UNITED STATES DEPARTMENT OF THE INTERIOR

GEOLOGICAL SURVEY

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

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with a section on

Oil and Gas Potential

by

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OPEN-FILE REPORT

OF-78-1076

1978

This report is preliminary and has not been edited or reviewed for conformity with U.S. Geological Survey standards and nomenclature.

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. In the case of 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.

SI UNITS AND INCH-POUND SYSTEM EQUIVALENTS

[SI, International System of Units, a modernized metric system of measurement. All values have been rounded to four significant digits except 0.01 bar, which is the exact equivalent of 1 kPa. Use of hectare (ha) as an alternative name for square hectometer (hm^2) is restricted to measurement of land or water areas. Use of liter (L) as a special name for cubic decimeter (dm^3) is restricted to the measurement of liquids and gases; no prefix other than milli should be used with liter. Metric ton (t) as a name for megagram (Mg) should be restricted to commercial usage, and no prefixes should be used with it. Note that the style of meter^2 rather than square meter has been used for convenience in finding units in this table. Where the units are spelled out in text, Survey style is to use square meter]

SI unit		U.S. customary equivalent	
Length			
millimeter (mm)	=	0.039 37	inch (in)
meter (m)	=	3.281	feet (ft)
	=	1.094	yards (yd)
kilometer (km)	=	0.621 4	mile (mi)
	=	0.540 0	mile, nautical (nmi)
Area			
centimeter^2 (cm^2)	=	0.155 0	inch^2 (in^2)
meter^2 (m^2)	=	10.76	feet^2 (ft^2)
	=	1.196	yards^2 (yd^2)
	=	0.000 247 1	acre
hectometer^2 (hm^2)	=	2.471	acres
	=	0.003 861	section (640 acres or 1 mi^2)
kilometer^2 (km^2)	=	0.386 1	mile^2 (mi^2)

SI unit		U.S. customary equivalent	
Mass			
gram (g)	=	0.035 27	ounce avoirdupois (oz avdp)
kilogram (kg)	=	2.205	pounds avoirdupois (lb avdp)
megagram (Mg)	=	1.102	tons, short (2 000 lb)
	=	0.984 2	ton, long (2 240 lb)

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

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U. S. Bureau of Mines

Summary

The Mill Creek, Mountain Lake, and Peters Mountain Wilderness Study Areas comprise about 8200 ha1/ of steep wooded slopes in the Jefferson National Forest in west central Virginia and adjacent West Virginia. Mill Creek area contains about 1800 ha and Peters Mountain area about 1600 ha in Giles County, Va. Mountain Lake area contains about 3000 ha in Giles County, a little more than 570 ha in Craig County, Va., and nearly 1230 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 non-marine 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 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 up into structural blocks by several major thrust faults. Mill Creek area is a simple syncline lying 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, which lies between the Saltville and St. Clair faults, contains several low-plunging folds and is crossed by several minor thrust faults which may represent the Narrows fault zone.

1/ All measurements are given in SI units. A conversion table for U.S. customary units is given on page i .

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 covered by more than 750 m of younger sediments within the study areas. Potential resources of dimension stone and silica sandstone have no unique properties that differentiate them from similar materials that are 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 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 (Figures A and B). Mill Creek area contains an estimated 370

Figures A and B near here.

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million metric tons of hematitic sandstone, or 55 to 74 million metric tons of iron; Mountain Lake area contains an estimated 1020 million metric tons of hematitic sandstone with 153 to 204 million metric tons of iron; and Peters Mountain area contains 360 million metric tons of hematitic sandstone with 55 to 72 million metric tons of iron. This low-grade iron resource is contained in sandstone beds and lenses 1 to 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 Devonian age are small in the three areas. Less than 100,000 metric tons of limonite-cemented sandstone containing 15 to 20 percent Fe 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.

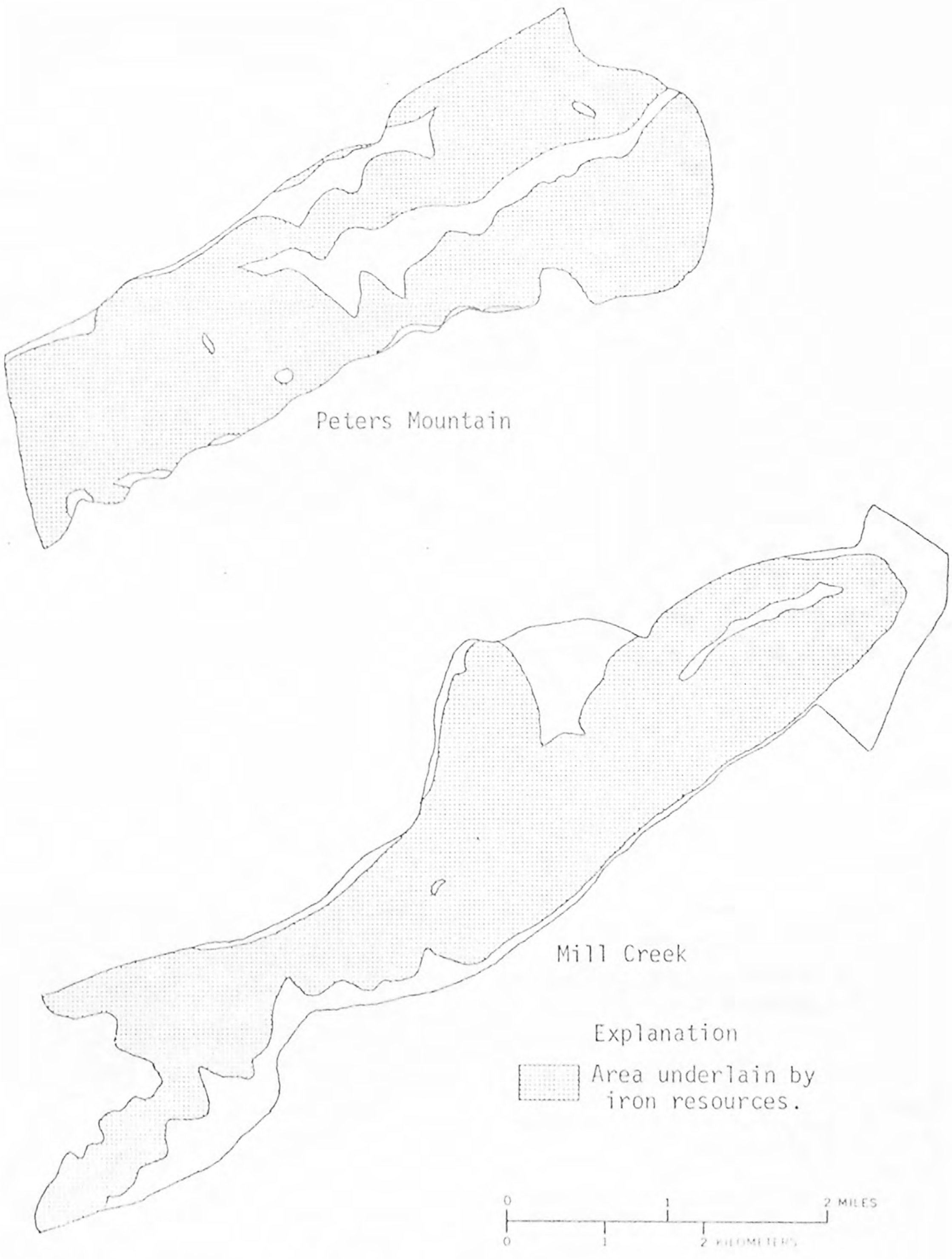

Figure A.--Maps showing areas of iron resources in Mill Creek and Peters Mountain Wilderness Study Areas.

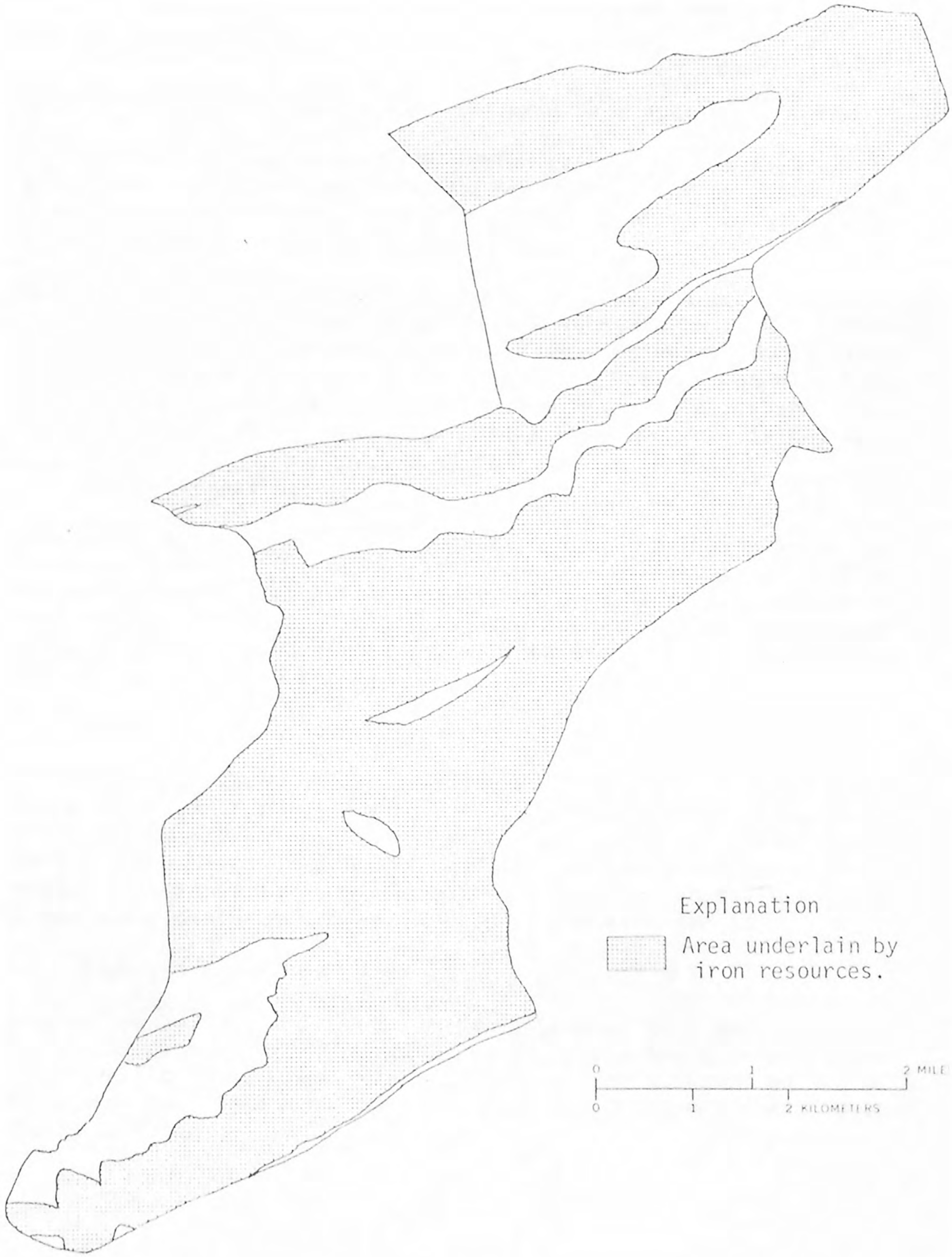

Figure B.--Map showing area of iron resources in Mountain Lake Wilderness Study Area.

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

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Figure 1 near here.

1800 ha1/ in Giles County, Va. The area is a synclinal upland

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1/ The acreages used in this report are estimated by planimetry of U.S. Forest Service boundary maps. Acreages in PL 93-622 are: Mill Creek, 4000 acres (1620 ha); Mountain Lake 8,400 acres (3400 ha); and Peters Mountain, 5000 acres (2023 ha).

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forming the upper drainage basin of Mill Creek and its tributary, Mercy Branch, 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. 2), 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

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Figure 2 near here.

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northwest of the area. Elevations range from 1081 m above sea level on Wolf Creek Mountain, 1107 m at Angels Rest, and 1203 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 (Figures 3 and 4).

Figures 3 and 4 near here.

Mountain Lake study area covers about 4800 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 Mountains and the upper end of Johns Creek valley (Figure 5) and lies along the divide between New River and James River drainage. About 1230 ha of the area are in

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Figure 5 near here.

Monroe County, W. Va., 570 ha in Craig County, Va., and 3000 ha in Giles County, Va. Elevations range from a low of 640 m above sea level in Johns Creek valley to more than 1250 m on Potts Mountain and 1325 m on Bald Knob near the southwest end of Salt Pond Mountain.

