Mineral Resources of the Barbours Creek and Shawvers Run Wilderness Study Areas, Craig County, Virginia

U.S. GEOLOGICAL SURVEY BULLETIN 1758

Mineral Resources of the Barbours Creek and Shawvers Run Wilderness Study Areas, Craig County, Virginia

By FRANK G. LESURE

An evaluation of the
mineral potential of
two study areas

U.S. GEOLOGICAL SURVEY BULLETIN 1758

DEPARTMENT OF THE INTERIOR
DONALD PAUL HODEL, Secretary

U.S. GEOLOGICAL SURVEY
Dallas L. Peck, Director

UNITED STATES GOVERNMENT PRINTING OFFICE: 1988

For sale by the Books and Open-File Reports Section, U.S. Geological Survey
Federal Center, Box 25425, Denver, CO 80225

Library of Congress Cataloging in Publication Data

Lesure, Frank Gardner, 1927–
Mineral resources of the Barbours Creek and Shawvers Run
Wilderness Study Areas, Craig County, Virginia

(U.S. Geological Survey bulletin ; 1758)
Bibliography: p.
Supt. of Docs. no. : I 19.3:1758
1. Mines and mineral resources—Virginia—Barbours Creek
Wilderness. 2. Mines and mineral resources—Virginia—
Shawvers Run Wilderness. 3. Barbours Creek Wilderness. 4.
Shawvers Run Wilderness. I. Title. II. Series.
QE75.B9 no. 1758 557.3 s 87–600235
[TN24.V8] [553'.09755'795]

Studies Related to Wilderness

Under the provisions of the Wilderness Act (Public Law 88–577, September 3, 1964) and related acts, the U.S. Geological Survey and the U.S. Bureau of Mines have been conducting mineral surveys of wilderness and primitive areas. Areas officially designated as "wilderness," "wild," or "canoe" when the act was passed were incorporated into the National Wilderness Preservation System and have been studied. The act provided that areas under consideration for incorporation into the Wilderness System should be studied for suitability. The mineral surveys constitute one aspect of the suitability studies. The act directs that results of each survey are to be made available to the public and are to be submitted to the President and the Congress. This report discusses the results of a mineral survey of the Barbours Creek and Shawvers Run Wilderness Study Areas, Virginia. The areas, which are in the Jefferson National Forest in Craig County, are part of the Barbours Creek Roadless Area (08–183), which was classified as nonwilderness during the Second Roadless Area Review and Evaluation (RARE II) by the U.S. Forest Service, January 1979. The redefined areas were designated wilderness study areas by the Virginia Wilderness Act of 1984 (Public Law 98–586), October 30, 1984.

CONTENTS

PLATE

FIGURES

TABLES

Mineral Resources of the Barbours Creek and Shawvers Run Wilderness Study Areas, Craig County, Virginia

By Frank G. Lesure

SUMMARY

Mineral-resource surveys made in 1985 indicate that large portions of the Barbours Creek and Shawvers Run Wilderness Study Areas in the Jefferson National Forest, Craig County, Virginia, contain inferred low-grade iron resources that occur in folded sedimentary rocks of Paleozoic age. The areas have an estimated 400 million long tons of contained iron in hematitic sandstone and 300,000 long tons of contained iron in deposits of sandy and cherty limonite. Similar deposits have been worked or prospected widely outside the study areas, but they have little economic potential for the foreseeable future. Other mineral resources in the areas include various rocks suitable for crushed stone, quartzite possibly suitable for high-silica uses, limestone suitable for agricultural uses, and shale suitable for structural clay products. These resources can be obtained readily outside the study areas. A potential for natural gas may exist but cannot be quantified from present knowledge.

Character and Setting

The Barbours Creek and Shawvers Run Wilderness Study Areas include about 10,175 acres of the Jefferson National Forest in the Valley and Ridge province in west-central Virginia. The study areas, which are northwest of New Castle, are on Potts Mountain at the southwest edge of the Clifton Forge iron district (figs. 1 and 2). The highest point in the Barbours Creek study area is 3,804 ft above sea level on Potts Mountain; the lowest point is about 1,660 ft above sea level at the south end along Barbours Creek. The highest point in the Shawvers Run study area is 3,785 ft above sea level on Potts Mountain, and the lowest is 1,720 ft above sea level on Potts Creek.

