19.2	----	.14	68		Do.
VML 623	.5	<.001	N	<.002	>4	.012	<.002	N	13.2	.0190	----	65	3.7	Devonian Rocky Gap Sandstone of Swartz (1929).
VML 624	.08	<.001	N	<.002	>4	.012	.004	<.01	8.4	.0190	----	68	.9	Do.
VML 625 [3]	.2	<.001	N	<.002	>4	.007	.002	<.01	6.5	.0210	----	78	1.8	Do.
VML 626	.3	<.001	N	<.002	>4	.007	<.002	.02	7.5	.0120	----	88	4.9	Do.
VML 628	>3	<.001	N	<.002	>4	.009	.002	N	14.1	----	.08	74	3.0	Silurian Rose Hill Formation.
VML 629	.75	<.001	N	<.002	>4	.005	.002	N	8.1	----	.09	84	4.8	Do.
VML 632	.6	<.001	N	<.002	>4	.006	<.002	N	18.9	----	.18	67	7.3	Do.
VML 635 [4]	.9	N	.007	<.002	>4	>3	.025	N	8.4	26.1	----	22		Dump material, prospect pit.
VML 636 [5]	.5	N	.004	<.002	>4	1.5	<.002	N	13.6	1.5	----	61	.5	Outcrop trace.
VML 638	.5	<.001	N	<.002	>4	.008	<.002	N	21.6	----	.23	64		Silurian Rose Hill Formation.

[1] Contains 0.3 percent P.
[2] Contains 0.35 percent Ba and 0.035 percent Sn.
[3] Contains 0.04 percent Zn.
[4] Contains 0.7 percent Ba and 0.04 percent Sn.
[5] Contains <0.07 percent Ba.

sandstone in metric tons. By using two average-grade figures, 15 and 20 percent Fe, we can obtain a reasonable range of iron content. Because some of this iron would be lost in mining and beneficiation, these figures do not represent recoverable iron, but they do represent an estimate of the amount available. The total submarginal iron resources potential for the three areas is 1,750 million metric tons of hematitic sandstone containing 260–350 million metric tons of iron (table 5).

Such resource figures seem large, but they are not when compared with U.S. iron-ore reserves of about 17 billion metric tons of ore containing about 3.6 billion metric tons of recoverable iron or with the U.S. total resources (which include reserves) of about 108 billion metric tons of rock containing about 27 billion metric tons of iron (U.S. Bureau of Mines, 1979, p. 79). Furthermore, the resources of the three study areas are only a fraction of the total amount of hematitic sandstone in the Rose Hill Formation throughout its outcrop area in Maryland, West Virginia, and Virginia.

Mill Creek area

The Mill Creek area is in a shallow syncline; the formations dip gently toward the center of the area, and wide outcrop belts are formed on dip slopes. Large-scale stripping or quarrying of the hematitic sandstone

TABLE 5.—*Summary of submarginal iron resources in hematitic sandstone of the Rose Hill Formation in the Mill Creek, Peters Mountain, and Mountain Lake Wilderness Study Areas*

[See text for explanation of calculations and for discussions. Outlines of areas containing resources are shown on pl. 6]

Area	Hectares	Hematitic sandstone: Total (millions of metric tons)	Containing indicated percentage of iron (millions of metric tons): 15 percent	20 percent
Mill Creek				
Rose Hill outcrop	960	250	37	50
Covered, 3–60 m	460	120	18	24
Subtotal	1,420	370	55	74
Mountain Lake				
Rose Hill outcrop	1,310	350	52	70
Covered, 3–60 m	1,780	470	71	94
Covered, 60 m	750	200	30	40
Subtotal	3,840	1,020	153	204
Peters Mountain				
Rose Hill outcrop	720	190	29	38
Covered, 3–60 m	660	170	26	34
Subtotal	1,380	360	55	72
Total	6,640	1,750	263	350

would require removal of little overburden, but a large amount of lower grade sandstone and shale mixed with the hematitic sandstone would have to be moved. A more detailed discussion of possible mining and land-restoration plans was given by Cooper (1960). His estimate (p. 1) of "300 to 400 million [short] tons" of hematitic sandstone agrees with our estimates. He was, however, more optimistic concerning grade and gave a range of 23 to 37 percent Fe (Cooper, 1960, p. 1).

The average iron content in 19 samples collected by the USGS, representing 21 m of hematitic sandstone, is 21.8 percent Fe. The USBM collected eight outcrop samples representing 44 m of sandstone and averaging 12 percent Fe. Five additional USBM samples of float averaged 17.6 percent Fe.

Mountain Lake area

Mountain Lake area also contains extensive outcrop belts of Rose Hill Formation. Several large areas of dip slope on moderately to gently dipping Rose Hill Formation form parts of the crest of Salt Pond Mountain. In the rest of the area where the Rose Hill dips steeply on Little Mountain, Potts Mountain, and Johns Creek Mountain, outcrop belts are narrow. On Potts Mountain, the formation is cut by several thrust faults.

The easternmost hole drilled by the USBM on Butt Mountain is only 3 km west of Salt Pond Mountain. This hole, BM 7, shows two zones of hematitic sandstone. The upper zone is 5.8 m thick and contains 15.8 percent Fe; the lower zone is 9.1 m thick and averages 20.2 percent Fe (Fish, 1967, p. 13–15). The 25 USGS samples of hematitic sandstone from Mountain Lake area represent 19.3 m of sandstone and average 21.5 percent Fe. Six USBM outcrop samples represent 45 m of sandstone and contain an average of 14 percent Fe; six samples of float also average 14 percent Fe.

Peters Mountain area

Peters Mountain area has nearly as much potential for hematitic sandstone as does Mill Creek area (table 5). Slightly more than half this material is in outcrop belts of the Rose Hill; the rest is covered by as much as 60 m of younger sediments. The outcrop belts are wide dip slopes, but in half the area, they are separated by several thrust faults. Dips are generally steeper than those in Mill Creek area and might complicate mining and recovery. The average iron content of 21 samples collected by the USGS and representing at least 25 m of hematitic sandstone is 18.5 percent Fe, slightly less than the average for the Mill Creek area. The average for eight outcrop samples collected by the USBM is 12.7 percent Fe; the average for five float samples is 13.4 percent Fe.

BENEFICIATION

Future potential of the hematitic sandstones depends primarily on an economically feasible beneficiation process. Beneficiation studies conducted by the USBM Tuscaloosa Metallurgy Research Center, Ala., (Lamont and others, 1967) on samples from the Butt Mountain area show that from material containing between 14.6 and 20.0 percent Fe, the best concentrates were obtained by reduction roasting, fine grinding, and wet magnetic separation. Magnetic concentrates were produced that contained 49.5–56.7 percent Fe, and recoveries were 89.0–92.6 percent; the product, however, is relatively high in phosphorus, 0.245–0.271 percent P (Lamont and others, 1967, p. 27).