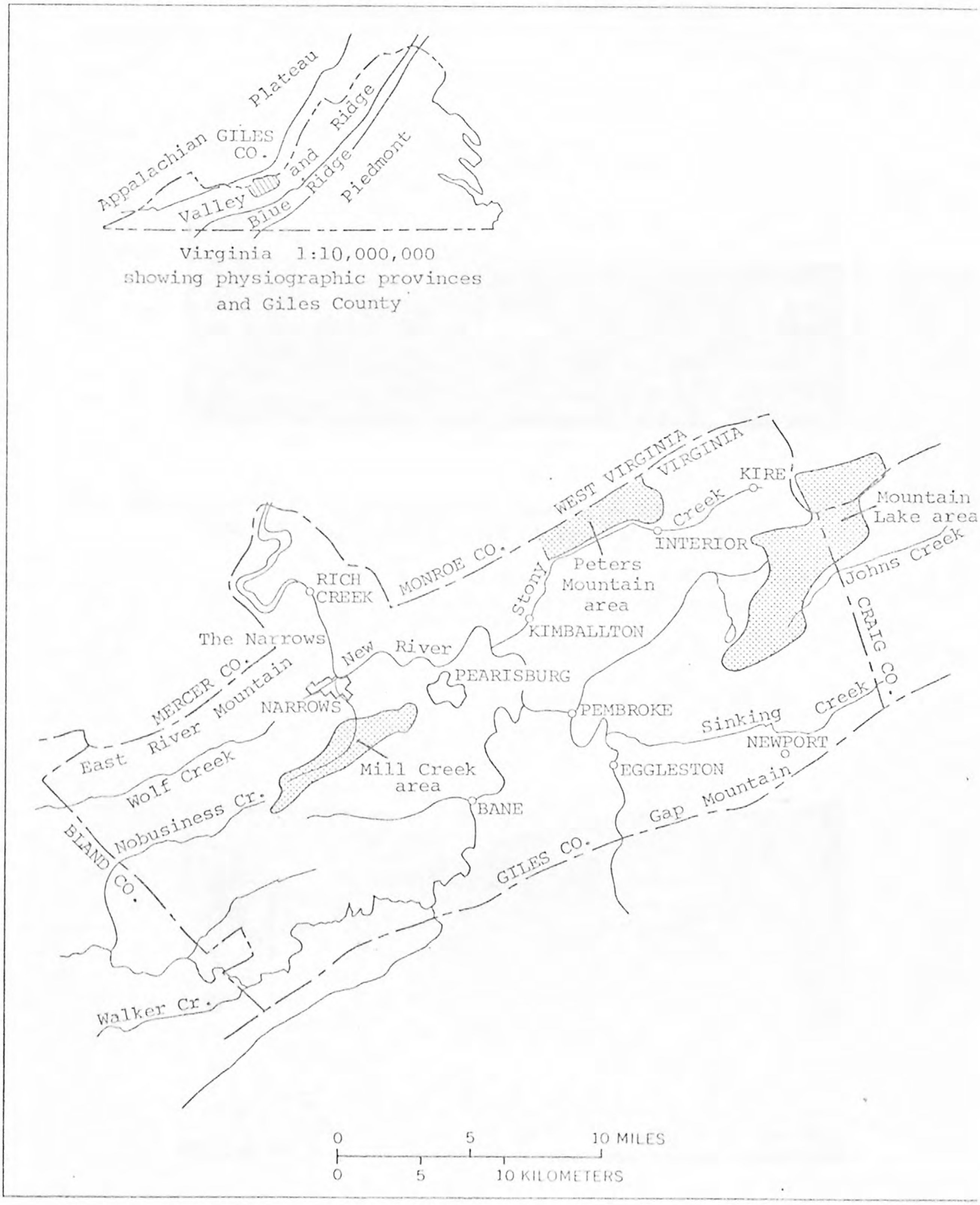

Figure 1. Index map showing location of the three study areas.

Figure 2. View of Angels Rest looking southwest from U.S. Highway 460 east of Pearisburg, Va.

Figure 5. View in the Mountain Lake study area looking southwest along the flank of Salt Pond Mountain towards War Spur in the distant center. Bald Knob is farther distant right. Johns Creek Mountain, the long ridge on the left, is mostly outside the study area.

Figure 3. Panoramic view of Mill Creek study area looking north from the fire tower on Flat Top Mountain, Giles County, Va.

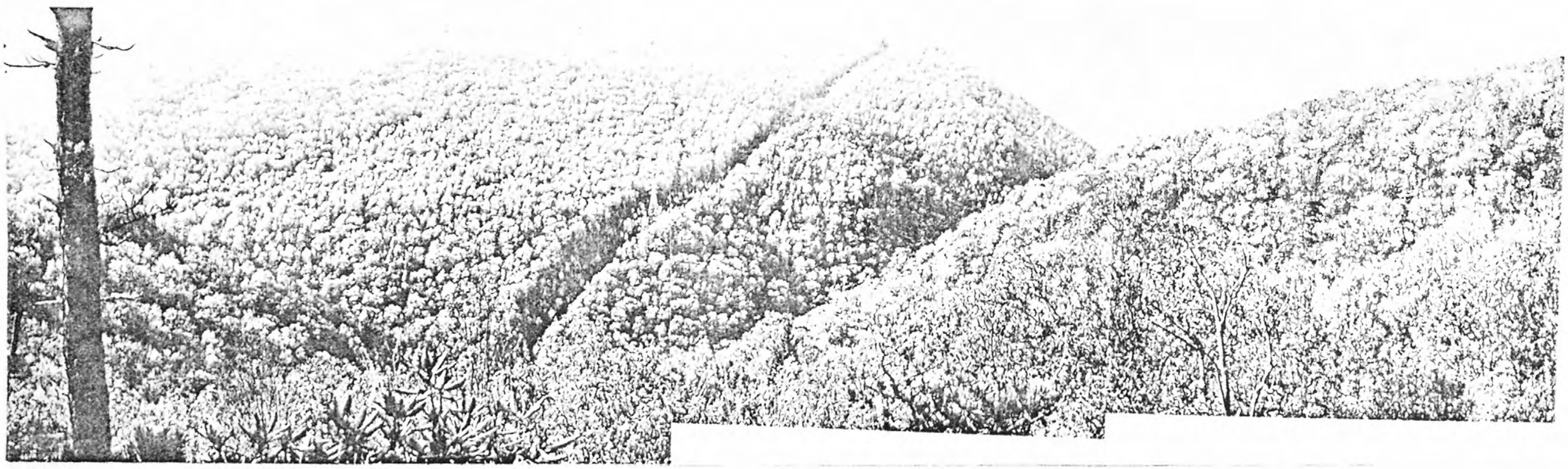

Figure 4. Panoramic view of Wolf Creek Mountain and Mill Creek valley along the northern edge of Mill Creek study area showing one of the two power lines that cross the study area.

Peters Mountain study area covers about 1600 ha of National Forest land that includes a number of 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, Va. 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. (Figure 6). Elevations range from a high of 1205 m on Peters

Figure 6 near here.

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 (figure 7).

Figure 7 near here.

Locally, there are thick areas 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, and the north end of the Mountain Lake area. Mill Creek is crossed by two power lines with cutover right-of-way (fig. 4); Mountain Lake is crossed by one power line.

Previous work

The earliest account of the geology of the three areas is given by W.B. Rogers, 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 (Rogers, 1836, p. 111-112). 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 and three of his cross sections, prepared then but not published until later (1884, plate VII, section 13, plate VIII, sections 12 and 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 published a brief account of the mineral resources of southwest Virginia including Giles County (Boyd, 1881, p. 934-950). Stevenson (1887, p. 61-108) made a reconnaissance of southwest Virginia and recorded some of the geology of Giles County (p. 87-95). Watson (1907, p. 447-8), 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, p. 307-377) 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

Figure 6. View of the northeast end of Peters Mountain study area taken from Interior looking northwest across the valley of Stony Creek towards Peters Mountain.

Figure 7. View southwest up War Spur Branch in the Mountain Lake study area looking towards a small stand of virgin hemlock in the distant center.

description of the rock units of the Appalachian Valley in Virginia that includes the three study areas. Cooper (1944, p. 11-46) described the limestone and dolomites of the county, but these deposits are exposed outside the study areas.

Beginning in 1955, numerous students at Virginia Polytechnic Institute mapped small areas of Giles County for Masters theses. A few of these are pertinent to the wilderness study areas. W.M. Eckroade (1962) studied a large area centered on Butt Mountain, including all of the Peters Mountain and part of the Mountain Lake study area. H.M. 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 began a study of the economic potential of hematitic sandstone in the Rose Hill Formation in southwest Virginia (Cooper, 1958, 1960; Williams, 1957; Chauvin, 1957). Cooper's work led to an exploration drilling program by Minerals Development Corporation, Roanoke, Va., on a large area of National Forest that includes all of 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 Geological Survey personnel during 3 weeks in April and May 1975 and two weeks in May 1976. For Mill Creek area, we used unpublished maps by Whitman (1964) and the Minerals Development Corporation. 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 U.S. Geological Survey 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 based on our reconnaissance mapping, Lesure spent several days field checking the area in April 1976 assisted by J.T. Hanley. 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 of the area. Our field work consisted of six 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. D'Agostino and Grosz collected 50 soil samples in May 1976.

Field investigation by B.B. Williams and M.L. Dunn, U.S. Bureau of Mines, 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 sampling ore material. Also, with regard to the areas' mineral potential, Bureau 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 U.S. Bureau of Mines Reno Metallurgy Research Center, Reno, Nev.. Limestone and silica sandstone tests were made on certain samples. The U.S. Bureau of Mines Tuscaloosa Metallurgy Research Center, Tuscaloosa, Ala., evaluated ceramic properties of shale samples.

Surface and mineral ownership

A portion of each study area is privately owned. Under Wilderness designation, these lands will remain in private hands provided 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. 8). In the Mountain Lake area, about 20 percent of the proposed wilderness is privately owned (fig. 9). In Peters Mountain, only two 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 not. These are FS Tract J-892, 121 ha, and FS Tract J-557, one-half interest of 40.5 ha (fig. 10).

Figures 8, 9, and 10 near here.

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, State Geologist, 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. The Minerals Development Corporation, Roanoke, Va., supplies copies of drill logs and maps of the Mill Creek area. Cooperation of local quarry operators and many local residents is greatly appreciated.

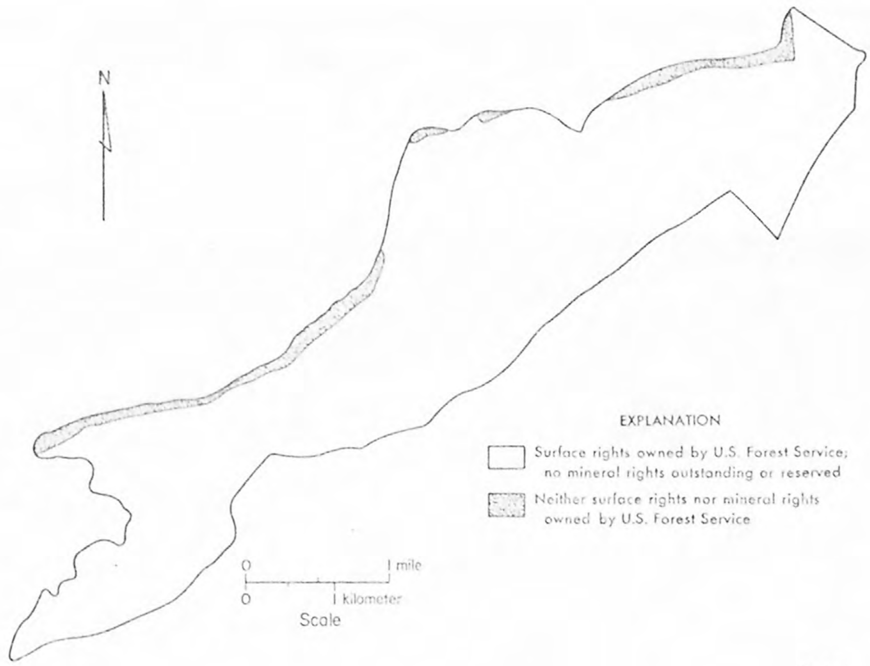

Figure 8.--Land ownership, Mill Creek study area.