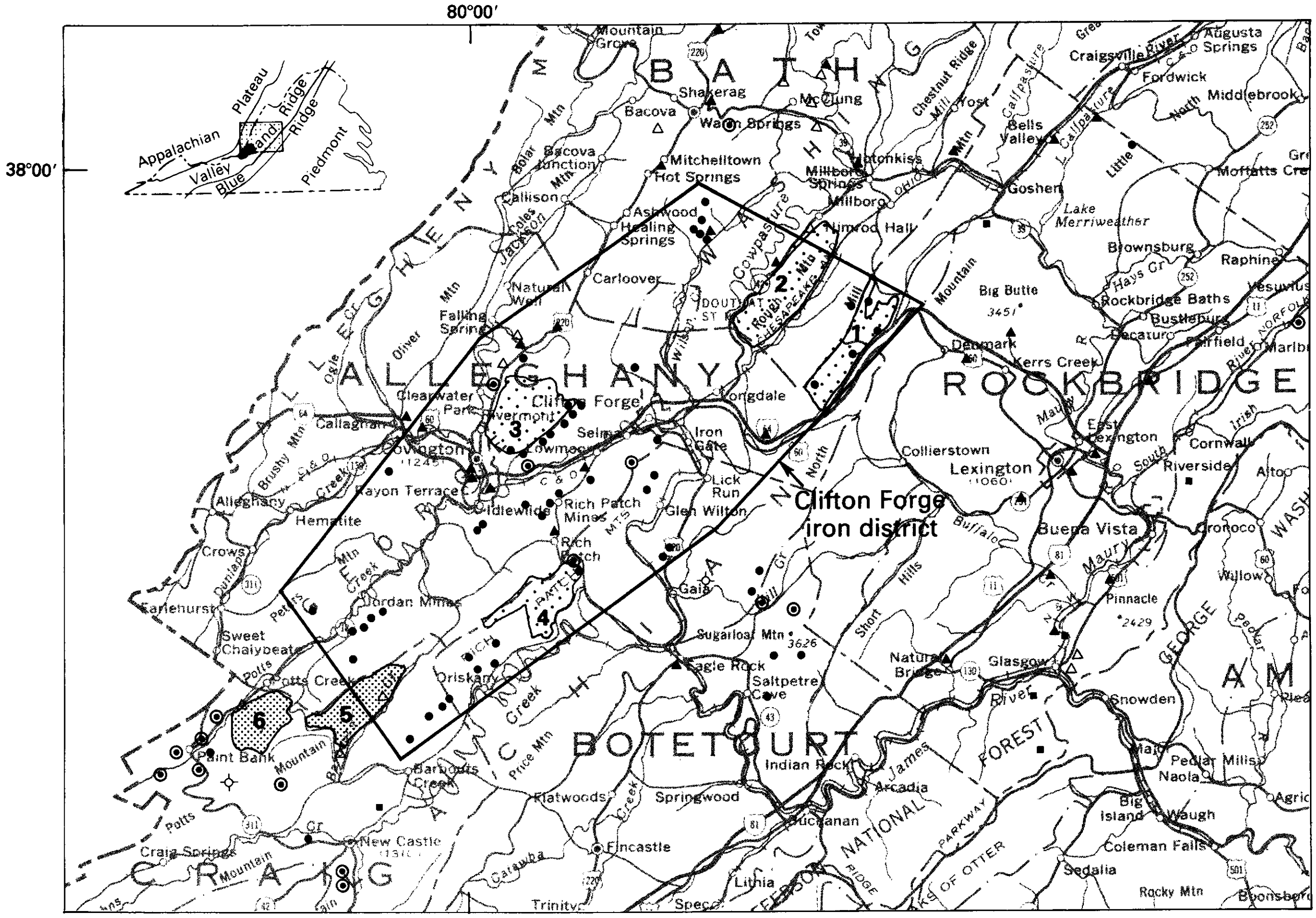
The Federal Government owns all but 100 acres of the surface rights in the Barbours Creek study area and all but 40 acres in the Shawvers Run area. Mineral rights on 10 acres of Government land in the Barbours Creek area and one-eighth of the mineral rights on 28 acres of Government land in the Shawvers Run area are privately owned. Oil and gas lease applications filed for the land in the study areas between 1978 and 1980 have been authorized or were pending in August 1985.

About 5,700–6,300 ft of folded, marine sedimentary rocks of Paleozoic age are poorly exposed in the study areas (Lesure and others, 1987). The oldest of these rocks, interbedded shale, siltstone, and limestone of Late Ordovician age, are present in a small area on the northern edge of the Barbours Creek study area and in much of the southern part of the Shawvers Run study area. The overlying beds of sandstone, quartzite, and hematitic sandstone of Late Ordovician to Middle Silurian age are resistant to erosion and form most of the bedrock in the northern half of the Barbours Creek area and in the central part of the Shawvers Run area. Upper Silurian to Upper Devonian formations overlying the resistant rocks are poorly exposed; they include interlayered limestone, sandstone, and shale units. A Lower Devonian limestone locally contains surficial deposits of limonite through the central part of the Barbours Creek area and in the eastern and northern parts of the Shawvers Run area. The rocks were folded in late Paleozoic time into open, upright to overturned folds. A thrust fault cuts through the central part of the Shawvers Run area and brings Ordovician and Silurian rocks onto Upper Silurian and Devonian formations. This fault may be a splay off the zone of regional thrust faulting that is buried at depths of several thousands of feet below the study areas. A zone of poorly exposed, steeply dipping normal and reverse faults is between the two study areas and may be related to stresses caused by interference of large, plunging folds.