Similar studies by the Hanna Mining Co. (1964) on samples from the Big Ridge area, near Bluefield, W. Va., reported that for a bulk sample having 19.68 percent Fe, the most favorable process involved conversion of the hematite to artificial magnetite, followed by magnetic separation and cationic flotation of silica from the concentrate. In two tests, concentrates having 63.45 and 63.87 percent Fe were achieved, and recoveries were 73.01 and 69.19 percent. Principal contaminants were alumina (4.52–5.44 percent Al_2O_3) and phosphorus (0.267 percent P).

In general, both studies suggest that 1 t of iron concentrates can be produced from about 3 t of raw material. High-phosphorus content is a concern, and extremely fine concentrates produced during beneficiation would require some type of agglomeration process.

LIMONITE DEPOSITS

The limonite[4] deposits in the Rocky Gap Sandstone and underlying Tonoloway Limestone and the upper part of the Keefer Sandstone are secondary or supergene iron deposits. All the Lower Devonian sandstones in Virginia were originally correlated with the Oriskany Sandstone of New York State, and these iron deposits have long been known as Oriskany or Oriskany-type iron ores. They were formed long after the rocks were folded and faulted and had assumed their present position. Iron-rich ground water dissolved the original calcium carbonate cement of the sandstone and shaly limestone and deposited iron oxides and hydroxides as replacement for calcium carbonate, as cavity fillings, and as irregular masses of limonite-cemented sandstone.

The resulting small deposits of iron-rich rock are restricted to the near-surface part of the formations. This type of ore is richer and thicker in the Clifton Forge iron district, about 65 km northeast of

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[4] We use limonite as a general term for hydrous iron oxides that probably consist of mixtures of the minerals goethite ($Fe_2O_3 \cdot {}_2O$) and hematite (Fe_2O_3).

Giles County (Lesure, 1957, p. 80-119). There, most of the deposits were mined to depths of 30 to 60 m; the deepest mine reached 275 m.

The deposits exposed in Giles County seem neither large enough nor rich enough to justify further work. The material is very sandy and probably erratic in distribution. In Giles County, the Lower Devonian section does not contain the thick sandy limestone that is the host rock for large deposits in the Clifton Forge district. Although the Tonoloway Limestone may be replaced in part by iron to form larger iron-rich zones than could be found in the Rocky Gap Sandstone alone, the Tonoloway is generally shaly and would not be expected to provide the permeability on weathering that the sandy limestone provided in the Lower Devonian section of the Clifton Forge district. In summary, the supergene iron deposits of the Rocky Gap Sandstone in the three study areas are small, low grade, and siliceous. We found no reason to assume continuity at depth or along strike; the total resource is probably small.

Small limonite deposits have been mined at two locations: the Chestnut Flat Mine, in the Mill Creek study area, and the Interior Mine, in the Peters Mountain study area. The Mountain Lake area contains a few small prospects along the slopes of Johns Creek valley.

MILL CREEK AREA

Chestnut Flat Mine

Two massive exposures of iron-bearing Rocky Gap Sandstone are on Wolf Creek Mountain and on the drainage divide separating No Business and Mill Creeks (fig. 15). The two exposures, less than 600 m apart, represent opposite limbs of a small syncline. The ore consists of limonite cementing sandstone and limonite masses filling cavities. Development has been by opencut methods. Boyd (1881, p. 144) referred to the area as "the ore banks from which the John's Mountain Furnace, near Newport, derives its ores," and estimated that the site would yield 272,000 t of material analyzing 62.7 percent Fe. No additional information concerning mining has been found; total production is unknown.

In the southern part of the mine area, mineralized sandstone is exposed in several outcrops surrounding a knoll at an altitude of 1,086 m. A large open cut and two smaller trenches revealed several discontinuous mineralized zones (fig. 16). The most continuous zone is at the top of the cut and consists of 1-2 m of hard, dense, reddish-brown sandstone that has a limonite cement surrounding coarse quartz grains. The other mineralized zones are discontinuous lens-shaped masses of similar rock separated by unmineralized crossbedded sandstone. Porous goethite and hematite veins and fracture fillings, some several

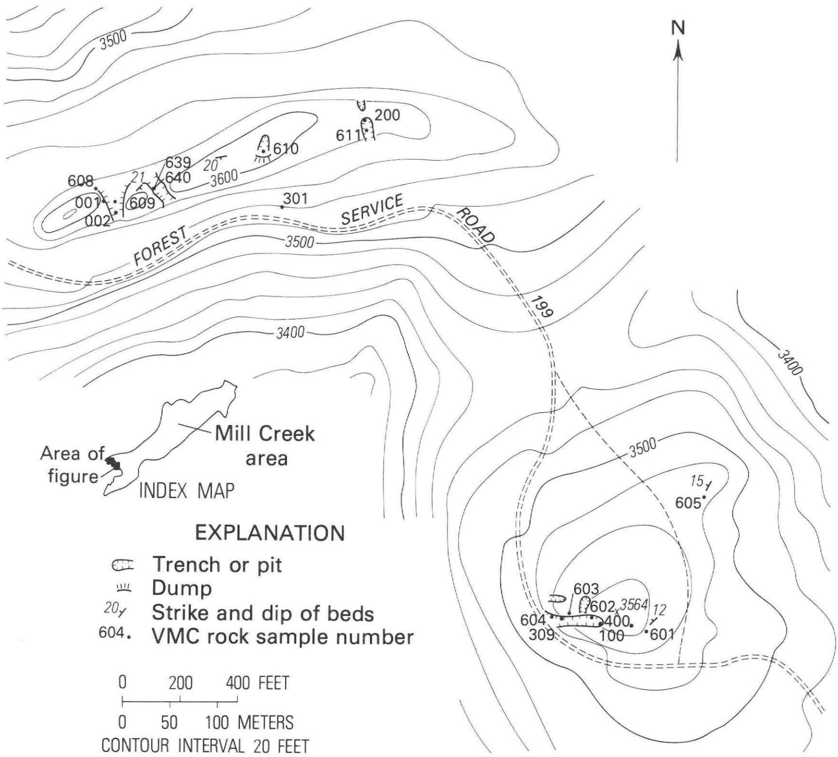

FIGURE 15.–Map of Chestnut Flat Mine, Mill Creek Wilderness Study Area, showing sample localities. The workings were sketched from a pace and compass traverse. The base is modified from U.S. Geological Survey Narrows 7.5-minute Quadrangle, 1:24,000, 1965.

centimeters thick, cut these mineralized lenses and the interlayered unmineralized sandstone. These veins fill cracks formed by collapse of sandstone during weathering and removal of the original calcite cement (fig. 17). Evidence of such collapse is seen where angular masses of sandstone are separated by porous limonite cavity fillings. Stalactites and stalagmites of limonite in the vein fillings are nearly vertical; the iron minerals formed in place after final deformation of the host rock. Some of the limonite (goethite and hematite) veins are parallel to the long direction of the cut. The apparent decrease in the concentration of veins away from the cut suggests a localization of vein formation, probably in an area of solution collapse.