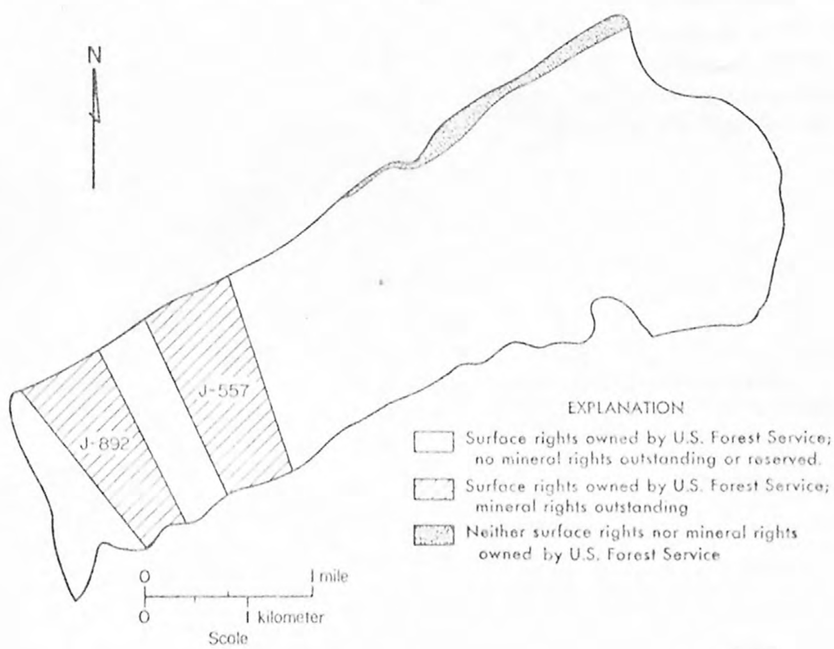

Figure 10.--Land ownership, Peters Mountain study area.

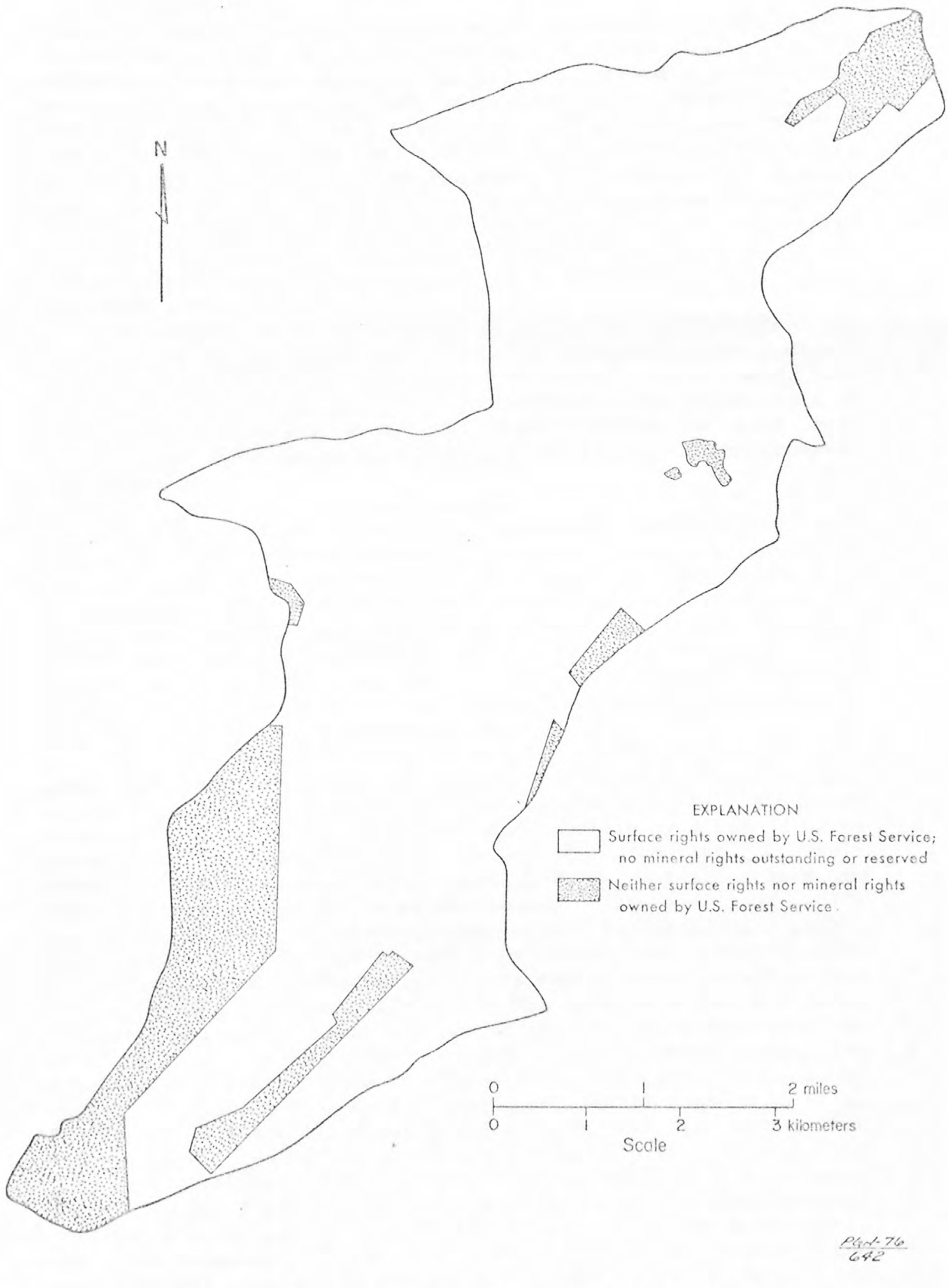

Figure 9.--Land ownership, Mountain Lake study area.

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 (Plate 1). The Mill Creek area is 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, 3, and 4). The youngest geologic units are minor deposits of alluvial clay, sand, and gravel of Quaternary age 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 non-marine 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 the Lower Devonian Rocky Gap Sandstone probably rests on Middle Silurian Keefer Sandstone in the Mill Creek area and on Upper Silurian Tonoloway Limestone or unidentified Upper Silurian sandstones in parts of the Peters Mountain and Mountain Lake areas.

The formations are fairly distinctive lithogic units, but some confusion is possible in mapping 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 and greenish 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 sandstones, 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 and 4) present our best interpretation of the structure based on reconnaissance mapping, photo interpretation, and previous geologic mapping. Additional mapping could improve many minor details.

Ordovician System

Martinsburg Formation

The Martinsburg Formation 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) reports good exposures of Martinsburg at the Narrows reservoir on Mill Creek. None is exposed in the Peters Mountain area, although several small streams have cut so deeply into the overlying Juniata Formation that Martinsburg could be expected along the northeast flank of Peters Mountain (pl. 3). In the Mountain Lake area, 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 Formations. Good exposures of the Martinsburg are 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 Formation is about 550 m thick near the Mill Creek area (Whitman, 1964, p. 38) and 450 to 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, 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 sandstone. Much of the sandstone is crossbedded; cross beds are thin, 1-15 cm, and in layers 30 to 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 areas. The shale is not well exposed except along road cuts.

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 reports 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 red Juniata sandstones ranges from a tenth of one percent to as much as five percent, but is commonly about one or two percent (table 1). The ranges shown in table 1 for 40 other elements do not suggest any unusual concentrations when compared with average sandstone (table 1).

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 much more resistant to weathering than the Juniata. Locally, beds of white quartzite in the Juniata 15 m or more below the top of the formation may be mistaken for Tuscarora or even 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 separate 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 (Figure 11). This distinctive ridge-maker was named

Figure 11 near here.

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.

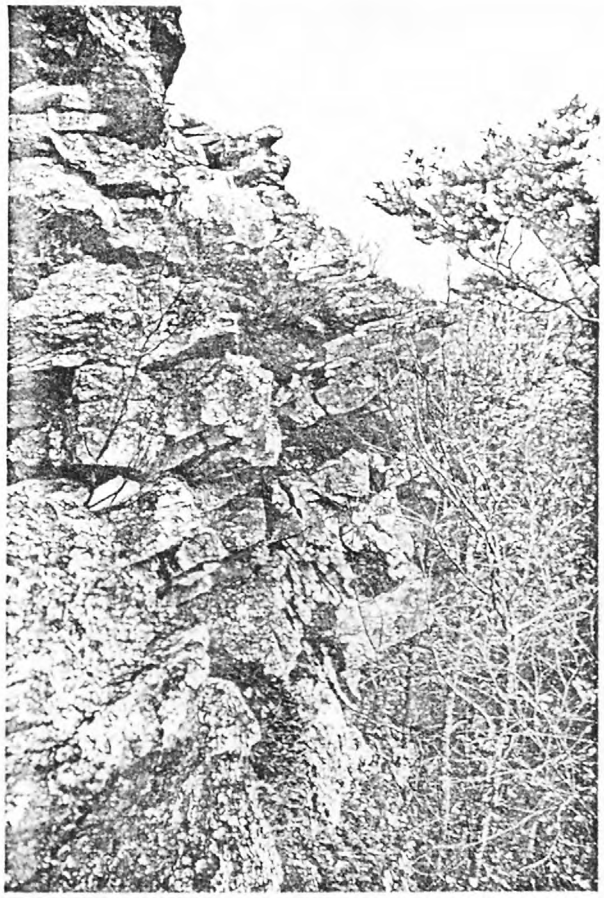

Figure 11a. Tuscarora Quartzite at Wind Rock on Potts Mountain, Mountain Lake study area, looking southwest along strike. The cliff is about 7 meters high.

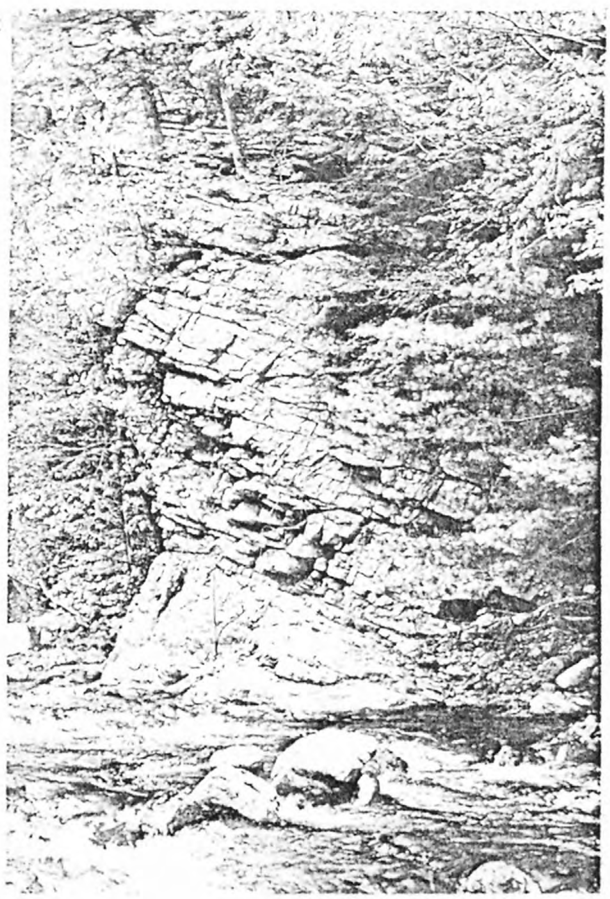

Figure 11b. Tuscarora Quartzite along Stony Creek near the south end of Peters Mountain study area.

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 State Highway 635.

The largest outcrop area of 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 which expose the underlying Juniata Formation below spectacular cliffs of Tuscarora Quartzite such as Bear Cliffs (pl. 4). To the north, straight, narrow outcrops of Tuscarora are present where the formation dips steeply or is repeated by faulting as along the flank of Potts Mountain, and sinuous, narrow exposure patterns form along plunging folds as between White Rocks and Little Mountain. In the three areas, the highest peaks are formed by the resistant beds of 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) reports 30 m of Tuscarora in the Narrows of the New River. Eckroade (1962, p. 35) reports 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 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 towards the top and locally contains minor amounts of shaly interbeds. Bedding is thin, 2 to 10 cm, to massive, 1 to 2 m. Locally, the rock is crossbedded, especially in the conglomeratic layers. The quartzite is generally white to light gray but red and purplish iron stains are common on most outcrops. A silica cement makes it 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 for 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 Tuscoroa where metallic elements have accumulated in the sandstone, replacing 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.

Table 2. Analyses of iron- and manganese-rich rock samples from the Mill Creek, Peters Mountain, and Mountain Lake areas, collected by U. S. Geological Survey.

[For sample locations see plates 2-4. Emission spectrographic analyses by Leung Mei and Norma Rait , U. S. Geological Survey, Reston, Va. G, greater than; N, less than. The standard deviation of any single value should be taken as plus 50 percent and minus 33 percent; iron content in parentheses by Hezekiah Smith, U.S. Geol. Survey, Reston, Va., using colorimetric methods]

	Percent			Parts per million							
Sample No.	Al	Fe	P	Ag	Co	Cu	Mn	Ni	Pb	Zn	Sample description
							Tuscarora Quartzite				
VML 143	1	8	N(.06)	N(.4)	1	1	180	3	16	N(14)	Composite sample of Fe-cemented cobbles of quartzite in layer 30-60 cm thick.
147	N(.06)	11	.39	6	300	77	49,000	380	N(6)	560	Composite sample of Fe-Mn cemented sandstone; old prospect.
148	1.7	1	.18	N(3)	340	270	71,000	700	N(6)	780	Composite sample of Mn-cemented sandstone; old prospect.
151	1.6	9	N(.06)	N(.4)	1	N(1)	71	6	13	N(14)	Chip sample, 45 cm layer, Fe-cemented sandstone; top of formation.
419	.44	9	.22	N(.4)	1	6	290	12	160	24	Fe-cemented, brecciated sandstone.
438	1.1	.48	.10	3	420	230	59,000	260	23	540	Mn-cemented, brecciated sandstone.
							Rose Hill Formation				
VMC 004	1	G23	N(.06)	N(.4)	1	3	59	5	26	120	Hematitic sandstone near base of formation. Specific gravity (Sp.G.) 3.12.
006	1	15	''	''	3	30	77	14	12	32	60 cm thick ledge hematitic sandstone, 3m above base of formation. Sp.G. 2.90.