Mineral surveys made in 1983 included geologic mapping (Lesure and others, 1987) and geochemical sampling (Bailey and others, 1986; Lesure, 1987).

Mineral Resources

The study areas, which are in the southwestern edge of the Clifton Forge iron district, contain two types of



Base from U.S. Geological Survey 1:500,000
Virginia State map, 1973

0 5 10 MILES
0 5 10 15 KILOMETERS

EXPLANATION

Wilderness study areas, this report
5. Barbours Creek
6. Shawvers Run

Other wilderness study and roadless areas
1. Rich Hole
2. Rough Mountain
3. Dolly Ann
4. Hoop Hole

◎ Manganese mine or prospect
• Iron mine or prospect
▲ Limestone quarry
△ Shale borrow pit
▪ Silica sand or quartzite quarry
✧ Dry hole

Figure 1. Location of Barbours Creek and Shawvers Run Wilderness Study Areas, other wilderness study areas and roadless areas, and some of the mines, prospects, and quarries in Alleghany, Bath, Botetourt, Craig, and Rockbridge Counties, Va.

low-grade iron deposits—primary deposits of hematitic sandstone in the Rose Hill Formation and secondary deposits of limonite in the Licking Creek Limestone. In the primary deposits, the iron was precipitated from seawater and was concentrated as the sediments were deposited. The iron content is fairly consistent throughout any one sandstone bed and persists to depth.

In the secondary deposits, the iron minerals form discontinuous masses that cannot be projected for any extended distance. The deposits are inferred to have formed during weathering by acidic, iron-rich ground water that dissolved the limestone host rock and precipitated mixtures of iron oxides and hydroxides, loosely termed "limonite." The deposits are near-surface features and grade into unweathered limestone at depth. This type of deposit has been mined extensively 2 mi southeast of the Barbours Creek area and mined to a lesser extent near Paint Bank, about 1 mi southwest of the