Sample VMC 604 (table 4), taken from a 20-cm vein in the large cut, assays 54.9 percent Fe; sample VMC 602 (table 4), from the 1- to 2.4-m upper zone, or "cap rock," of mineralized sandstone, contains 23.2 percent Fe. A middle zone, nearly 1.5 m thick, probably contains 25 to 28

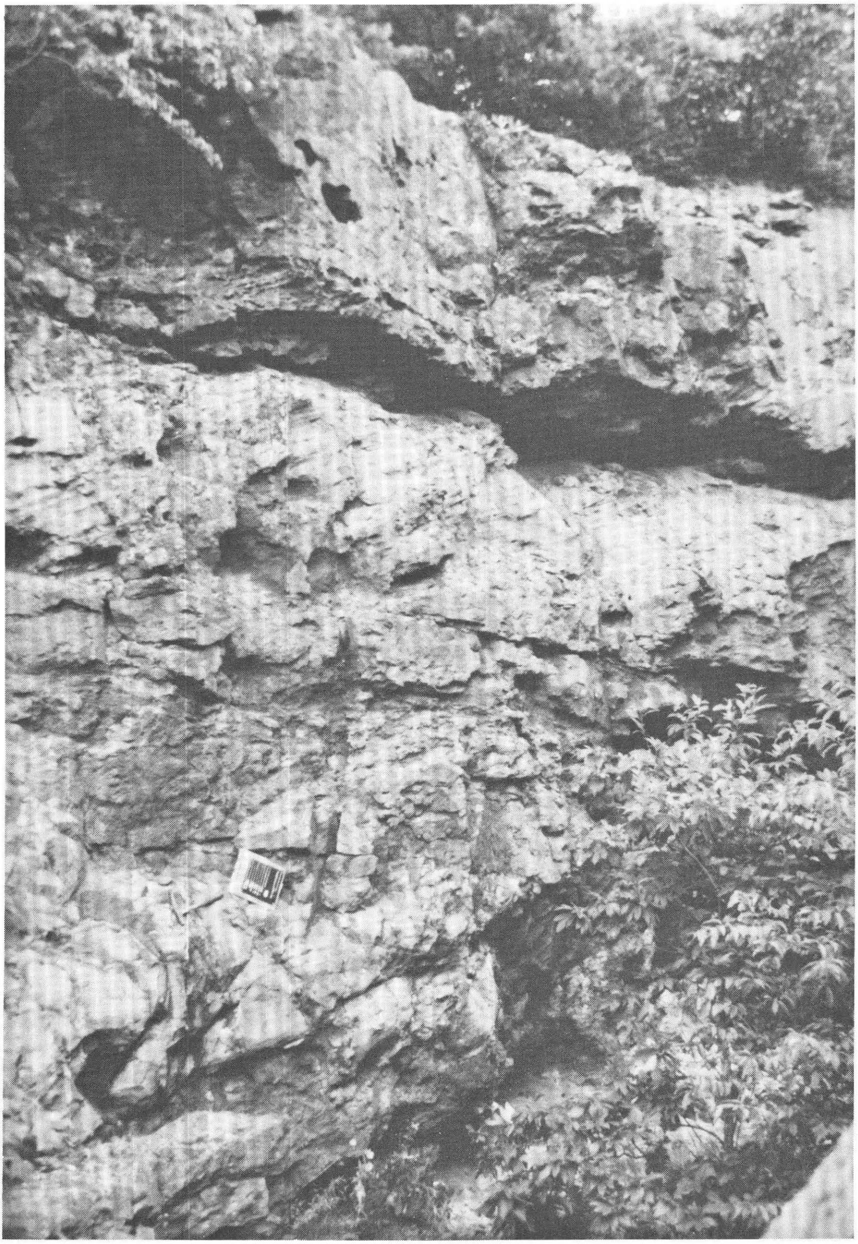

FIGURE 16.—View of the northwest wall of the southern cut of the Chestnut Flat workings showing limonite cemented "cap" rock overlying friable crossbedded sandstone containing stringers and veins of limonite.

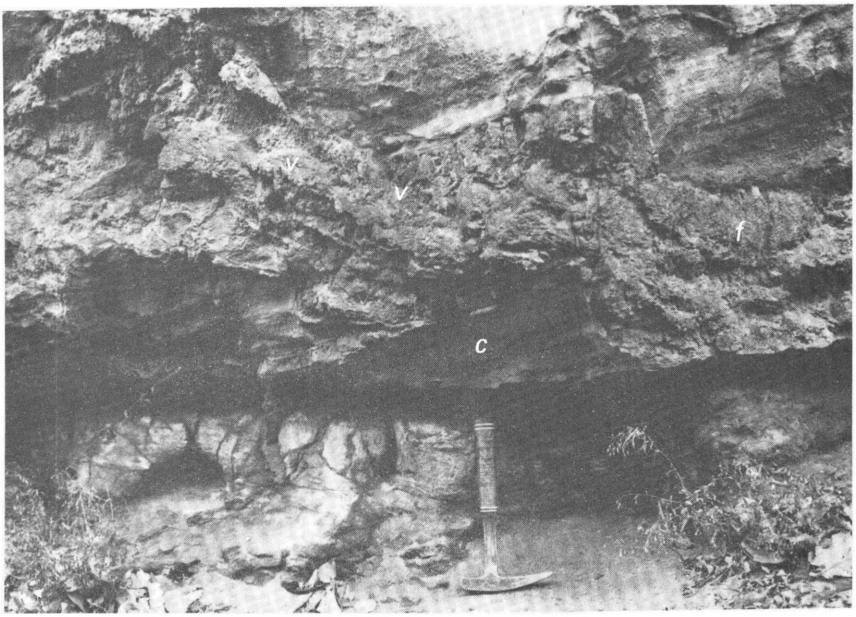

FIGURE 17. – Closeup of the base of the northwest wall of the southern cut of the Chestnut Flat workings, showing a collapsed block of sandstone (c), vuggy limonite cavity filling (f), and vertical stalagmites of limonite (v).

percent Fe but appears to pinch out within 10 m along strike. Samples VMC 100, 300, and 400 are from the "cap rock" or limonite veins in the same workings and contain similar amounts of iron (table 2). Sample VMC 603 (table 4) was taken vertically from the top of the middle mineralized zone through the bottom of the underlying nonmineralized sandstone, a distance of 3.4 m, and shows an iron content of 13.1 percent, probably a more realistic estimate of iron content.