Table 2 (cont'd)

Sample No.	Al	Fe	P	Ag	Co	Cu	Mn	Ni	Pb	Zn	Sample description
VMC 008	.63	24(28.5)	N(.06)	N(.4)	1	44	49	4	27	100	Chip sample, 4.8 m section hematitic sandstone.Sp.G. 2.96.
009	.61	20	"	"	N(1)	46	100	4	15	84	Hematitic sandstone above sample 008. Sp.G. 2.86.
021	1.1	G23	"	"	3	2	120	19	27	110	Hematitic sandstone near base of formation. Sp.G. 3.11.
022	.96	13(10.2)	.33	"	2	N(1)	51	7	10	N(14)	Chip sample, 1.2 m, hematitic sandstone.
031	1.1	25	N(.06)	"	3	N(1)	60	20	16	23	Chip sample, 30 cm,hematitic sandstone. Sp. G. 2.99.
102	1.2	27(18.5)	"	"	2	39	60	11	19	32	Chip sample, 1.5 m, hematitic sandstone, near top of formation. Sp. G. 2.98.
104	1.3	18	"	"	1	64	61	6	18	70	Chip sample 1.5 m, hematitic sandstone. Sp.G. 2.74.
110	.95	G23(20.5)	.56	"	2	27	58	7	18	81	Chip sample, 3 m hematitic sandstone, 6 m base of formation. Sp. G. 2.92.
111	.83	19	N(.06)	"	1	36	70	5	13	N(14)	Chip sample, 60 cm hematitic sandstone, shale chips, Sp.G.2.81
115	1.4	G23	1.7	.5	11	200	360	52	37	210	Composite sample, float from 2 m zone limonite in sandstone. Sp. G. 3.32.
117	1.1	G23	N(.06)	N(.4)	1	100	100	6	21	42	Chip sample, 1.5 m, hematitic sandstone. Sp.G. 2.89.
120	1	24(23.4)	"	.5	21	18	3,300	11	14	81	Chip sample, 1.5 m, hematitic sandstone near top of formation. Sp.G. 3.1.

Table 2 (Cont'd)

Sample No.	Al	Fe	P	Ag	Co	Cu	Mn	Ni	Pb	Zn	Sample description
VMC 207	1.3	11	N(.06)	N(.4)	4	34	100	16	7	N(14)	Hematitic sandstone Sp.G. 2.76.
305	.98	G23	"	"	1	32	42	4	24	57	Hematitic sandstone. Sp.G. 3.13.
403	1	G23	N(.06)	N(.4)	5	92	110	17	47	83	Composite, float, hematitic sandstone. Sp. G. 3.16.
406	.69	15	"	"	2	81	59	9	18	N(14)	Hematitic sandstone. Sp.G. 2.63.
412	.91	21	"	"	3	85	92	13	14	80	Hematitic sandstone, 2-3 m below top of formation.
VPM 002	.78	23	"	"	N(1)	N(1)	120	9	14	20	Hematitic sandstone. Sp. G. 2.9.
007	1.3	15(10.0)	.31	"	3	"	270	11	14	21	Chip sample, 60 cm, hematitic sandstone, lower part of formation. Sp. G. 2.85.
011	2.2	G23(20.3)	.57	"	4	"	130	16	20	53	Chip sample, 30 cm hematitic sandstone, lower part of formation, Sp.G. 3.02.
012	.69	G23(18.4)	.57	"	1	"	89	6	15	24	Chip sample, 60 cm, hematitic sandstone. Sp. G. 2.85.
016	1.3	19	.40	"	4	"	110	14	14	20	Hematitic sandstone Sp.G. 2.91.
017	.83	G23	N(.06)	"	1	"	73	8	18	42	Chip sample, 1 m, hematitic sandstone. Sp.G. 2.94.
019	1.3	25	.54	"	3	"	260	16	19	39	Chip sample, hematitic sandstone near base of formation, Sp.G. 2.93.
022	1.2	G23	.48	"	4	6	150	22	17	48	Chip sample, 60 cm, hematitic sandstone. Sp. G. 2.9.
030	.61	20	N(.06)	"	N(1)	N(1)	38	5	13	24	Chip sample, 60 cm, hematitic sandstone. Sp.G. 2.96.

Table 2 (cont'd)

Sample No.	Al	Fe	P	Ag	Co	Cu	Mn	Ni	Pb	Zn	Sample description
VPM 104	.98	16	N(.06)	N(.4)	2	N(1)	130	10	16	29	Chip sample, 3 m, hematitic sandstone. Sp. G. 2.79.
116	1.2	G23(23.3)	"	"	1	"	110	9	19	55	Chip sample, 2m, hematitic sandstone.Sp. G. 2.94.
124	.87	18(15.7)	"	"	1	N(1)	61	9	N(6)	76	Chip sample, 2 m, hematitic sandstone. Sp. G. 2.99
125	1.6	25(18.4)	.49	"	2	"	410	9	22	42	Chip sample, 1 m, hematitic sandstone. Sp. G. 2.96.
215	1.7	18	N(.06)	"	3	"	110	14	14	31	Chip sample, 3 m, hematitic sandstone.Sp. G. 2.87.
217	2.0	23	.63	"	4	"	320	11	18	37	Grab sample, hematitic sandstone Sp. G. 2.93.
220	1.2	18	.37	"	6	"	130	26	12	30	Chip sample, 7 m, hematitic sandstone.Sp. G. 2.89.
400	.73	20	N(.06)	"	2	7	100	6	15	74	Hematitic sandstone.Sp. G. 2.95.
401	.94	14	.33	"	3	1	81	51	12	N(14)	Do. Sp. G. 2.89.
404	2.1	16	N(.06)	"	3	3	75	18	11	33	Do. Sp. G. 2.84.
412	1.3	25	"	"	5	1	84	20	16	44	Do. Sp. G. 2.90.
423	1.3	G23	"	"	4	N(1)	370	14	15	94	Composite, float, hematitic sandstone.Sp. G. 2.87.
VML 013	1.1	G23(29.7)	"	"	2	1	140	15	23	130	Chip sample, 1.5 m, hematitic sandstone.Sp. G. 3.07.
017	3	18	"	"	8	N(1)	220	28	15	37	Chip sample, 60 cm, hematitic sandstone.Sp. G. 2.88.

Table 2 (cont'd)

Sample No.	Al	Fe	P	Ag	Co	Cu	Mn	Ni	Pb	Zn	Sample description
VML 019	1.4	23	.67	N(.4)	1	N(1)	140	9	20	86	Hematitic sandstone.
100	1.1	16(11.9)	N(.06)	"	1	3	160	10	12	18	Chip sample, 2 m, hematitic sandstone. Sp. G. 2.87.
102	1	20	"	"	3	N(1)	120	10	16	33	Chip sample, 1 m, hematitic sandstone. Sp. G. 2.85.
109	.9	G23	"	"	2	6	85	13	18	100	Chip sample, 1 m, hematitic sandstone. Sp. G. 3.04.
115	.77	25(19.8)	.48	"	1	2	57	9	16	46	Chip sample, 2 m, hematitic sandstone. Sp. G. 3.12.
126	.68	G23	.51	N(.4)	3	N(1)	100	25	16	74	Chip sample, 1 m, hematitic sandstone. Sp. G. 3.07.
135	.89	G23	.61	"	9	2	260	25	21	120	Chip sample, 2 m, hematitic sandstone. Sp. G. 3.12.
145	.83	G23	N(.06)	"	4	1	320	13	26	49	Chip sample, 1 m, hematitic sandstone. Sp. G. 3.07.
149	1.6	25(22.4)	"	"	5	47	540	18	35	88	Chip sample, 2 m, hematitic sandstone. Sp. G. 3.02.
210	1	G23	.57	.5	2	7	87	8	20	60	Hematitic sandstone. Sp. G. 3.02.
222	1.4	16	N(.06)	N(.4)	1	N(1)	83	3	9	N(14)	Hematitic sandstone. Sp. G. 2.75.
302	1.1	G23	.62	.9	2	9	100	14	650	1000	Hematitic sandstone, near base of formation.
312	1.5	"	N(.06)	N(.4)	4	27	82	14	20	69	Hematitic sandstone, near base of formation.
401	1.1	"	"	"	1	6	100	6	29	44	Hematitic sandstone. Sp. G. 3.01.

Table 2 (cont'd)

Sample No.	Al	Fe	P	Ag	Co	Cu	Mn	Ni	Pb	Zn	Sample description
402	.86	G 23	.97	N(.4)	3	16	230	21	13	130	Limonitic and hematitic sandsto Sp. G. 3.32.
405	3.2	"	N(.06)	"	3	4	330	13	15	68	Hematitic sandstone, near base of formation. Sp. G. 3.09.
414	1	25	.46	"	2	4	93	19	33	53	Hematitic sandstone.Sp. G. 2.88
417	.85	10	.14	"	N(1)	1	100	2	N(6)	N(14)	Hematitic sandstone.Sp. G. 2.78
423	1.2	G23	N(.06)	"	5	10	1000	15	26	130	Hematitic sandstone
440	1.5	"	.62	"	3	1	680	10	39	68	Do.
444	1.2	"	N(.06)	"	4	3	610	10	28	120	Do.
452	.43	21	"	"	1	51	81	6	14	81	Do.
502	1.2	26	.45	"	2	6	99	9	18	93	Chip sample, 1 m, hematitic sandstone. Sp. G. 3.02.
						Keefer Sandstone					
VMC 112	.63	18	.68	N(.4)	7	130	600	37	110	100	Chip sample, 1.5 m. limonite-cemented ,brecciated sandstone.
VPM 205	1	23	.7	N(.4)	35	101	2300	110	130	1500	Composite sample, Fe-cemented sandstone from dump.
VML 009	2.4	G23	N(.06)	.8	1	48	160	9	G1000	190	Bedded (?) limonite.
010	.86	5	"	1	22	2	16000	22	10	58	Fe-Mn cemented sandstone.
424	.24	7	.2	N(.4)	11	34	910	30	53	140	Brecciated sandstone.
425	1.4	1	.12	4.8	780	150	49000	360	210	1700	Mn-Fe cemented sandstone.

Table 2 (cont'd)

Sample No.	Al	Fe	P	Ag	Co	Cu	Mn	Ni	Pb	Zn	Sample description
						Tonoloway Limestone(?)					
VPM 111	.96	G23	.69	N(.4)	18	41	1700	170	42	1300	Limonite replacing thin bedded limestone.
						Rocky Gap Sandstone					
VMC 001	.77	G23	N(.06)	N(.4)	8	14	100	120	42	450	Chip sample, 5 m, Fe-rich sandstone, upper part of formation.
002	.79	20	N(.06)	"	6	14	100	65	32	410	Chip sample, 5 m, Fe-rich sandstone, lower part of formation. Sp. G. 2.60.
100	1.6	G23	N(.06)	"	14	51	300	86	110	450	Chip sample, 3 m, Fe-rich sandstone.
119	.22	G23	N(.06)	"	N(1)	53	88	10	35	190	Chip sample, 1.5 m, Fe-cemented sandstone. Sp.G. 2.81.
200	1.2	G23	N(.06)	N(.4)	10	100	N(68)	100	85	460	Fe-cemented sandstone.
300	2.4	G23	"	"	94	250	320	120	130	590	Do.
301	.93	G23	"	.5	34	80	200	150	51	580	Chip sample, 2.5 m, Fe-cemented sandstone. Sp.G. 2.71.
312	1.8	G23	.9	.8	8	31	210	36	440	140	Fe-cemented sandstone.
400	1.7	G23	N(.06)	N(.4)	21	50	300	78	58	420	Fe-cemented, friable sandstone.
401	.95	G23	"	.6	2	9	52	22	45	280	Do.
VPM 003	.92	G23	1.2	N(.4)	41	87	580	320	30	2000	Do.
004	.19	G23	.5	.8	23	17	4100	68	20	280	Do.