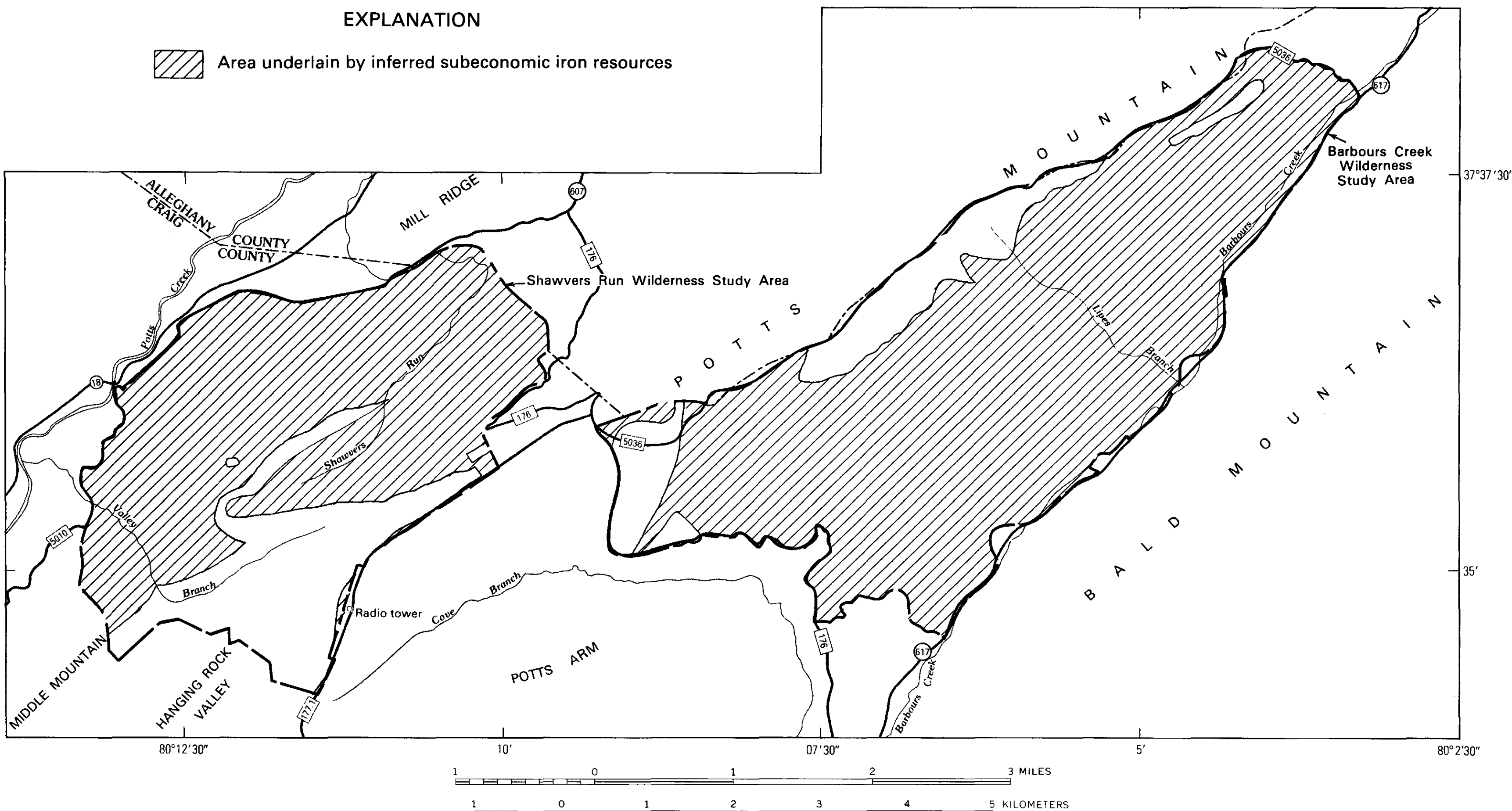


Figure 2. Areas containing inferred subeconomic iron resources, Barbours Creek and Shawvers Run Wilderness Study Areas, Va.

Shawvers Run area. Only minor prospecting has been done within the study areas.

Inferred low-grade iron resources in the hematitic sandstone of the Rose Hill Formation of Middle Silurian age may total as much as 125 ft in beds 1–20 ft thick, interlayered with more than 100 ft of shale and nonhematitic sandstone. The hematitic beds locally contain 28 percent iron but average only 15 percent iron. They underlie an area as large as 5,200 acres in the Barbours Creek area and 3,600 acres in the Shawvers Run area, either as exposed rock or covered by 1 to more than 300 ft of younger rock (fig. 2). This area of inferred low-grade iron resources could contain as much as 2.8 billion long tons of hematitic sandstone or 410 million long tons of contained iron. This iron-bearing formation, which extends from Maryland to Tennessee, is distributed widely in west-central Virginia and eastern West Virginia. It is particularly well developed in Giles County, Va., where it was prospected for iron in the 1950's and 1960's in the Mill Creek Wilderness Study Area.

Four areas of abandoned limonite iron prospects in the Shawvers Run area and one in the Barbours Creek area were worked in the 19th or early 20th centuries. Inferred iron resources in and near these prospects and in three other outcrop areas amount to 670,000 long tons of sandy and cherty limonite having an average grade of 44 percent iron or about 300,000 long tons of contained iron. The potential for subeconomic iron resources of limonite in areas away from the prospects is low to moderate. The limonite deposits of the Clifton Forge iron district have not been worked for more than 50 years and have little economic potential because of sporadic distribution, relatively low grade, distance from potential users, and competition from other richer and more readily available sources.

The study areas also contain sandstone and quartzite suitable for specialty sands, crushed rock, and building stone; limestone suitable for crushed rock and agricultural lime; and shales suitable for use in structural clay products and lightweight aggregate. These commodities, however, are abundant elsewhere in the region and can be obtained more readily outside the study areas.

Although hydrocarbon source beds in Ordovician and Devonian black shales and reservoir rocks in Silurian and Devonian sandstones occur in the study areas, these rocks have been heated to temperatures beyond the range for oil stability and are favorable only for the occurrence of dry natural gas. Inasmuch as the better reservoir rocks are exposed at the surface, any accumulation of gas probably escaped long ago. Extensive fracture porosity associated with the zone of buried thrust faults could have formed potential reservoirs for gas accumulation, but evaluation of this potential would require drilling.

The reconnaissance geochemical sampling in the study areas did not indicate the presence of any metallic mineral resources other than low-grade iron (Lesure, 1987). Minor amounts of zinc are present in the limonite deposits but are too low grade to be a resource. Locally, manganese is more abundant than iron in the limonite deposits, but the grade of the manganese-rich rock is too low, and the size of the manganese deposits too small, to constitute a resource. The black shales of Devonian age contain only minor amounts of uranium and are not potential sources of that element.

INTRODUCTION

The Barbours Creek Wilderness Study Area comprises 5,875 acres, and the Shawvers Run Wilderness Study Area 4,300 acres of Jefferson National Forest land in the Valley and Ridge physiographic province of west-central Virginia (fig. 1). The Barbours Creek area is on the east flank of Potts Mountain, and the Shawvers Run area is on the west flank of Potts Mountain, northwest of New Castle in Craig County (pl. 1*A*). The county line between Craig and Alleghany Counties runs along the ridge of Potts Mountain and forms the northwestern boundary of the Barbours Creek area. The northeastern boundary of the study area is U.S. Forest Service (USFS) trail 5036; the southeastern boundary is Virginia State road 617 along Barbours Creek, and the southern boundary is USFS road 176. On the east, the boundary of the Shawvers Run area follows the Craig-Alleghany County line and then a short length of USFS road 176 on the western side of Potts Mountain; then it turns southwest along USFS road 177 on the crest of Potts Mountain. Six-tenths of a mile south of the radio facility on Potts Mountain, the boundary turns northwest, across the head of Hanging Rock Valley, to the north end of Middle Mountain and down the west side of that ridge to USFS road 5010. There the boundary crosses Valley Branch and continues to near Virginia State road 18 along Potts Creek. The rest of the northern boundary follows the Forest Service boundary line a few hundred feet from Virginia State roads 18 and 607.