In the northern part of the Chestnut Flat workings, exposures of the Rocky Gap Sandstone are more extensive, cropping out over a distance of nearly 300 m along the ridge crest and continuing less conspicuously 800 m farther northeast. Both mineralized and barren sandstones are present, but, except for the "cap rock," the mineralized rock here shows no definite stratigraphic division. Four major workings cross the exposures, each progressively smaller as the amount of iron decreases northeastward along strike. The largest opencut (fig. 18), on the southwestern edge of the outcrop, exposes a 12-m thickness of mineralized rock similar to that of the southern workings. Limonite veinwork is, however, more extensive, and some veins are nearly parallel to the long direction of the cut. Iron content over the entire section is 25.6 percent, as indicated by sample VMC 608 (table 4), but

FIGURE 18.–View south through the westernmost cut in ferruginous Rocky Gap Sandstone of Swartz (1929) at the north edge of the Chestnut Flat workings. The area has been partly graded and seeded by the Forest Service.

because of the discontinuous nature of the veins, a truly representative sample is hard to obtain. A composite sample of the vein material (VMC 609, table 4) contains 33.9 percent Fe. Samples VMC 001 and 002 have comparable amounts of iron (table 2).

In the next cut to the east, two samples were taken near the center of the west wall. The upper sample (VMC 639) represents about 2 m of limonitic sandstone and contains 17 percent Fe; the lower sample (VMC 640, table 4) also represents 2 m of limonitic sandstone and contains 15.9 percent Fe. These samples are probably representative of the material in place away from the concentration of small veins seen in the western cut.

At sample locality VMC 612 (pl. 2), the iron-bearing sandstone, or "cap rock," is 2.6 m thick at outcrop and contains 17.1 percent Fe (table 4). Sample VMC 119 (table 2) from nearby contains more than 23 percent Fe. The exposure is poor, and the thickness may not represent that of the entire mineralized zone. This locality may mark a northeastern extension of the main mineralized body, thus indicating a possible strike length of 1,200 m. Without additional data, however, it is difficult to determine the actual limits of the deposit or to surmise the degree of continuity of thickness and grade.

At the Chestnut Flat Mine, two outcrop areas of iron-bearing sandstone have a 12.2-m section locally containing 25 percent Fe. However, where sampled, the sandstone contains abundant veinlets and cavity fillings of limonite, which appear to decrease in number and volume away from the cuts. The average amount of limonitic sandstone is probably no more than 2–4 m thick. This iron-bearing sandstone can be projected downdip for no more than 15 m and along strike for about 250 m at the southeast part and 600 m at the north part of the mine area. The amount of submarginal resource represented in this mass of rock is about 100,000 t of limonitic sandstone containing 15,000–20,000 t of iron.

Unnamed prospect

A prospect pit 6×2.4×1 m in the Keefer Sandstone is at an altitude of 884 m in the area between Mill Creek and Mercy Branch (sample locality VMC 628, pl. 2). The pit trends N. 2° W. A select grab sample of material from the dump contains 42.7 percent Fe (table 4). Iron oxide occurs as small veinlets in both brown clay and light-colored sandstone, material that was not found beyond the immediate area of the pit.

PETERS MOUNTAIN AREA

Interior Mine

Iron ore has been mined about 0.8 km northwest of Interior on the south slope of Peters Mountain (Watson, 1907, p. 448). Here, strata dip 20°–40° SE., and workings (fig. 19) follow the dip of the slope.

A network of old roads and railbeds leads from a probable washing and loading point near the base of the hill on what was once a spur of the abandoned Potts Valley branch of the Norfolk and Western Railway. The mine is believed to have operated in the early 1900's, but no records of past activity are available.

The mined area contains four opencuts, several smaller trenches, and many test pits in limonite-cemented sandstone near the contact of the Keefer Sandstone and the Tonoloway Limestone. Slumping and overgrowth conceal the ore zone, but rock debris within the excavation indicates that the ore probably consisted of sandy masses and thin stringers of goethite in both clay and friable sandstone. A nonmineralized sandstone several feet thick is poorly exposed in the large cuts and presumably represents the hanging wall. If this presumption is true, the material mined could have averaged 2.4–6 m in thickness (the vertical distance between the hanging wall and the floor of the cut). Much of the mined rock was discarded in large dumps, and how much ore was actually shipped from the site is not known.

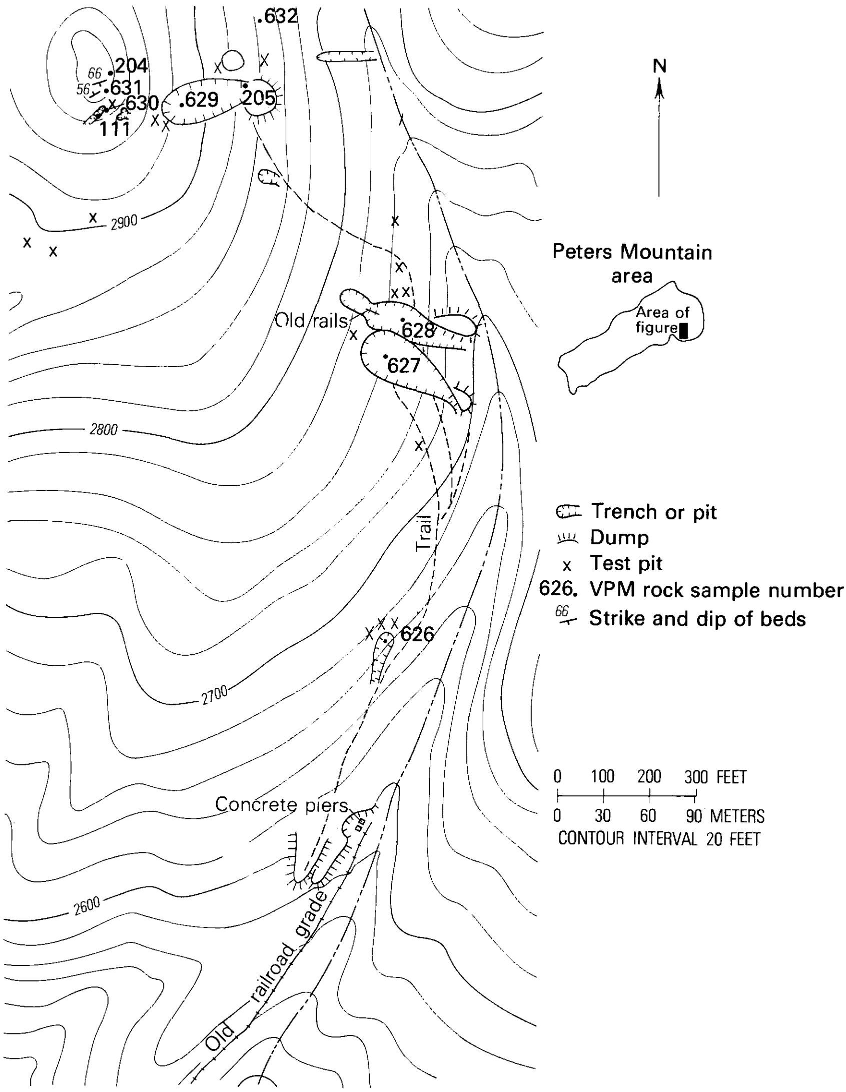

FIGURE 19.—Map of the Interior Mine, Peters Mountain study area, showing sample localities. The workings were sketched from a pace and compass traverse. The base is modified from U.S. Geological Survey Interior 7.5-minute Quadrangle, 1:24,000, 1965. (The location of fig. 19 is shown on pl. 3*D*.)