Table 2 (cont'd)

Sample No.	Al	Fe	P	Ag	Co	Cu	Mn	Ni	Pb	Zn	Sample description
VPM 028	.7	25	.7	N(.4)	23	51	150	180	18	1100	Fe-cemented, friable sandstone. Sp. G. 2.60.
033	.93	G23	.7	"	1	46	47	22	20	210	Chip sample, 2 m, Fe-cemented sandstone.
109	.68	21	N(.06	"	1	47	100	26	34	250	Chip sample, 7 m, Fe-cemented sandstone.
127	.72	13	N(.06)	"	1	25	300	12	21	110	Chip sample, 1 m, Fe-cemented, friable sandstone.
203	.39	17	N(.06)	"	1	24	240	15	11	260	Chip sample, 4 m, Fe-cemented sandstone.
204	.51	G23	N(.06)	.4	6	24	120	97	33	1100	Chip sample, Fe-cemented sandstone.
VML 107	.24	G23	N(.06)	.5	15	10	190	360	21	890	Chip sample, 2 m, Fe-cemented sandstone.
112	.32	"	.86	N(.4)	40	36	1800	350	33	930	Chip sample 2 m, Fe-cemented sandstone.
132	.58	13	.41	"	30	59	210	250	14	870	Chip sample, 1 m, Fe-cemented sandstone.
234	.5	10	.44	"	N(1)	18	120	2	14	250	Fe-cemented sandstone.
301	.24	16	1.1	"	12	11	1600	72	21	910	Fe-cemented sandstone. Sp.G. 2.68
409	.66	20	N(.06)	2.5	35	32	30000	14	110	700	Fe-cemented, friable sandstone.

Table 2 (cont'd)

Sample No.	Al	Fe	P	Ag	Co	Cu	Mn	Ni	Pb	Zn	Sample description
VML 426	1.5	2	.13	4.3	870	130	160000	420	1000	4600	Mn-cemented sandstone.
428	.34	23	.67	N(.4)	9	33	320	100	92	880	Fe-cemented sandstone.
429	.74	G23	1.3	"	18	30	470	240	85	2500	Limonite-cemented,brecciated sandstone.
450	1.4	G23	1	"	12	73	430	70	62	1600	Fe-cemented sandstone.
453	.50	20	.7	"	17	96	170	160	310	1800	Do.
						Huntersville Chert					
VPM 110	1.4	18	0.4	N(.4)	4	51	180	34	75	295	Fe-cemented,brecciated chert.
126	.3	13	0.3	N(.4)	9	82	290	83	27	630	Chip sample, 60 cm, Fe-cemented, brecciated chert.

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 were developed and if the need to use such low-grade materials existed. This iron-rich rock has been correlated with the Clinton 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 with only minor variations in the proportions of sandstone and shale. The red beds are its most distinctive characteristic. Rocks we mapped as Rose Hill were included in the Cacapon 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 sandstones and shales. Most common are dark grayish red, very fine- to coarse-grained quartzitic sandstones, well cemented with hematite. Some minor granule and fine-grained pebble 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 crops out well, but interlayered shales are poorly exposed. The shale in intervening areas is covered by abundant flat, slabby cobbles and boulders of sandstone (figure 12).

Figure 12 near here.

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 seems to range from about one-fourth to one-third of the formation but appears to be greater because of the tendency of large amounts of sandstone debris to cover the less resistant shale.

The hematitic sandstone is dense, heavy, and well cemented. Specific gravity of samples collected ranges from 2.63 to 3.32 and averages 2.94. Specific gravity of non-hematitic 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 average sandstones (table 2), but these amounts are not important economically. In addition to these elements, cerium, niobium, strontium, thorium, and zirconium are also a little above the average for sandstone (table 1).

Figure 12a. A typical exposure of Rose Hill Formation in young forest cover on War Spur ridge, Mountain Lake study area.

Figure 12b. Massive and crossbedded Rose Hill hematitic sandstone on State Road 635 up Stony Creek at the south end of Peters Mountain study area.

Whitman (1964, p. 88-91) reports the thickness of the Rose Hill Formation in the Mill Creek area to be 79-82 m, but drilling by Minerals Development Corporation, Roanoke, Va., in that area did not reveal more than 45 m of Rose Hill. Butts (1940, p. 242) reports 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 road cut than the exposure Butts measured. Fish (1967, p. 7) reports 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.

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 both older and younger beds than the Keefer type-section (Woodward, 1941, p. 94-95; Cooper, 1944, 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 road cut 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. Cross bedding 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 tends to be 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 Formation.

The Keefer Sandstone is 30 to 33 m thick in the Mill Creek area (Whitman, 1964, p. 48), 47 m along U.S. 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. 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 the Rocky Gap Sandstone include an unknown thickness of friable sandstones of the upper Keefer and probably 15 to 20 m of Tonoloway Limestone. The contact shown on the geologic maps has been drawn at the base of recognizable Rocky Gap Sandstone.

The ranges in trace element content in 51 samples of Keefer Sandstone are given in table 1. One sample from Mill Creek, one from Peters Mountain, and three from Mountain Lake contain large amounts of iron (table 2). These 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 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 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 of a total lack of exposures. There is no firm evidence that Tonoloway is present in the Mill Creek area. It may have been removed by erosion before deposition of the Lower Devonian Rocky Gap Sandstone. 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

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 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 Sandstone 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 Rocky Gap Sandstone but mostly in the interval normally occupied by Tonoloway Limestone and upper Keefer Sandstone. In Mountain Lake area, the Rocky Gap Sandstone 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, Allegheny 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 Sulfur 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 Sandstone 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.

Huntersville Chert

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 the formation of 20 m along Peters Mountain north of Interior. Some chert was also seen in the soil above Rocky Gap Sandstone 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 analysed. All contain more zinc and iron than 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 Middle Devonian Millboro Shale.

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 Formation. This contact is not well exposed and no attempt to map it was made 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 reports 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.

Cenozoic 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 meters 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 (plate 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 to 30 degrees towards 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 that 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 with 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 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 was also 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 Formations, 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 one area in Peters Mountain, are from the A_2 or upper B soil zones, just below the dark organic-rich surface soil or A_1 zone.

All stream sediment and rock samples were scanned spectrographically for 64 elements and analyzed chemically for gold in the U. S. Geological Survey laboratories, Reston, Va. Soil samples were scanned spectrographically for 30 elements and analyzed chemically for zinc in the U. S. Geological Survey laboratories, Denver, Colorado. 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 outline areas rich in iron and manganese; they do not outline 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); 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 (Plate 5) suggest a bimodal distribution. Other elements tested for seem to have a normal or background distribution in the stream sediments.

In the Mill Creek area, the streams with 70 ppm or more zinc are all outside the study area (Plate 5). These streams drain areas underlain mostly by Ordovician carbonate rocks that are not found within the study area. Limestones and dolomites like these commonly contain traces of zinc.

In Peters Mountain, most of the streams with 70 ppm or more zinc are clustered at the east end of the study area (Plate 5). The stream containing 700 ppm zinc (VPM 207) drains an area which includes the Interior iron mine. Sediment in this stream is heavily contaminated with fines from mining the iron ore. The limonite from the Interior mine contains as much as 1500 ppm zinc; hence the high zinc content of the stream sediment sample. Three other streams in the Peters Mountain area that contain sediment with 100 ppm zinc also drain areas having limonite-cemented Rocky Gap Sandstone.

In 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 (Plate 5).

In order to evaluate further the stream sediment data, soil samples were collected in six areas that have drainage basins containing anomalous zinc. Forty of the soil samples come 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 23 elements in the soils shows no unusual values for most elements (table 1). The median value of zinc in soil from Peters Mountain area is 50 ppm and for 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 Sandstones.

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

The high 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 which produced the small deposits of limonite.

Mineral resources

Mineral resources of the three study areas include both metallic and non-metallic 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 (plate 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 (BLM) drilling permits, BLM-A-050368, 051840, and 051841, issued in 1961 to the Minerals Development Corporation, 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 of these mine and prospect workings have been overgrown 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 generally occurs in three forms: 1) as flattened flaxseed-like particles, called oolites, 2) as replacements of fossil remains that preserve the shape of the original calcareous shells, and 3) as cementing material coating and filling in around 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 one percent (Whitlow, 1962). The ore-grade material is commonly enclosed in or grades into hematitic sandstone or shale. Hematitic sandstone associated with the fossil and oolitic ores of the Birmingham, Ala., district contains 15 to 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 area, Va., 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) reports 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 to 30 percent iron and represent a significant identified conditional or submarginal iron resource.1/

1/ Identified resources are specific bodies of mineral-bearing rock whose existence and location are known. They may or may not be evaluated as to extent and grade. 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 which 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).

Recent exploration

Drilling permits were granted in 1961 by the Bureau of Land Management to the Minerals Development Corporation, Roanoke, Va., to explore, by drilling, a deposit believed at that time to contain more than 272 million metric tons of quarriable hematitic sandstone 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 boundary (Plate 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) describes 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 to 3 m thick; the third is 36-45 m above the base of the formation and is 12 m thick; and 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 Corporation mined "two bulk samples weighing 9 short tons" [8.2 metric tons] 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 was originally expected.

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 amounts of shale interbeds. One prominent sandstone unit drilled by the U.S. Bureau of Mines on Butt Mountain, 3-8 km west of Mountain Lake, was intersected in 8 out of 9 holes (Fish, 1967, p. 14-15). It ranges in thickness from 1.5 to 9 meters 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).

Table 3. - Partial chemical analyses of composite samples from drill core, Mill Creek area.

(Data from Minerals Development Corporation, Roanoke, Virginia)

Hole Number	Sample interval1/ (feet)			Analyses (percent) Fe	P
T2-1a	46.8	-	57.3	8.6	0.17
	59.7	-	61.8	9.1	.13
	63.8	-	77.7	13.6	.18
	107.6	-	118.7	20.1	.32
	118.7	-	119.2	6.7	.18
	119.2	-	124.0	17.7	.38
	124.0	-	125.6	20.8	.436
	125.6	-	130.7	12.0	.20
	130.7	-	135.3	15.5	.28
	135.3	-	135.9	16.6	.28
	135.9	-	140.4	23.7	.48
T2-2a	8.8	-	19.5	10.6	.14
	19.5	-	32.3	13.5	.15
	75.2	-	80.0	23.0	.32
	84.2	-	86.9	21.9	.32
	98.0	-	99.8	32.4	.76
T5-10a	5.5	-	15.0	28.85	.293
	20.5	-	37.9	17.51	.095
T6-12a	4.0	-	14.0	12.57	.079
	14.0	-	16.5	16.60	.133
	49.7	-	56.5	24.02	.323
	57.5	-	59.4	20.63	.120
	62.3	-	65.9	27.40	.321
	73.2	-	77.5	28.53	.461
	83.6	-	83.9	28.88	.842
	125.9	-	127.6	10.80	.124
T5-13a	5.0	-	11.0	24.48	.108
	13.5	-	16.9	28.69	.193
	23.1	-	26.7	24.48	.201
	83.0	-	94.1	18.96	.129
T5-14a	98.1	-	101.6	10.14	.146
	107.0	-	127.5	13.52	.166
	153.8	-	157.6	20.54	.354
	164.1	-	169.6	15.29	.125
	171.0	-	175.3	26.88	.644
T6-15a	4.0	-	10.0	8.91	0.073
	15.4	-	20.5	13.29	.115
	20.8	-	25.0	16.70	.139
	26.5	-	30.0	15.56	.109
	61.1	-	66.1	22.85	.121
	67.1	-	67.5	24.15	.135
	71.9	-	75.2	24.45	.190
	80.1	-	80.8	15.07	.189
	82.9	-	85.6	17.51	.312
	92.9	-	93.8	27.07	1.569
T6-17a	3.0	-	7.2	11.20	.042
	8.5	-	12.5	16.80	.040
	48.0	-	49.5	18.75	.221
	49.5	-	55.3	19.88	.232
	60.0	-	64.5	30.03	.437
	72.5	-	75.9	25.16	.372
T2-18a	4.0	-	9.2	10.47	.018
	9.2	-	13.7	10.98	.108
	13.7	-	21.0	8.55	.136
	23.5	-	37.0	8.23	.140
	38.0	-	41.0	15.98	.118
	74.0	-	79.9	15.98	.122
	81.4	-	88.5	15.01	.128
	88.5	-	95.8	16.30	.110
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.

Chauvin (1957, p. 300) estimated that about 24 percent of the Rose Hill Formation was hematitic sandstone in a well-exposed section along U.S. Highway 460 in the Narrows of the New River. Drilling by the Minerals Development Corporation in the Mill Creek area indicates roughly 30 percent of that part of the formation drilled in 10 holes was hematitic sandstone. The drilling by the U.S. Bureau of Mines on Butt Mountain indicates between 15 and 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 Corporation in the Mill Creek area is 17 percent Fe. The "upper zone" has an average of 6 m of hematitic sandstone with an iron content of 14 percent; the "lower zone" has an average of 4.5 m of sandstone with an iron content of 20.7 percent. Similarly, a weighted average of 17.5 percent iron was obtained for 75 m of hematitic sandstone in U.S. Bureau of Mines drill core from Butt Mountain; nine samples of float from the same area have an average content of 18.1 percent iron (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 road cut on U.S. Highway 460 on Gap Mountain just east of Giles County (tables 2 and 4). Ninety-six samples contain 10 or more percent Fe; 44 contain more than 23 percent Fe. Sixty-two had detectable phosphorus, but the spectrographic method used for analysis of the Geological Survey samples may not be sensitive enough for phosphorus determinations in rock with a high iron content. Sixty-five of the Geological Survey samples represent about 66 m of ferruginous material in outcrop and float and have a weighted average of 20.5 percent Fe. The Bureau of Mines collected 21 samples of thicker sections of rock; these represent 145 m of hematitic sandstone with an average of 14.1 percent Fe. In addition, 17 character samples of float collected by the Bureau of Mines 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 to 3.32.