Barbours Creek and its tributaries, including Lipes Branch, are the principal streams draining the Barbours Creek study area; Shawvers Run and Valley Branch, tributaries of Potts Creek, are the principal streams in the Shawvers Run study area. The highest point in the Barbours Creek study area, 3,804 ft above sea level, is along the ridge line of Potts Mountain on the north edge of the area; the lowest point is about 1,660 ft above sea level at the southern end along Barbours Creek. The highest point in the Shawvers Run study area is 3,785 ft above sea level on Potts Mountain near the southern end of the study area, and the lowest point is 1,720 ft above sea level on Potts Creek along the western border. In general, the slopes are steep and heavily wooded with second- or third-growth hardwoods and scattered pine and hemlock. Neither area has maintained trails. Old trails in the Lipes Branch area of the Barbours Creek study area are overgrown and hard to find on the upper slopes of Potts Mountain. Abandoned logging trails up Valley Branch and Shawvers Run are poorly defined in some areas. In general, however, the woods are open enough to allow access by foot in both study areas.

Previous Studies

W.B. Rogers (1836, 1838), the first State Geologist of Virginia, studied the geology of the general area between 1835 and 1838. Rogers assigned numbers to the different rock units (Rogers, 1838, p. 21–23), and his units III–VIII are exposed in the study areas. N.H. Darton (1894, 1899) mapped the geology of the Staunton and the Monterey 30-minute quadrangles, which are north of the areas. Geologists who studied the so-called Oriskany iron ores while the deposits were being mined include Benton (1886), Lyman (1886), Pechin (1891, 1896), Chance (1900), Eckel (1906), Holden (1907, 1936), Harder (1909), and Weld (1915). The related manganese deposits were studied by Stose and Miser (1922) and Ladd (1944). The area was included by Butts (1933, 1940) in his general studies of the Appalachian Valley in Virginia. More recent work includes wartime studies of the Oriskany iron ores (Morrison and Grosh, 1950), a summary of iron resources in Virginia by Gooch (1954), and a study of the geology and ore deposits of the Clifton Forge iron district by Lesure (1957).

Present Work

F.G. Lesure, assisted by J.R. Estabrook (U.S. Geological Survey (USGS)) and M.A. Linden (U.S. Forest Service), mapped and sampled the area in October 1985. Altogether, 26 stream-sediment and 73 rock samples were collected and analyzed in the USGS laboratories, Denver, Colo. (Bailey and others, 1986). Debby Kay (USGS) made X-ray diffraction identifications of manganese minerals.

Surface- and Mineral-Rights Ownership

The Federal Government owns all but 100 acres of surface rights in the Barbours Creek study area and all but 40 acres in the Shawvers Run area. Mineral rights on 10 acres of Government land in the Barbours Creek area are privately owned, and one-eighth of the mineral rights on 28 acres of Government land in the Shawvers Run area are privately owned. Oil and gas lease applications filed for land in the study areas between 1978 and 1980 have been authorized or were pending in August 1985.

Acknowledgments

Palmer Sweet of the Virginia Division of Mineral Resources provided mine and prospect data and other reference material for this area in Virginia. M.A. Linden, U.S. Forest Service, Jefferson National Forest, and Janet Hale, Bureau of Land Management, provided information regarding oil and gas leasing and surface and mineral ownership.

GEOLOGY

The rocks exposed in the study areas are chiefly marine clastic sedimentary rocks of Ordovician to Devonian age (pl. 1*A*), which have an aggregate thickness of about 5,700–6,300 ft (table 1) (Lesure and others, 1987). The oldest formation present in outcrop is the Martinsburg Shale of Middle and Late Ordovician age, which is exposed in a small area along the northern boundary of the Barbours Creek area on Potts Mountain and in the head of Valley Branch, west of Potts Mountain in the south-central part of the Shawvers Run area (pl. 1*A*). An overlying sequence of resistant sandstone and quartzite beds interlayered with shale, ranging in age from Late Ordovician to Middle Silurian, includes the Juniata Formation, Tuscarora Quartzite, Rose Hill Formation, and Keefer Sandstone, which form the bedrock of the northern half of the Barbours Creek study area and the central and southern parts of the Shawvers Run area. The Upper Silurian and Lower Devonian formations overlying these resistant units are poorly exposed along the lower eastern slopes of Potts Mountain in the Barbours Creek area and in the northwestern and eastern parts of the Shawvers Run area. These formations include the Wills Creek Shale, Williamsport Sandstone, Tonoloway Limestone, Keyser Limestone, Healing Springs Sandstone, Licking Creek Limestone, and Ridgeley Sandstone. The Middle and Upper Devonian Romney Shale and Jennings Formation are poorly exposed along the southeastern one-third of the Barbours Creek area and in the lower parts of the valleys of Potts Creek and Shawvers Run.