From what can be seen and inferred now, the ore itself appears to have been richer near the ridge crest, thickest in the area of the two larger cuts, and progressively sandier and lower in grade toward the lowermost workings. The ore horizon is generally a thin surface covering, absent in places. Thickest ores have been exhausted, and no development potential remains.

MOUNTAIN LAKE AREA

In the Mountain Lake area, iron resources of the limonitic type are only hypothetical. The Rocky Gap Sandstone crops out sporadically along the southeast slopes of Salt Pond and Potts Mountain, northwest of Johns Creek; these outcrops suggest a nearly continuous belt of potentially mineralized rock several kilometers long. No ore-grade material is exposed in the several prospect pits examined. Further exploration by test pitting or drilling would be necessary to establish the existence of an ore-bearing zone in the area. The small size of the limonite-type deposits in the general area is a deterrent to further exploration.

MANGANESE RESOURCES

Small deposits of low-grade manganese ore have been mined in this part of Virginia and West Virginia (Stose and Miser, 1922; Ladd and Stead, 1944; and Reeves, 1942). The deposits are shallow and limited in area. They consist of manganese oxides in fracture fillings, as cement in sandstone, as nodules in residual sand and clay, and as thin black films on weathered rock. Those deposits in Lower Devonian sandstones have been called Oriskany-type and are related in part to the limonitic iron deposits. The total amount of manganese present at any one locality that we examined is far too small to warrant economic consideration. Analyses (tables 2 and 4) show manganese in amounts generally less than 1 percent, associated with iron-rich rock. Concentrations are so low that the low-grade iron ore could not be utilized for manganese. Only eight samples containing more than 1 percent Mn (manganese) were collected in the three study areas (tables 2 and 4). Five of these are from the Tuscarora, two from the Keefer, and one from the Rocky Gap. The greatest manganese mineralization that we found is at the Denison(?) prospect, but neither thickness nor grade of mineralized rock compares favorably with those of the other abandoned manganese mines visited outside the study area.

Our reconnaissance studies do not indicate the presence of significant manganese resources in the three study areas. The minor deposits already known are siliceous and low grade. The chances of finding larger or higher grade deposits are poor.

PETERS MOUNTAIN AREA

SIMPKINS(?) PROSPECT

A manganese prospect 4 km west-northwest of Interior on the southeast slope of Peters Mountain was reported by Stose and Miser (1922, p. 124). Openings were made in 1917 in a buff-colored, much fractured sandstone thought to be of Oriskany age (Rocky Gap Sandstone) near the crest of a spur at an altitude of 853 m. Manganese oxide was reported in small quantities filling cracks between sandstone fragments and replacing part of the sandstone. Also described is a shaft 6.7 m deep, altitude 902 m, sunk at the contact of a fractured sandstone, dipping 60° E., and purple and white laminated clay that is probably residual from the weathering of limestone. Psilomelane in small quantities is said to have occurred near this contact in both the sand and clay.

Workings similar to those described are on a small spur just west of Pine Swamp Branch (pl. 3). A caved circular pit about 3 m in diameter and 2 m deep at an altitude of 860 m may be the shaft reported by Stose and Miser. Two small prospect pits in the same stratigraphic horizon are 20 m northeast and southwest, down slope. Manganese oxides stain the sandstone bedrock and locally cement and replace sand grains. Much of the mineralized rock is low grade. A sample (VPM 638, table 4) of nodular, manganese-cemented sandstone contains 11.1 percent Mn and 1.4 percent Fe. The sandstone is probably in the upper part of the Keefer Sandstone and not in the Rocky Gap Sandstone, as described previously. No other workings were found, and this locality is probably the Simpkins prospect.

MOUNTAIN LAKE AREA

DENISON(?) PROSPECT

Three prospect pits were found on the crest of Johns Creek Mountain, altitude 1,106 m, near the southernmost study boundary. These may be the Denison prospect described by Stose and Miser (1922, p. 123). Prospecting activities were centered on a manganese-bearing buff-colored sandstone and brown claylike unit of the Tuscarora Quartzite. Two of the pits, one 6.1 × 3.4 × 1.2 m and the other 3.6 × 1.8 × 1.2 m, are 18.3 m apart along strike. Both trend about N. 25° W. and intersect a mineralized zone less than 0.6 m thick. Although a select grab sample (VML 635, table 4) collected from material on the floor of one of the pits contains 26.1 percent Mn, a second sample (VML 636, table 4) taken from a poorly exposed trace of the mineralized unit midway between the two pits has a manganese content of 1.5 percent. Float material from this unit is found for a distance of about 60 m along the ridge crest. A third pit 6.7×3.4×1.2 m, trending N. 30° W., is about 90 m southwest of the two prospects. Samples VML 147 and 148 from this pit contain 5–7 percent Mn and anomalous amounts of cobalt and nickel (table 2). Probably less than a metric ton of siliceous manganese nodules and manganese-cemented sandstone is in the area of the pits.

MISCELLANEOUS PROSPECTS

An excavation in the Keefer Sandstone was found on the crest of Potts Mountain approximately 2.7 km by jeep trail southwest of Virginia State Road 636. A 3.6×1.2×0.9 m trench extends southward off an outcrop and exposes a mineralized zone 0.5 m thick. Manganese oxide occurs as a surface coating or scale less than 3 mm thick, but little mineralization is discernible in the rock itself. Sample VML 606, taken across the unit, shows 8.2 percent Fe and 0.091 percent Mn (table 4).

Two test trenches, one in the Keefer Sandstone and one near the base of the Rocky Gap Sandstone, are on the southeast slope of Salt Pond Mountain adjacent to the Appalachian Trail at altitudes 853 and 823 m, respectively. A piece of float material – white Keefer Sandstone showing signs of manganese replacement – was found on the trail; it probably represents the material prospected for in the upper trench. Sample VML 425 (table 2), from nearby, contains 4.9 percent Mn, but no mineralized material was found in the trench. No significantly mineralized rock was in the lower trench; nearby outcrop samples (VML 623, 624, table 4) of Rocky Gap Sandstone contain only 13.2 and 8.4 percent Fe, respectively. Both samples show a manganese content of 190 ppm. However, sample VML 426, from the same general area, contains 16 percent Mn (table 2). The existence of the trenches and several similar prospect pits along the Rocky Gap outcrop trace, northeast of the Appalachian Trail and nearer to Negro Branch, suggests that a more than cursory exploration effort has been made in this stratigraphic interval (pl. 4). These pits reveal similar mineralized rock but are not discussed individually. No significant amounts of either iron or manganese are present.