Resource calculations

A rough calculation of the submarginal iron resource potential in the three study areas can be made based on 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 (Plate 6). For thickness, we assume an average of 9 m of hematitic sandstone within the 45 to 60 m of total Rose Hill Formation. This is a reasonable figure that 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 iron in holes drilled by Minerals Development Corporation is 9 m, and in the holes drilled by the Bureau of Mines on Butt Mountain 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 sandstone in metric tons. By using two average grade figures, 15 percent Fe 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 are not recoverable iron but 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, including reserves of about 108 billion metric tons of rock containing about 27 billion metric tons of iron (U.S. Bur. 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.--Mill Creek area lies in a shallow syncline; the formations dip gently towards the center of the area, and wide outcrop belts are formed on dip slopes. Large-scale stripping or quarrying of the hematitic sandstone 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 has been made by B. N. Cooper (1960). His estimate of "300 to 400 million [short] tons" of hematitic sandstone agrees with our estimates. He was, however, more optimistic concerning grade, and gives a range of 23 to 37 percent Fe (Cooper, 1960, p. 1).

The average iron content in 19 samples collected by the Geological Survey and representing 21 m of hematitic sandstone is 21.8 percent Fe. The Bureau of Mines collected eight outcrop samples representing 44 m of sandstone and averaging 12 percent Fe. Five additional Bureau 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.

Table 5.--Summary of submarginal iron resources in hematitic sandstone of the Rose Hill Formation in the three study areas. See text for explanation of calculations and discussions. Outlines of areas containing resources shown on Plate 6.

Area	Hectares	Hematitic sandstone Millions of metric tons	Contained Iron Millions of metric tons 15 percent Fe	Contained Iron Millions of metric tons 20 percent Fe
Mill Creek				
Rose Hill outcrop	960	250	37	50
Covered 3-60 m	460	120	18	24
Subtotal	1420	370	55	74
Mountain Lake				
Rose Hill outcrop	1310	350	52	70
Covered 3-60 m	1780	470	71	94
Covered>60 m	750	200	30	40
Subtotal	3840	1120	153	204
Peters Mountain				
Rose Hill outcrop	720	190	29	38
Covered 3-60 m	660	170	26	34
Subtotal	1380	360	55	72
Total		1750	263	350

The easternmost hole drilled by the Bureau of Mines on Butt Mountain is only 3 km west of Salt Pond Mountain. This hole, BM 7, shows two zones of hematitic sandstones. The upper is 5.8 m thick and contains 15.8 percent Fe; the lower is 9.1 m thick and averages 20.2 percent Fe (Fish, 1967, p. 13-15). The 25 Geological Survey samples of hematitic sandstone from Mountain Lake area represent 19.3 m of sandstone and average 21.5 percent Fe. Six Bureau of Mines 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 Mill Creek area (table 5). A little more than half of 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 in Mill Creek area and might complicate mining and recovery. The average iron content of 21 samples collected by the Geological Survey and representing at least 25 m of hematitic sandstone is 18.5 percent Fe, a little less than the average for the Mill Creek area. The average for 8 outcrop samples collected by the Bureau of Mines 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 the development of an economically feasible beneficiation process. Beneficiation studies conducted by the U.S. Bureau of Mines Tuscaloosa Metallurgy Research Center (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 from 49.5 to 56.7 percent Fe with recoveries from 89.0 to 92.6 percent; the product, however, is relatively high in phosphorus, 0.245 to 0.271 percent P (Lamont and others, 1967, p. 27).

Similar studies by the Hanna Mining Company (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 with recoveries of 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 a metric ton of iron concentrates can be produced from about 3 metric tons 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 [1] deposits in the Rocky Gap Sandstone and underlying Tonoloway Limestone and upper 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.

1/ We use limonite as a general term for hydrous iron oxides that probably consist of mixtures of the minerals goethite ($Fe_2O_3 \cdot H_2O$) and hematite (Fe_2O_3).

The resulting small deposits of iron-rich rock are restricted to the near-surface part of the formations. This type of ore is best developed in the Clifton Forge iron district, about 65 km northeast of 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 with 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. There is 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 the drainage divide separating No Business and Mill Creeks (fig. 13). The two exposures, less than

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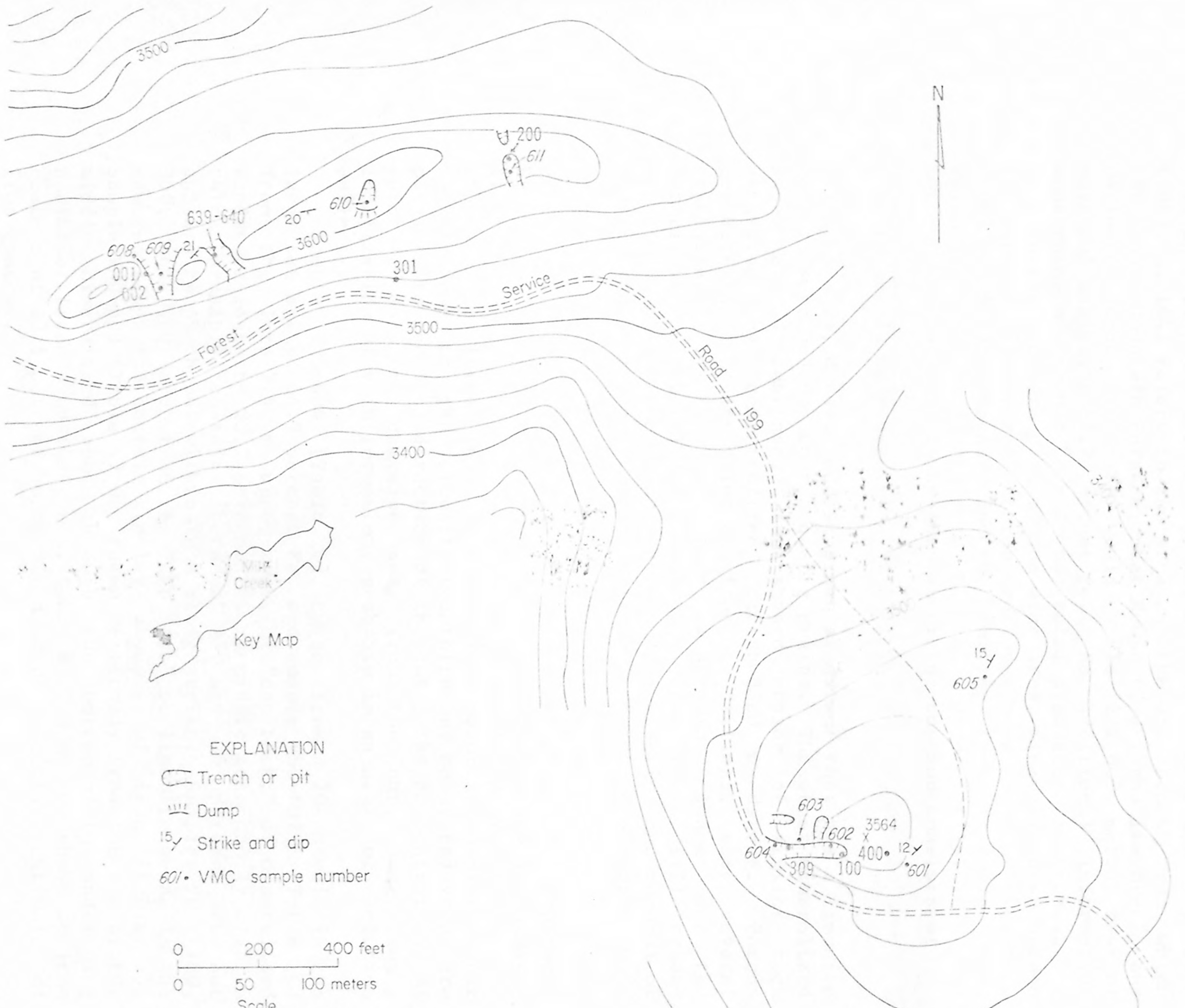
Figure 13 near here.



Contour interval 20 feet

Base enlarged and redrawn from U.S. Geological Survey Narrows, 1965.
Workings sketched from pace and compass traverse.

Figure 13.--Map of Chestnut Flat Mine, Mill Creek study area, showing sample localities.

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) refers 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 metric tons 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 elevation 1,086 m. A large opencut and two smaller trenches were made, revealing several discontinuous mineralized zones (fig. 14). The most continuous zone is at the top of the cut and consists of

Figure 14 near here.

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 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 (figure 15). Evidence of such

Figure 15 near here.

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 essentially 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 concentration of veins appears to decrease away from the cut, suggesting 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, and 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 between 25 and 28 percent iron 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 non-mineralized sandstone, a distance of 3.4 m, and shows an iron content of 13.1 percent, probably a more realistic estimate of iron content.

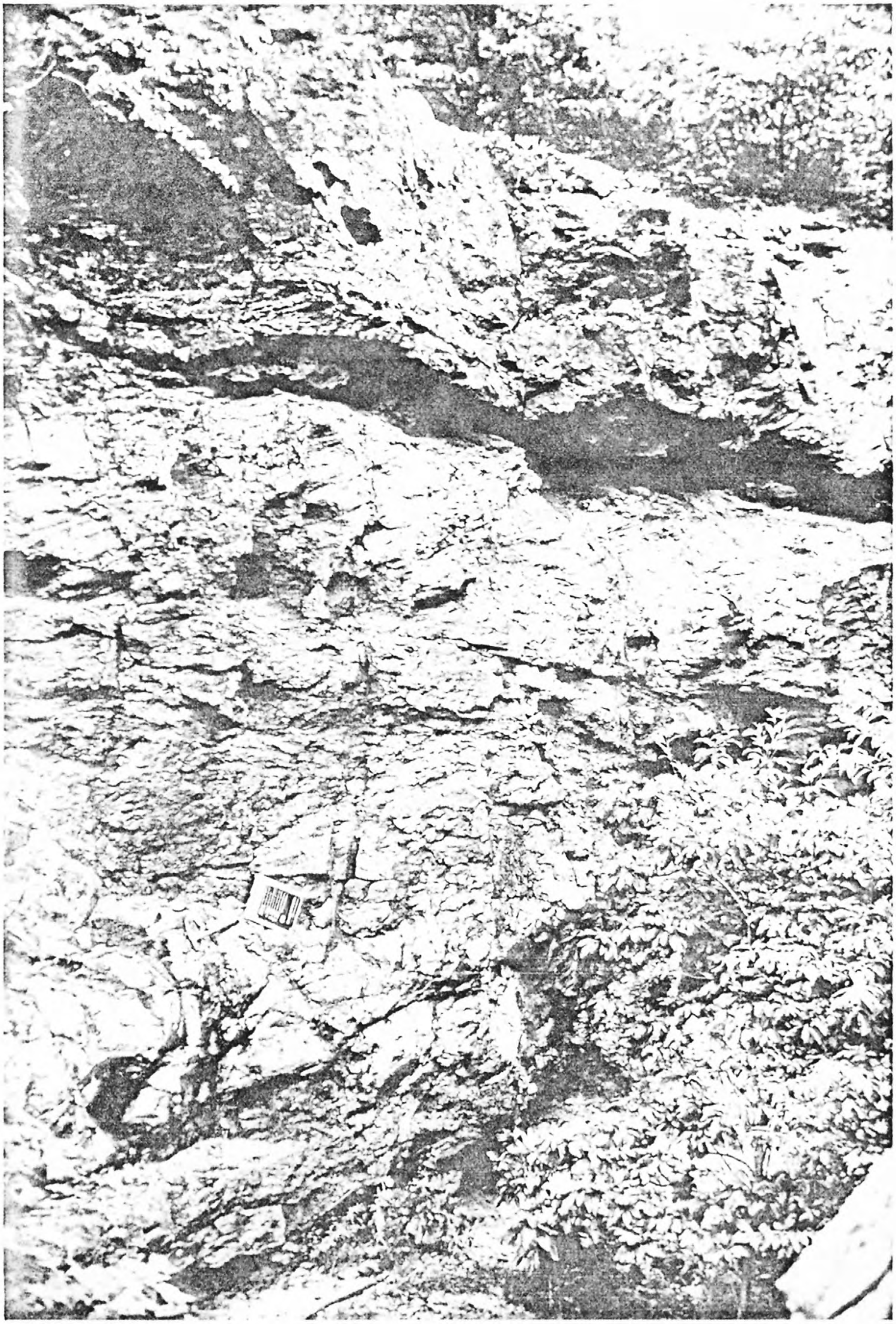


Figure 14. View of the northwest wall of the southern cut of the Chestnut Flat workings showing limonite cemented "cap" rock overlying friable crossbedded sandstone with stringers and veins of limonite.