The sedimentary rocks were deformed in late Paleozoic time during the Alleghany orogeny into upright to overturned folds. The Barbours Creek study area is on the east limb of the Potts Mountain anticline (Lesure, 1957, p. 61). In the southeast, the Shawvers Run study area contains an overturned anticline that is a continuation of the Rich Patch anticline (Lesure, 1957, p. 61) and several parallel folds. The syncline northwest of the Rich Patch anticline has been thrust northwestward over another syncline and an adjacent anticline. This thrust

Table 1. Summary of the geologic formations in the Barbours Creek and Shawvers Run Wilderness Study Areas, Craig County, Va.
[Modified from Lesure, 1957, p. 20]

Age			Name	Thickness, in feet	Lithologic character
Cenozoic	Quaternary	Holocene	Alluvium and colluvium		
			Alluvium	0–30	Clay, sand, and gravel on floodplains and terraces.
			Landslide and colluvium	0–50	Angular sandstone blocks forming talus fields on higher ridges.
Paleozoic	Devonian	Upper	Jennings Formation	2,000	Interbedded shale, siltstone, and fine-grained sandstone, generally thin bedded but locally thick bedded. Lower nonfossiliferous beds correlated with Brallier Shale; upper fossiliferous beds correlated with the Chemung Formation. Probably only lower beds present.
		Middle	Romney Shale		
			Upper part (correlates with Millboro Shale).	900	Black fissile shale; calcareous concretions in upper part grade laterally into dark-gray calcareous beds; includes some olive-gray shale.
			Lower part (correlates with Needmore Shale).	100	Medium- to light-olive-gray shale; poorly exposed.
		Lower	Ridgeley Sandstone	5(?)	Medium- to coarse-grained calcareous sandstone; where cemented with iron oxides forms hanging wall of many of the Oriskany iron deposits.
			Licking Creek Limestone	100–120	Upper part, arenaceous limestone; where replaced by iron oxides forms Oriskany iron-ore zone. Lower part, cherty limestone; forms footwall of the Oriskany iron deposits.
			Healing Springs Sandstone	15–25	Medium-grained calcareous sandstone; not exposed and may not be present.
	Silurian	Upper	Keyser Limestone	60	Upper part, nodular limestone; lower part, calcareous sandstone, poorly exposed, is the Clifton Forge Sandstone Member.
			Tonoloway Limestone	150–200	Thin-bedded argillaceous limestone; poorly exposed.
		Middle	Williamsport Sandstone(?) and (or) Willis Creek Shale(?).	50(?)	Thin-bedded calcareous sandstone and shale; poorly exposed.
			Keefer Sandstone	300–350	Resistant quartzitic sandstone; a few thin beds of dark shale.
		Lower	Rose Hill Formation	200–250	Dark-red hematitic sandstone and greenish-gray shale; some medium-gray sandstone and moderate-red shale.
			Tuscarora Quartzite	100–125	Resistant, quartzitic sandstone; thin lenses of pebble conglomerate.
	Ordovician	Upper	Juniata Formation	200–250	Mostly grayish-red, reddish-brown, yellowish-brown, and olive-gray sandstone; some grayish-red and olive-gray shale.
			Martinsburg Shale	1,000–2,000	Medium- to light-gray calcareous shale and thin-bedded argillaceous limestone; some interbedded coarse crystalline limestone.

may be a splay off the zone of regional thrust faulting that is buried at depths of several thousands of feet below the study areas (Milici, 1980). A zone of poorly exposed, steeply dipping normal and reverse faults between the two study areas may be related to stresses caused by interference of large, plunging folds. Movement along these faults may have been in part scissorlike or hinged.

Parts of the areas are covered by a series of landslide masses and by colluvial material consisting of boulders and cobbles of red and white sandstone from the Lower and Middle Silurian formations. This debris conceals the bedrock mostly where the Upper Silurian and Lower Devonian formations would otherwise be exposed (Lesure and others, 1987).

MINING ACTIVITY

Although both the Barbours Creek and Shawvers Run study areas contain iron prospects, little iron ore has been mined in either area. Both iron and manganese ore were mined in surrounding areas (fig. 1). Limestone, sandstone, and shale have been mined for crushed rock and fill in several small open cuts in nearby areas.