MANGANESE MINING ACTIVITY IN NEARBY AREAS

Many manganese mines and prospects are in or near the study areas (pl. 1); we visited several of these, including the Williams Mine, the Chevy Mine, the Stange Mine, and the Gusler (or H. M. Reynolds) Mine, during field investigations. All these mines produced manganese, and all but the Gusler Mine, which is a fault-related residual deposit in lower Paleozoic carbonate rocks, are Oriskany-type deposits in Lower Devonian sandstone.

WILLIAMS MINE

The Williams Mine is in Monroe County, W. Va., on the east end of Fork Mountain, altitude 853 m, 2,560 m N. 85° W. from the post office at Waiteville, W. Va. (location 57, pl. 1). The mine was opened in November 1941 (Reeves, 1942, p. 27). By 1950, more than 140 t of concentrate had been produced and shipped from an opencut (USBM War Minerals file). The ore is in a 1.5-m clay bed that is almost certainly Tonoloway residuum. Analysis of a sample of ore collected from the surface of the clay during field examination showed 27.1 percent Mn and 3.4 percent Fe.

CHEVY MINE

The Chevy Mine is on a small spur on the southeastern slope of Sinking Creek Mountain at an altitude of 582 m (location 72, pl. 1). The mine is in Craig County, Va., and is 2,440 m N. 29° E. of the benchmark at Webbs Mill. Mining began in fall 1916, and by 1919, the mine had been abandoned, having produced about 544 t of manganese ore (Stose and Miser, 1922, p. 115–117; USBM statistical files, manganese, 1916–1919). Psilomelane, the principal manganese mineral, has replaced sandstone and fills joints and fissures in rock observed on the mine dumps. Some psilomelane is found in trenches farther uphill, but goethite predominates. Two samples collected from the abandoned workings during field investigations contained 31.4 and 29.4 percent Mn and 13.6 and 6.0 percent Fe, respectively.

STANGE MINE

The Stange Mine is in Bland County, Va., near the Giles County line on the crest of Flat Top Mountain, at an altitude of about 915 m (location 13, pl. 1). It is 2,680 m N. 39½° E. of the intersection of Virginia State Roads 606 and 629 at Holly Brook. Except for two periods when the mine was idle (1920–23, 1944–51), production was continuous from 1917 until 1959, the year Federal stockpiling of manganese ceased. Cumulative production was more than 45,000 t of manganese ore; high-grade-ore (more than 35 percent Mn) shipments averaged about 44 percent Mn (USBM statistical files, manganese 1916–1959). Manganese oxides occur along bedding planes, fill joints and fractures, and rarely, replace sandstone. A grab sample that we collected from the dump at the northern cut contains 29.4 percent Mn and 6.0 percent Fe. The Stange Mine was described by Stose and Miser (1922, p. 134–142) and by Ladd and Stead (1944, p. 221–227). Investigations by the USBM in early 1941 were described by Moon (1950).

GUSLER MINE

The Gusler Mine is in Giles County, Va., on the southeastern slope of Clover Hollow Mountain at an altitude of 700 m (location 49, pl. 1). It is 3,600 m N. 41½° E. of the benchmark at Newport and is easily visible from the main road, Virginia State Highway 42. During a 4-year period of Federal stockpiling (1956–59), J. Gordon Gusler produced more than 8,163 t of manganese ore (USBM statistical files) from an opencut about 90×60×18 m. Ore shipments (high grade) averaged 45 percent Mn. Mr. H. M. Reynolds, the owner, stated that Gusler trucked the ore to Holly Brook in Bland County for washing. Development has been in a thick clay mantle formed by weathering cherty carbonate rocks of the Knox Group. Manganese oxides occur as the earthy mixture known as "wad" and as recemented masses of chert breccia. A sample collected during our visit contains 26.4 percent Mn and 0.65 percent Fe. Some replacement of chert is also evident. Apparently, faulting has provided an avenue for ore solutions, as well as conditions favorable to deep weathering. Similar conditions exist at the Carrie and Laing prospects, described by Stose and Miser (1922, p. 119–122).

NONMETALLIC RESOURCES

Nonmetallic resources in the region around the three study areas include large deposits of dolomite and high-calcium limestone and potential sources of high-silica sandstone. Traces of phosphate in several formation are too low grade to be considered resources at present. Construction materials are abundant. Rock for crushed stone, limestone for cement, and shale for brick are abundant. Sandstone and limestone have been used for various types of building and dimension stone. Sand and gravel are limited to small deposits along some of the major streams; the largest deposits are in areas of colluvium and alluvium in Johns Creek valley. Of these materials, only dolomite and limestone are currently mined. Both are used for crushed rock, and the better quality limestone is used for high-calcium lime products.

Transportation costs limit the extent of the market area of most nonmetallic and construction materials. The three study areas contain no nonmetallic or construction materials that are not as abundant, more readily available, and closer to transportation facilities outside the boundaries of these areas.

LIMESTONE AND DOLOMITE

Limestone and dolomite are currently produced by three companies and hydrated lime by two companies near Kimballton and Repplemead between Mill Creek and Peters Mountain study areas (pl.1). The limestone and dolomite for crushed rock come from various formations of Early and Middle Ordovician age. The hydrated lime is mostly from the Five Oaks Limstone Member of the Cliffield Formation of Cooper and Prouty (1943, p. 863; Cooper, 1944b, p. 22–28), which is of Middle Ordovician age.

The Five Oaks is a fine-grained light-gray rock that has, according to analyses from different companies, an average composition, in percent, of

$CaCO_3$	$MgCO_3$	SiO_2	Al_2O_3	Fe_2O_3	Miscellaneous
98	0.5	0.5	0.8	0.1	0.1

The rock ranges in thickness from 7 to 20 m and can be mined by underground methods where the dip is low (Eilertsen, 1964, p. 4–6). The unit does not crop out closer than a kilometer to any of the study areas and is covered by more than 750 m of younger rock within the study areas. It is not likely to be considered a good target for exloration.

The only limestone within the areas is in the Martinsburg Shale of Middle and Late Ordovician age and the Tonoloway Limestone of Late Silurian age. Analyses (table 6) of three samples of limestone from the Martinsburg and one from the Tonoloway indicate impure siliceous limestones that have little value except as crushed rock.

SILICA SANDSTONE

The high ridges in Giles and surrounding counties are formed by bold outcrops of quartz-rich Tuscarora Quartzite and Keefer Sandstone. These rocks have been used locally for dimension stone and crushed rock and are probably a potential resource of high-silica sandstone. Semiquantitave spectrographic analyses for 72 samples of Tuscarora and 46 samples of Keefer show that many parts of these two formations contain only minor amounts of most impurities (table 1). Twelve samples analyzed chemically (table 7) contain too many impurities to meet specification for better quality glass sand without beneficiation. All would be suitable, however, for silica refractory brick (Carter, 1968, p. 337–338).