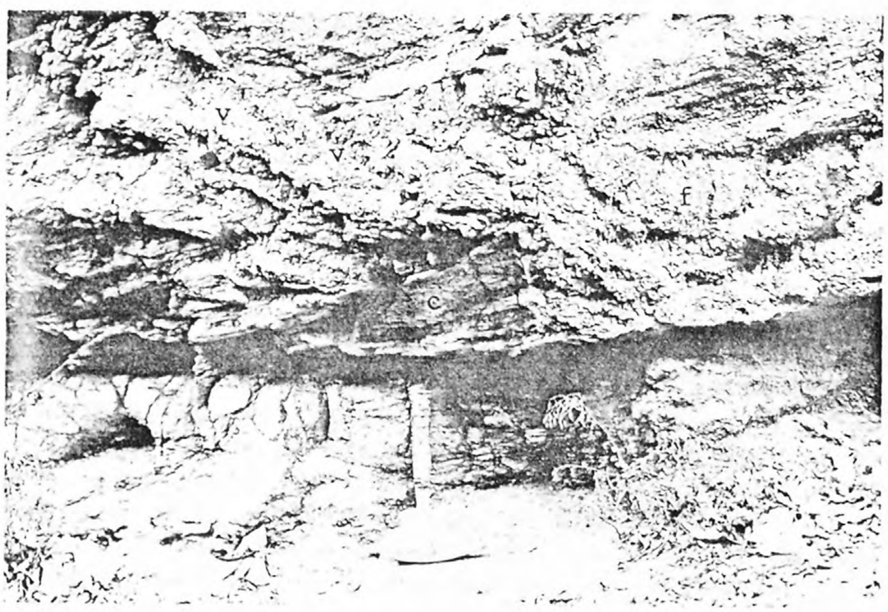


Figure 15. Close-up of the base of the northwest wall of the southern cut showing collapsed block of sandstone (c), vuggy limonite cavity filling (f), and vertical stalagmites of limonite (v).

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 further northeast. Both mineralized and barren sandstones are present, but, except for the "cap rock," the mineralized rock here displays no definite stratigraphic division. Four major workings cross the exposures, each becoming progressively smaller as the amount of iron decreases northeastward along strike. The largest opencut (fig. 16), on the southwestern edge of the outcrop, exposes a 12 m

Figure 16 near here.

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 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 (plate 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 iron. 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 1200 m. Without additional data, however, it is difficult to determine 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 iron. 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 down-dip 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 metric tons of limonitic sandstone containing 15,000 to 20,000 metric tons of iron.

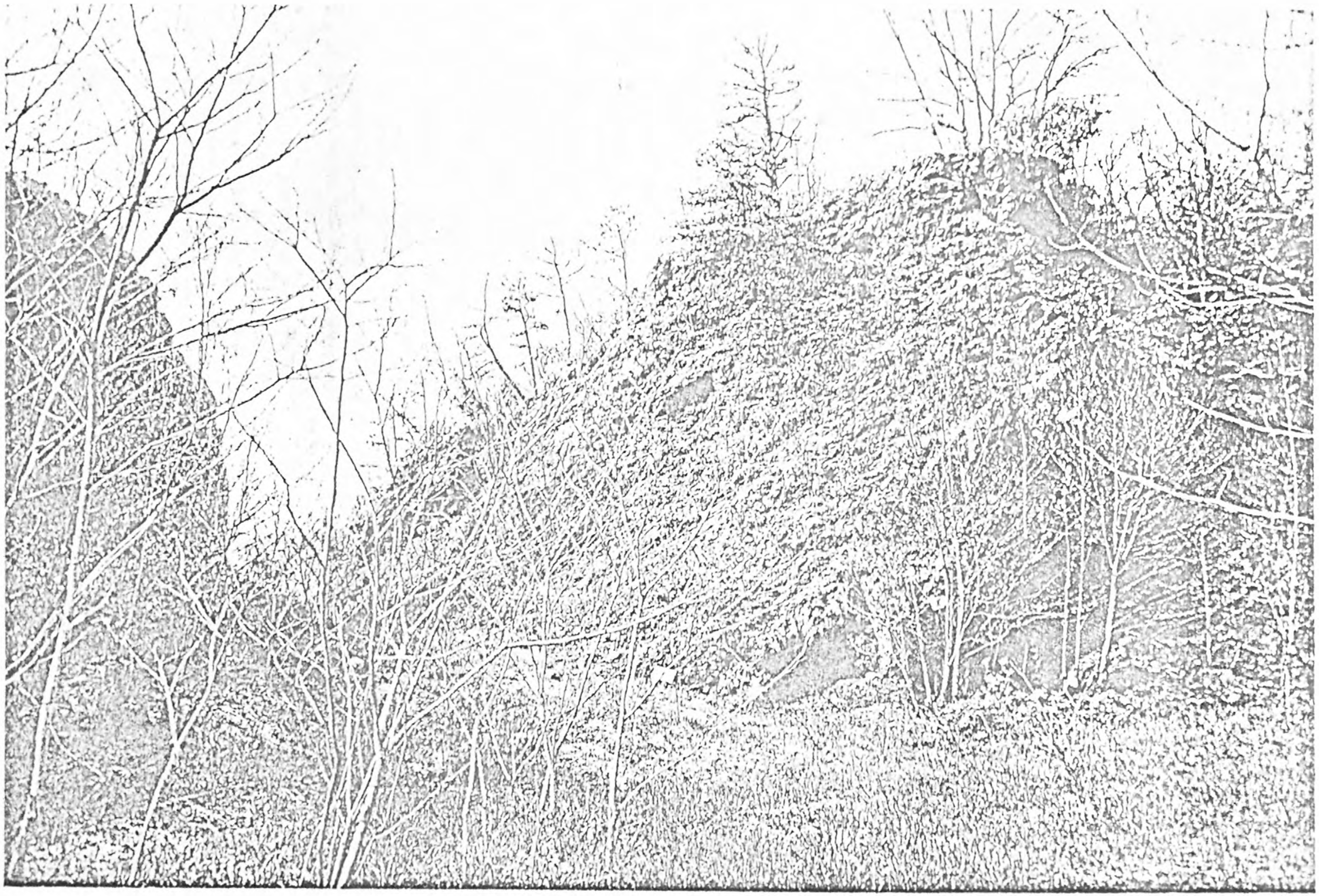


Figure 16. View looking south through the westernmost cut in ferruginous Rocky Gap Sandstone at the north edge of the Chestnut Flat workings. Area partly graded and seeded by the Forest Service.

Unnamed prospect

A prospect pit 6 x 2.4 x 1 m in the Keefer Sandstone is at an elevation of 884 m in the area between Mill Creek and Mercy Branch (Sample Locality VMC-628, plate 2). The pit trends N. 2° W. A select grab sample of material from the dump contains 47.2 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 between 20 and 40 degrees to the southeast and workings (fig. 17) follow the dip of the slope in a north-south direction.

Figure 17 near here.

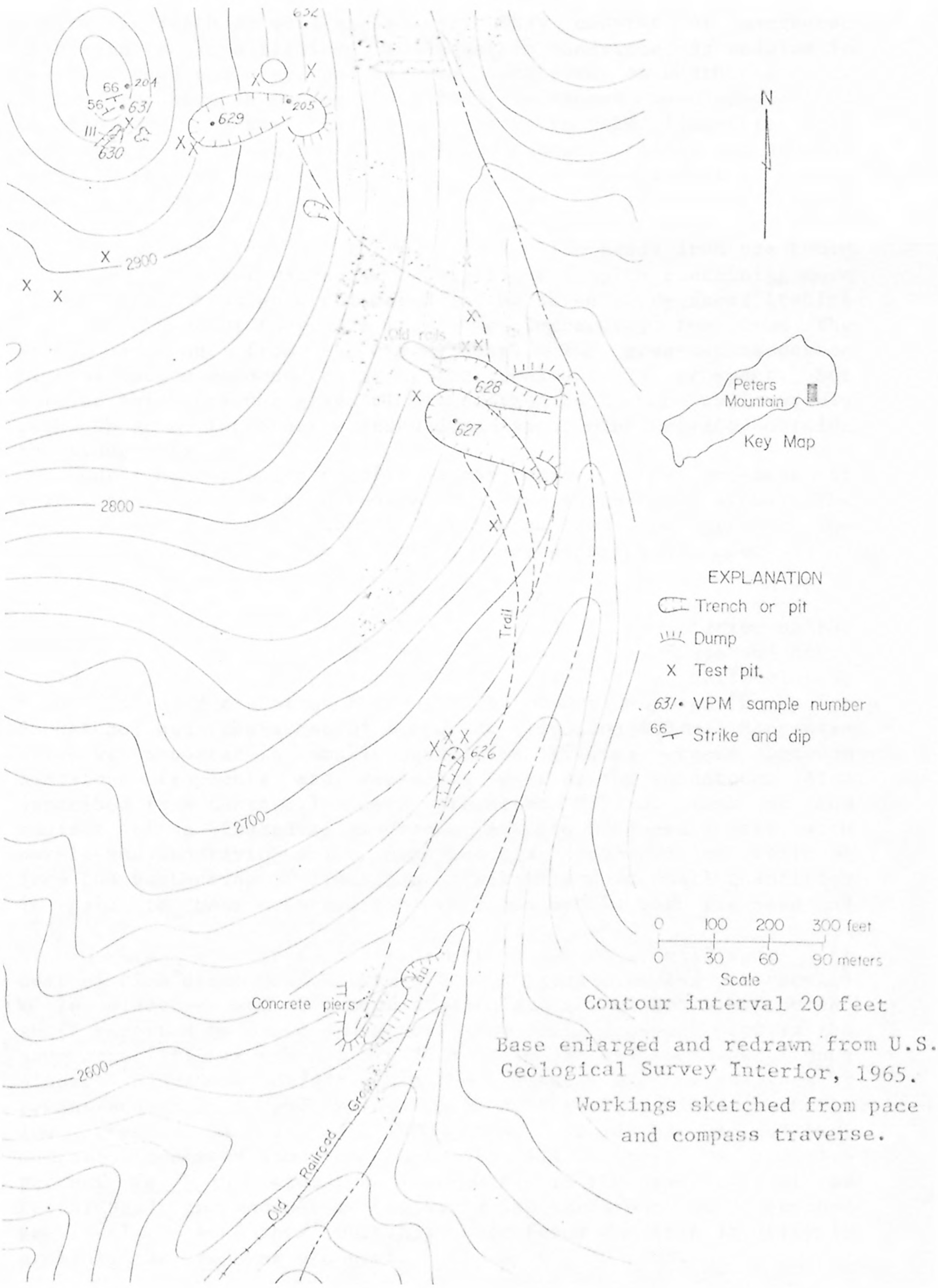
A network of old roads and railbeds are discernible leading from a probable washing and loading point on what was once a spur of the abandoned Potts Valley branch of the Norfolk and Western Railway near the base of the hill. The mine is believed to have operated in the early 1900's but no known records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

The mined area contains four opencuts, with several smaller trenches and numerous test pits, in limonite-cemented sandstone near the contact of the Tonoloway Limestone and the Keefer Sandstone. Slumping and overgrowth conceal the ore zone, but judging from rock debris within the excavation, the ore probably consisted of sandy masses and thin stringers of goethite in both clay and friable sandstone. A non-mineralized sandstone several feet thick is poorly exposed in the large cuts and presumably represents the hanging wall. Assuming this to be true, the material mined could have averaged between 2.4 and 6 m thick (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.

From what can be presently seen and inferred, 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. Rocky Gap Sandstone crops out sporadically along the southeast slopes of Salt Pond and Potts Mountain, northwest of Johns Creek, suggesting a nearly continuous belt of potentially mineralized rock several kilometers in length. 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 are a deterrent to further exploration.



Contour interval 20 feet

Base enlarged and redrawn from U.S. Geological Survey Interior, 1965. Workings sketched from pace and compass traverse.