Iron and Manganese Prospects

The two study areas are at the southwestern edge of the Clifton Forge iron district, a region of many abandoned iron mines. Iron production in the district began before 1800 (Lesley, 1859, p. 68–73; Bruce, 1931, p. 454), peaked during the period 1890–1920 when most mines in the district were in operation, and ceased by 1925 when all mining operations stopped. Production records are incomplete, but the district as a whole has been credited with a production of 13 million long tons of iron ore (Morrison and Grosh, 1950, p. 3). Total production for 11 mines in the central part of the district was more than 6 million long tons of iron ore (Lesure, 1957, p. 81-82). Manganese deposits in the district are small, low-grade deposits that were never worked extensively (Stose and Miser, 1922, p. 101–119).

The nearest iron mining to the study areas was at the Fenwick and Lignite mines on the southeast slopes of Bald Mountain 2 mi southeast of the Barbours Creek study area, the Double Ridge mine on the northwest slope of Little Mountain 1 mi northwest of the Barbours Creek area, and the Paint Bank iron mines 1 mi or more southwest of the Shawvers Run area (fig. 1). Several manganese prospects and small mines are in the Potts Creek valley north and west of Paint Bank (Ladd, 1944), and other iron and manganese prospects are south of the study areas nearer New Castle (Stose and Miser, 1922, p. 112–119).

Only one iron prospect is known in the Barbours Creek study area (pl. 1*A*, prospect E). This prospect, which is in the central part of the study area, consists of a short trench, 30 ft long, leading to an adit that continues for 20 ft or more, N. 75° W., into the hillside. About 5–10 ft of iron-cemented sandstone containing 48–50 percent iron is poorly exposed in the adit, and limonite-cemented sandstone is present as loose boulders for 1,000 ft to the southwest and 500 ft to the northeast. The lack of any well-defined road suggests that little ore was removed from the site.

Four prospect areas were found in the Shawvers Run study area (pl. 1*A*, prospects A–D). Prospect area A is on a small hill south of Shawvers Run and on the edge of the study area. It includes several small pits or trenches, 5 ft long and 2–3 ft deep, on the south slope of the hill and a small adit on the east side of the hill that extends into the hillside for 50 ft(?) N. 80° W. Mineralized rock at the adit appears to be low-grade, limonite-cemented sandstone breccia. Similar rock is present as float or in small outcrops for 500 ft along strike to the northeast and southwest.

Prospect areas B and C are on a low ridge just south of Shawvers Run and just north of the thrust fault in the east-central part of the study area. Prospect B, at the north, is at an altitude of 2,300 ft. It consists of a shallow trench about 20 ft long, trending N. 50° W., and exposing low-grade limonitic sandstone. Prospect area C is 500 ft to the southwest at an altitude of 2,400 ft. A trench about 20 ft long, 5 ft wide, and 3 ft deep is on the west side of the low knob, and a pit about 20 ft long, 5–20 ft wide, and 10 ft deep is on the east side. Low-grade limonitic sandstone is poorly exposed in the workings and on the knob between them for a distance of 200 ft or more.

Prospect D, about 3,000 ft south of C, is at an altitude of 2,760 ft on the south side of a small stream valley. A small cut, 30 ft long, 10 ft wide, and 15 ft deep trends S. 50° W. into the hillside. Limonite-cemented sandstone is poorly exposed for 1,500 ft or more to the southwest across two minor ridges but not to the northeast.

GEOCHEMICAL SURVEY

A reconnaissance geochemical survey was made of the Barbours Creek and Shawvers Run study areas on the basis of analyses of stream-sediment and rock samples (Bailey and others, 1986; Lesure, 1987). Most of the small drainage basins in the study areas were sampled by collecting a few handfuls of the finest grained sediment available. The major rock types exposed in the area were sampled by taking several small chips from beds of one lithology and across a known thickness. All samples were scanned spectrographically for 31 elements and analyzed by atomic absorption for zinc (Bailey and others, 1986). The iron- and manganese-rich rocks also were analyzed by induction-coupled plasma methods for iron, manganese, phosphorus, barium, cobalt, lead, nickel, and zinc.

The analytical data for samples from the study areas compare closely with analyses on similar samples collected in the Dolly Ann Roadless Area, Alleghany County (Lesure, 1982) (fig. 1), in the Rich Hole Roadless Area, Alleghany and Rockbridge Counties (Lesure, 1986) (fig. 1), and in the Mill Creek, Mountain Lake, and Peters Mountain Wilderness Study Areas, Craig and Giles Counties, Va., and Monroe County, W. Va. (Lesure and others, 1982). These five study areas, of which the first two are 10–25 mi to the northeast and the other three are 18–36 mi to the southwest, have the same rock formations exposed as in the Barbours Creek and Shawvers Run areas. The median concentrations of many elements for samples from each formation in the study areas are as similar to those from the Dolly Ann, Rich Hole, Mill Creek, Mountain Lake, and Peters Mountain areas, as can be expected, considering that the data are semiquantitative and that the analyses were done by different analysts using different machines and techniques. The median values are also similar to the average values for comparable rock types (Lesure, 1987). The analytical data indicate areas rich in iron and manganese; they do not indicate any well-defined anomalous areas obviously related to other types of mineralized rock.