Lowry (1954, p. 15–21) described areas of residual sand formed by deep and prolonged weathering of these sandstone formations in nearby areas of Virginia. Similar deposits were not seen in our reconnaissance work, but several areas of low-dipping Tuscarora and Keefer on Salt Pond and Potts Mountains in the Mountain Lake area offer the best conditions for the formation of such residual sand.

Samples of Rocky Gap Sandstone from exposures in the study areas generally contain too much iron for use as a high-silica resource. Sections of this formation in other areas where it has weathered but has not been cemented with iron minerals are good sources of silica sand.

TABLE 6.—*Partial chemical analyses, in percent, of limestone samples from the Mill Creek, Peters Mountain, and Mountain Lake Wilderness Study Areas*

[Samples are random chips taken every 5–15 cm through the interval noted]

Sample	Sample interval (meters)	Chemical analyses											Formation name
		Si_2O	CaO	MgO	Al_2O_3	Fe_2O_3	K_2O	Na_2O	Total S	SO_4	H_2O	P_2O_5	
Mill Creek area													
VMC 620	9.7	9.86	46.3	0.82	2.8	1.50	0.57	0.50	0.787	0.058	0.49	0.0018	Martinsburg Shale.
Peters Mountain area													
VPM 601	24.5	34.0	24.8	1.3	9.1	4.07	2.01	0.78	0.052	0.049	1.1	0.0028	Martinsburg Shale.
VPM 625	22.2	21.6	39.5	1.4	2.1	1.26	.65	.098	.043	.045	.35	.00041	Tonoloway Limestone.
Mountain Lake area													
VML 639	9.1	32.2	25.6	1.3	9.26	4.27	2.10	0.93	0.18	0.029	----	0.0031	Martinsburg Shale.

TABLE 7.—*Partial chemical analyses, in percent, of silica sandstone samples from the Mill Creek, Peters Mountain, and Mountain Lake Wilderness Study Areas*

[Samples are random chips taken every 5-15 cm through the interval noted]

Sample	Sample interval (meters)	Chemical analyses						Formation name
		SiO_2	Al_2O_3	Fe_2O_3	TiO_2	Na_2O	K_2O	
				Mill Creek area				
VMC 624	6	96.8	1.1	1.08	0.28	0.041	0.25	Tuscarora Quartzite.
VMC 634	8.2	97.8	.33	1.56	.20	.075	.080	Do.
				Peters Mountain area				
VPM 611	4.2	98.0	0.38	1.02	0.13	0.016	0.088	Keefer Sandstone.
VPM 615	13.3	97.0	1.0	1.08	.22	.041	.26	Tuscarora Quartzite.
VPM 619	5.3	98.5	.19	1.04	.044	.021	.048	Do.
VPM 620	6.5	97.5	.49	1.42	.11	.021	.11	Do.
VPM 624	4.5	98.3	.24	.96	.11	.016	.049	Keefer Sandstone.
				Mountain Lake area				
VML 605	11.8	97.8	0.53	0.98	0.15	0.032	0.13	Tuscarora Quartzite.
VML 611	5.5	98.4	.41	.64	.11	.015	.085	Do.
VML 627	16.2	98.0	.79	.45	.22	.023	.22	Do.
VML 630	19.2	96.9	.56	1.00	.13	.023	.13	Do.
VML 634	16.4	98.1	.75	.52	.31	.038	.19	Do.

Such exposures of Lower Devonian sandstone similar in lithology to the Rocky Gap are mined in Virginia near New Castle, Craig County; Gore, Frederick County; and Goshen, Rockbridge County (Carter, 1968, p. 342).

In summary, the Silurian sandstones are a high-silica resource, but they are also present outside the study areas in more readily accessible localities, in some of which they form residual deposits more readily minable. The Devonian sandstones contain too much secondary iron in surface exposures to be considered a silica resource. None of these sandstones is considered to be economically important in the study areas.

PHOSPHATE

Traces of phosphate have been found in the Martinsburg Shale (Butts, 1940, p. 208; Woodward, 1951, p. 368), and phosphorus is a minor constituent in the iron-rich sandstones of the Rose Hill Formation and the Rocky Gap Sandstone (table 2). In the roadcut on U.S. Highway 460 North along the Narrows, two brown sandy limestone units 2.7 and 4.9 m thick near the top of the Martinsburg Formation contain phosphatic fossils and pebbles about 5 mm in diameter. X-ray fluorescence analyses by USBM, Reno Metallurgy Research Center, Nev., indicate a phosphorus content of 0.17 percent for sample VML 637 (2.7 m) and 0.23 percent for sample VML 638 (4.9 m). The phosphorus is in the mineral apatite, as determined from x-ray methods by P. L. Loferski, USGS. A buff-olive sandstone in the same general horizon of the Martinsburg Formation near the west-central corner of the Mountain Lake area (locality VML 619, pl. 4) was sampled over an interval of 6 m and found to contain 0.54 percent P. The phosphate (P_2O_5) content of these samples ranges from 0.39 to 1.24 percent, much too low for fertilizer raw material.

The P_2O_5 content of hematitic sandstone in the Rose Hill Formation and limonite-cemented sandstone of the Rocky Gap Sandstone is similar, and the rocks are of no value as a source of phosphorus (tables 2, 4).

SHALE

Mineral surveys conducted by the Commonwealth of Virginia, Department of Natural Resources (Calver and others, 1964, p. 126–134; Johnson and others, 1965, p. 32–40), showed that Devonian shales in the Craig-Giles Counties area have potential use as lightweight aggregate and possibly in the manufacture of brick. Shales of Devonian age within the Mountain Lake area were sampled at three localities (table 8). Preliminary tests and property determinations by the USBM, Tuscaloosa Metallurgy Research Center, Ala., suggest that the Millboro and Brallier Shales, along the southeastern boundary of Mountain Lake study area, would be suitable for brick manufacture. However, better exposures and larger deposits exist in Johns Creek valley northeast of the study area.

DIMENSION STONE

Thick-bedded sandstones from the Tuscarora Quartzite and Keefer Sandstone have been used for building stone in parts of western Virginia and eastern West Virginia. The rock in both formations is difficult to work because it is generally tightly cemented by silica. It is suitable for rough building stone (Arkle and Hunter, 1957, p. 26). The thinner bedded sandstones of the Juniata and Rose Hill Formations can be worked with mechanical trimmers and are, therefore, better suited for dimension stone. These formations have not been used for this purpose in the past.