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 limited in depth as well as 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 were collected in the three study areas (tables 2 and 5). Five of these are from the Tuscarora, two from the Keefer and one from the Rocky Gap. The greatest manganese mineralization encountered 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 (1920, 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 elevation 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, elevation 902 m, sunk at the contact of a fractured sandstone, dipping 60 degrees east, with purple and underlying white laminated clay reported as 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 (Plate 3). A caved circular pit about 3 m in diameter and 2 m deep at an elevation 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, elevation 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 clay-like unit of the Tuscarora Quartzite. Two of the pits, one 6.1 x 3.4 x 1.2 m and the other 3.6 x 1.8 x 1.2 m, occur 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 lying 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 x 3.4 x 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 to 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 State Route 636. A 3.6 x 1.2 x 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 910 parts per million 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 elevations 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 Mn content of 190 parts per million. However, sample VML 426, from the same general area, contains 16 percent Mn (Table 4). The existence of the trenches and a number of 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 (Plate 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

There are numerous manganese mines and prospects in or near the study areas (Plate 1) and several of these, including the Williams Mine, the Chevy Mine, the Stange Mine, and the Gusler (or H. M. Reynolds) Mine, were visited during field investigations. All of these mines produced manganese, and all but the Gusler mine, which is a fault-related residual deposit in Lower Paleozoic carbonates, 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, elevation 853 m, 2,560 m N. 85° W. from the post office at Waiteville, W. Va. (no. 57, Plate 1). The mine was opened in November 1941 (Reeves, 1942, p. 27). By 1950, over 140 metric tons of concentrate had been produced and shipped from an open cut (Bureau of Mines War Minerals file). The ore occurs in a 1.5 m clay bed which is almost certainly Tonoloway residuum. A sample of ore collected from the surface of the clay during field examination analyzed 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 elevation of 582 m (no. 72, Plate 1). The mine is in Craig County, Va., and is 2,440 m N. 29° E. from the benchmark at Webbs Mill. Mining began in the fall of 1916 and by 1919 the mine had been abandoned, having produced about 544 metric tons of manganese ore (Stose and Miser, 1922, pp. 115-117, and Bureau of Mines Statistical Data--Manganese, 1916 through 1919). Psilomelane, the principal manganese mineral, replaces sandstone and fills joints and fissures in rock observed on the mine dumps. Some psilomelane is found in trenches further 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.

Stange Mine

The Stange Mine is in Bland County, Va., near the Bland-Giles County line on the crest of Flat Top Mountain, elevation about 915 m (no. 13, Plate 1). It is 2,680 m N. 39-1/2 degrees E. of the intersection of state roads 606 and 629 at Holly Brook. Except for two periods when the mine was idle (1920-23 and 1944-51), production was continuous from 1917 until 1959, the year Federal stockpiling of manganese ceased. Cumulative production is over 45,000 metric tons of manganese ore, with high-grade ore (more than 35 percent Mn) shipments averaging about 44 percent Mn (Bureau of Mines statistical files, 1916 through 1959). Manganese oxides occur along bedding planes, fill joints and fractures, and, rarely, replace sandstone. A grab sample collected from the dump at the northern cut during our examination contains 29.4 percent Mn and 6.0 percent Fe. The Stange Mine is described by Stose and Miser (1922, pp. 134-142) and by Ladd and Stead (1944, pp. 221-227). Investigations by the Bureau of Mines in early 1941 are described by Moon (1950).

Gusler Mine

The Gusler Mine is in Giles County, Va., on the southeastern slope of Clover Hollow Mountain at an elevation of 700 m (no. 49, Plate 1). It is 3,600 m N. 41-1/2 degrees E. of the benchmark at Newport and is easily visible from the main road, State Route 42. During a 4-year period of Federal stockpiling (1956-59), J. Gordon Gusler produced over 8,163 metric tons of manganese ore (Bureau of mines statistical files) from an open cut about 90 x 60 x 18 m. Ore shipments (high-grade) averaged 45 percent manganese. 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 Knox carbonates. Manganese oxides occur both as the earthy mixture known as "wad" and 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 both an avenue for ore solutions and conditions favorable to deep weathering. Similar situations exist at the Carrie and Laing prospects described by Stose and Miser (1922, pp. 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 formations 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 their boundaries.

Limestone and dolomite

Limestone and dolomite are currently produced by three companies and hydrated lime by two companies near Kimballton and Ripplemead between Mill Creek and Peters Mountain study areas (Plate 1). The limestone and dolomite for crushed rock come from various formations of Lower and Middle Ordovician age. The hydrated lime is mostly from the Five Oaks limestone member of the Cliffield Formation of Cooper and Prouty (1943, p. 863; Cooper, 1944, 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	Msc
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 (Eilertson, 1964, p. 406). 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 exploration.

The only limestone within the areas is in the Martinsburg Formation of Upper Ordovician age and the Tonoloway Limestone of Upper 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 probably are a potential resource of high-silica sandstone. Semiquantitative 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 2). 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) describes areas of residual sands 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 sands.

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 not been cemented with iron minerals are good sources of silica sand. Such exposures of Lower Devonian sandstone similar in lithology to the Rocky Gap are mined in Virginia near New Castle, Craig Co.; Gore, Frederick Co.; and Goshen, Rockbridge Co. (Carter, 1968, p. 342).

In summary, the Silurian age sandstones are a high-silica resource but are present outside the study areas in localities more readily accessible, in some of which they form residual deposits more readily minable. The Devonian age sandstone contains 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 Formation (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. 460 North along the Narrows, two brown sandy limestone units 2.7 and 4.9 m thick near the top of the

Table 6. - Partial chemical analyses of limestone samples from the Mill Creek, Peters Mountain, and Mountain Lake Study Areas

Sample Number	Sample interval[1/] (meters)	Chemical Analyses (percent)											Formation Name
		SiO_2	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 Fm.
							Peters Mountain Area						
VPM-601	24.5	34.0	24.8	1.3	9.1	4.07	2.01	.78	.052	.049	1.1	.0028	Martinsburg Fm.
625	22.2	21.6	39.5	1.4	2.1	1.26	.65	.098	.043	.045	.35	.00041	Tonoloway Ls.
							Mountain Lake Area						
VML-639	9.1	32.2	25.6	1.3	9.26	4.27	2.10	.93	.18	.029	—	.0031	Martinsburg Fm.

1/ Samples are random chips taken every 5-15cm through the interval noted.

Table 7. - Partial chemical analyses of silica sandstone samples from the Mill Creek, Peters Mountain, and Mountain Lake Study Areas

Sample number	Sample interval[1] (meters)	Chemical analyses (percent)						Formation
		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 Ss.
634	8.2	97.8	.33	1.56	.20	.075	.080	do.
				Peters Mountain Area				
VPM-611	4.2	98.0	.38	1.02	.13	.016	.088	Keefer Ss.
615	13.3	97.0	1.0	1.08	.22	.041	.26	Tuscarora Ss.
619	5.3	98.5	.19	1.04	.044	.021	.048	do.
620	6.5	97.5	.49	1.42	.11	.021	.11	do.
624	4.5	98.3	.24	.96	.11	.016	.049	Keefer Ss.
				Mountain Lake Area				
VML-605	11.8	97.8	.53	.98	.15	.032	.13	Tuscarora Ss.
611	5.5	98.4	.41	.64	.11	.015	.085	do.
627	16.2	98.0	.79	.45	.22	.023	.22	do.
630	19.2	96.9	.56	1.00	.13	.023	.13	do.
634	16.4	98.1	.75	.52	.31	.038	.19	do.

1/ Samples are random chips taken every 5-15 cm through the interval noted.

Martinsburg Formation contain phosphatic fossils and pebbles about 5 mm in diameter. X-ray fluorescence analyses by U.S. Bureau of Mines, Reno Metallurgy Research Center, Reno, Nev., indicate a phosphorus (P) content of 0.17 percent for sample VML 637 (2.7 m) and 0.23 percent for sample VML 638 (4.9 m). The phosphorous is in the mineral apatite, as determined from x-ray methods by P.L. Loferski, U.S.G.S. 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, Plate 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 contents of hematitic sandstone in the Rose Hill Formation and limonite-cemented sandstone of the Rocky Gap Sandstone are similar, and the rocks of no value as a source of phosphorus (tables 2 and 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 U.S. Bureau of Mines, Tuscaloosa Metallurgy Research Center, Tuscaloosa, Ala., suggest that shales of the Millboro and Brallier Formations, which occur along the southeastern boundary of Mountain Lake study area, would be suitable for brick manufacture. 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. Both formations are generally tightly cemented by silica, making the rock difficult to work. 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 had little use for this purpose in the past.

Commercial marble deposits in Giles County have been described by Mathews (1934). The occurrences are in limestone and dolomite of Cambrian and Ordovician age. None are exposed within the study areas, and the best prospecting sites located near the Mill Creek study area are at the base of Pearis and Wolf Creek Mountains, where a 6 m "marble" member of the Ordovician Moccasin Limestone crops out at several places on the hillside (Whitman, 1964). The exposed rock appears fractured, and it is not known whether blocks large enough to be cut can be obtained. Similar rock if present in the study area is probably buried by nearly 1000 m of younger formations.

Table 8. - Evaluation of shale samples, Mountain Lake Study Area

Sample number	Sample interval[1/] (meters)	Raw properties[2/]	Slow firing test: Temp.[3/] °F	Munsell color	Mohs' hardness	Total shrinkage (percent)	Absorption (percent)	Apparent porosity (percent)	Bulk density (gm/cc)	Potential use
WML-601	16.7	Water of plasticity: 17.3%	1800	5 YR 7/8	3	5.0	14.3	26.9	1.88	Grade SW building brick
		Drying shrinkage: 2.5%	1900	2.5 YR 5/8	4	7.5	9.4	19.2	2.04	
		Dry strength: poor	2000	2.5 YR 4/6	7	7.5	6.6	14.2	2.15	
		pH: 5.2	2100*	—	-	—	—	—	—	
WML-602	6.7	Water of plasticity: 19.0%	1800	5 YR 8/4	3	5.0	17.4	30.9	1.77	Grade SW building brick
		Drying shrinkage: 2.5%	1900	5 YR 7/6	4	7.5	12.7	24.0	1.90	
		Dry strength: fair	2000	2.5 YR 6/6	6	10.0	9.2	18.4	2.01	
		pH: 4.1	2100*	—	-	—	—	—	—	
WML-617	21.3	Water of plasticity: 18.8%	1800	5 YR 7/8	3	7.5	15.4	28.8	1.87	Type FBS facing brick
		Drying shrinkage: 7.5%	1900	2.5 YR 6/10	3	7.5	12.3	24.3	1.97	
		Dry strength: fair	2000	2.5 YR 5/10	3	7.5	10.8	21.8	2.02	
		pH: 6.6	2100	10 R 4/6	6	10.0	6.3	13.6	2.17	
			2200	10 R 3/4	7	12.5	2.3	5.1	2.16	
			2300*	—	-	—	—	—	—	

1/ Samples are random chips through the interval noted.
2/ Tests indicate the following for all samples: Working properties - short; Drying defects - none; Bloating tests - negative; no effervescence with HCl.
3/ Asterisk denotes abrupt vitrification prior to temperature noted.

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. They have been subjected to heat and pressure greater than the conditions permitting the preservation of oil. Natural gas, however, can exist under the conditions to which the rocks have been subjected.

Oil and gas potential

By

William J. Perry, Jr.

Although no oil and natural gas have been discovered to date in commercial quantities in Craig and Giles Counties, Va., or Monroe County, W. Va., preliminary work on conodont 1/ color alteration as an index to organic metamorphism indicates that these counties are natural gas prospective in Mississippian and older rocks (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 (Plate 1) encountered numerous "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 (million cubic feet)/day from Middle Devonian chert at a depth of 1,989 m. However, this was not considered a commercial discovery. Other wells (Plate 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 nearest known oil and gas exploration 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 (Plate 1). This well, the California Company - F.B. Strader No. 1, penetrated 440 m before being abandoned (Huddle, Jacobson, and Williamson, 1956, p. 531) without hydrocarbon shows. The well starts in Lower Cambrian Rome Shale 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, thus discouraging 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, in preparation) shows that younger dolomites of the Knox Group of Late Cambrian-Early Ordovician age are below the older Rome Shale. A major thrust 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.

1/ Conodonts are tooth-like microfossils that change color as rock temperatures increase due to depth and length of time of burial. The same increase in rock temperatures also determines the generation of oil and natural gas.

The cross-sectional model (Plate 1, AA') shows two structurally prospective areas for natural gas within Giles County in the inferred Silurian and Devonian rocks beneath the St. Clair-Narrows fault under the north and south flanks of the Bane anticline. The northern of the two prospective areas lies 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 portion of the inferred tectonic slice below the St. Clair-Narrows fault (Perry, 1977). Therefore, prospects appear to be poor directly below the Mill Creek area, although excellent just to the south.

An anticline is outlined by the outcrop area of the Martinsburg Formation in the northeastern part of the Mountain Lake Wilderness Study Area in eastern Giles and western Craig Counties, Va. (Plate 4). This anticline may provide structural trapping conditions in the subsurface such that natural gas may be present in Ordovician and Cambrian rocks under the structural closure shown in the cross section (Plate 4). The anticline, in the hanging wall of the St. Clair fault system, may be developed over footwall structures of unknown attitude and dimension, providing additional trapping possibilities for natural gas. 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 portions of the Silurian and Devonian sandstones have been eroded.

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