Commercial marble deposits in Giles County have been described by Mathews and Pegau (1934). They are in limestone and dolomite of Cambrian and Ordovician age. None is exposed within the study areas, and the best prospecting sites near the Mill Creek study area are at the base of Pearis and Wolf Creek Mountains, where a 6-m "marble" member of the Moccasin Limestone (Middle Ordovician) crops out at several places on the hillside (Whitman, 1964). The exposed rock appears fractured and may not be present in blocks large enough to be cut. Similar rock, if present in the study area, is probably buried by nearly 1,000 m of younger formations.

TABLE 8.—*Evaluation of shale samples, Mountain Lake Wilderness Study Area*

[Samples are random chips taken through the intervals noted. Tests indicate the following for all samples: Working properties, short; drying defects, none; bloating tests, negative; no effervescence with HCL]

Sample	Sample interval (meters)	Raw Properties	Slow firing test: Temperature (°F)	Munsell color	Mohs' hardness	Total shrinkage (percent)	Absorption (percent)	Apparent porosity (percent)	Bulk density (gm/c^3)	Potential use
VML 601	16.7	Water of plasticity: 17.3 percent	1,800	5 YR 7/8	3	5.0	14.3	26.9	1.88	Grade SW[1] building brick.
		Drying shrinkage: 2.5 percent	1,900	2.5 YR 5/8	4	7.5	9.4	19.2	2.04	
		Dry strength: poor	2,000	2.5 YR 4/6	7	7.5	6.6	14.2	2.15	
		pH: 5.2	[2]2,100	---	---	---	---	---	---	
VML 602	6.7	Water of plasticity: 19.0 percent	1,800	5 YR 8/4	3	5.0	17.4	30.9	1.77	Grade SW building brick.
		Drying shrinkage: 2.5 percent	1,900	5 YR 7/6	4	7.5	12.7	24.0	1.90	
		Dry strength: fair	2,000	2.5 YR 6/6	6	10.0	9.2	18.4	2.01	
		pH: 4.1	[2]2,100	---	---	---	---	---	---	
VML 617	21.3	Water of plasticity: 18.8 percent	1,800	5 YR 7/8	3	7.5	15.4	28.8	1.87	Type FBS[3] facing brick.
		Drying shrinkage: 7.5 percent	1,900	2.5 YR 6/10	3	7.5	12.3	24.3	1.97	
		Dry strength: fair	2,000	2.5 YR 5/10	3	7.5	10.8	21.8	2.02	
		pH: 6.6	2,100	10 R 4/6	6	10.0	6.3	13.6	2.17	
			2,200	10 R 3/4	7	12.5	2.3	5.1	2.16	
			[2]2,300	---	---	---	---	---	---	

[1] Top grade of standard specification for building brick, American Society for Testing and Materials Designation C-62.

[2] Abrupt vitrification before indicated temperature was reached.

[3] General grade of standard specification for facing brick, American Society for Testing and Materials Designation C-216.

FOSSIL FUELS

Of the three common fossil fuels–coal, oil, and natural gas–only natural gas is a potential resource in the vicinity of the three study areas. The rocks of the study areas are older than the oldest coal beds known in either West Virginia or Virginia. The heat and pressure to which they have been subjected were too great to permit the preservation of oil. Natural gas, however, can exist under these conditions.

OIL AND GAS POTENTIAL

By WILLIAM J. PERRY, JR.

Although no oil and natural gas have been discovered to date in commerical quantities in Craig and Giles Counties, Va., or Monroe County, W. Va., preliminary work on conodont [5] color alteration as an index to organic metamorphism indicates that the Mississippian and older rocks in these counties are a potential source of natural gas (Epstein and others, 1977). North of the Hurricane Ridge Syncline, Mon–1, the G. L. Cabot (no. 1239)–M. S. Twohig deep well, drilled on the Abbs Valley Anticline in northern Monroe County (pl. 1), encountered many "shows" of natural gas in Devonian rocks. The well, drilled to a total depth of 2,010 m, had an initial open flow of 282 MCF (thousand cubic feet)/day from Middle Devonian chert at a depth of 1, 989 m. However, this was not considered a commercial discovery. Other wells (pl. 1) north of the Hurricane Ridge Syncline having "shows" of gas in Mississippian and Devonian rocks include Mer–1 near Bluefield in Mercer County, W. Va., and Sum–1 in Summers County, W. Va.

The known oil and gas exploration nearest to the three study areas is a stratigraphic and structural test well drilled in 1948 near Bane about 6.5 km south-southeast of the Mill Creek area (pl. 1). This well, the California Co.–F. P. Strader No. 1, penetrated 440 m before being abandoned without hydrocarbon shows (Huddle and others, 1956, p. 531). The well starts in Rome Formation (Lower and Middle Cambrian) on the crest of the Bane Anticline. Cooper (1964, p. 97) correlated the rock cut in the lower part of the hole with the Shady Dolomite of Early Cambrian age and thus discouraged any further exploration for oil and gas because of the thinness of the stratigraphic section. A reinterpretation of the stratigraphy in this well, based on a study of the conodonts in the drill cuttings (Perry and others, 1979), shows that younger dolomites of the Knox Group of Late Cambrian and Early Ordovician age are below the older Rome Formation. Evidence for a major thrust

[5] Conodonts are toothlike microfossils that change color as rock temperatures increase owing to depth and length of time of burial. The same increase in rock temperatures also determines the generation of oil and natural gas.

fault is present, therefore, in the test well. This interpretation and other information was used in drawing a cross-sectional model of Giles County, Va., to test the consequences of the revised stratigraphy on the evaluation of gas potential.

The cross-sectional model (pl. 1, *A–A'*) shows two structurally prospective areas for natural gas within Giles County in the inferred Silurian and Devonian rocks beneath the St. Clair and Narrows Faults under the north and south flanks of the Bane Anticline. The northern of the two prospective areas is immediately southeast of the Mill Creek Wilderness Study Area. Rocks of Devonian age in the subsurface at the southeastern edge of the Mill Creek area are inferred–not positively identified–and, if present, would be in a structurally low part of the inferred tectonic slice below the St. Clair and Narrows Faults (Perry, 1977). Therefore, prospects appear to be poor directly below the Mill Creek area, although they are excellent just to the south.

An anticline is outlined by the outcrop area of the Martinsburg Shale in the northeastern part of the Mountain Lake Wilderness Study Area in eastern Giles and western Craig Counties, Va. (pl. 4). This anticline may provide structural conditions in the subsurface such that natural gas may be trapped in Ordovician and Cambrian rocks under the structural closure shown in the cross section (pl. 4). The anticline, in the hanging wall of the St. Clair Fault system, may be formed over footwall structures of unknown attitude and dimension; if so, additional trapping possibilities for natural gas are present. The structure has not been drilled.

Structural conditions favorable for hydrocarbon accumulations appear to be absent beneath the Peters Mountain Wilderness Study Area. This area lies on the tilted upper plate of the St. Clair thrust fault, from which the structurally high parts of the Silurian and Devonian sandstones have been eroded.

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