Iron and manganese are the only metallic mineral resources reported for the areas adjacent to the study areas. Zinc is a trace to minor constituent (0.005–1.0 percent) in the limonitic iron ores (Lesure, 1982, 1986). Barium (220–5,000 parts per million (ppm)), cobalt (<20–3,300 ppm), lead (<20–1,600 ppm), manganese (400–16,000 ppm), and nickel (47–4,000 ppm) also occur in anomalously high trace amounts in the limonite deposits in the Lower Devonian formations. Locally, small deposits in which manganese is more abundant than iron are present in the Clifton Forge Sandstone Member of the Keyser Limestone stratigraphically below the iron deposits but topographically above them because of the geologic structure. One such deposit was found 0.6 mi west of the iron prospect in the Barbours Creek study area, and others may exist (pl. 1*A*). The manganese deposit consists of a few scattered boulders of sandstone partly cemented with the manganese mineral lithiophorite. The grade of material seen is low (6 percent manganese), and the occurrence does not appear to be a significant resource. The reconnaissance geochemical sampling in the area did not find evidence of any other indistinct or unexposed metallic mineral deposits that might be recognized by their geochemical halos.

ASSESSMENT OF MINERAL-RESOURCE POTENTIAL

Low-grade, subeconomic iron deposits, abundant rock for common building stone and crushed rock, limestone and quartzite for special uses, and limited amounts of shale suitable for common building brick are potential mineral resources in the Barbours Creek and Shawvers Run study areas. Natural gas may be present, but no drilling has been done in the area to substantiate such potential.

Iron Deposits

The study areas contain two types of iron deposits, hematite and limonite (table 2). Low-grade hematitic sandstone beds and lenses in the Rose Hill Formation extend throughout most of the study areas (pl. 1*B*). Limited prospecting of higher grade limonite deposits in the Licking Creek Limestone has occurred in the central part of the Barbours Creek area and in the northern and eastern parts of the Shawvers Run area (pl. 1*A*). Similar deposits have been mined and prospected mostly to the southeast in the Lignite and Fenwick mines, to the north and northeast in the main part of the Clifton Forge iron district, and on a smaller scale to the southwest near Paint Bank.

Hematite Deposits

Deposits of hematite, an iron oxide (Fe_2O_3) mineral, are distributed widely in sedimentary rocks of Silurian age from central New York to Alabama. They have been called Clinton iron ores (Campbell, 1882) 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 also were mined in Pennsylvania, Maryland, Virginia, and West Virginia (Wright and others, 1968, p. 409). In Virginia, these deposits are in the Rose Hill Formation.

The hematite in the Clinton-type iron ores generally occurs in one of the following three forms: as flattened spheroids, called oolites; as replacements of fossil remains that preserve the shape of the original calcareous shells; and as cementing material coating and filling pore space around detrital sand grains, oolites, and fossils (Wright and others, 1968, p. 407). The principal ores are either oolitic or fossil-replacement, and some are combinations of the two types.

The unweathered ore is hard and calcareous, whereas 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. Iron content of the soft or leached ore ranges from 40 to

Table 2. Summary of iron resources in the Barbours Creek and Shawvers Run Wilderness Study Areas, Craig County, Va.
[See text sections on hematite and limonite resources for explanation of calculations and discussion. Outline of areas containing resources shown in plate 1*B* and *C*. All tonnages rounded]

Type of deposit	Approximate area, in acres	Inferred subeconomic resources, in long tons	
		Rock in place	Contained iron
Barbours Creek Wilderness Study Area			
Hematitic sandstone in Rose Hill Formation:			
Outcrop	1,300	230,000,000	35,000,000
Covered, 1–300 ft	1,600	560,000,000	84,000,000
Covered, more than 300 ft	2,300	810,000,000	120,000,000
Total		1,600,000,000	240,000,000
Limonite deposits:			
Prospect area E	3	150,000	66,000
Shawvers Run Wilderness Study Area			
Hematitic sandstone in Rose Hill Formation:			
Outcrop	700	120,000,000	18,000,000
Covered, 1–300 ft	900	320,000,000	48,000,000
Covered, more than 300 ft	1,700	600,000,000	90,000,000
Covered, more than 300 ft beneath thrust fault	300	110,000,000	17,000,000
Total		1,200,000,000	170,000,000
Limonite deposits:			
Prospect area A	1	50,000	22,000
Prospect areas B and C	2	100,000	44,000
Prospect area D	2	150,000	66,000
Outcrop area H	3	200,000	88,000
Outcrop area F	.4	20,000	9,000
Total		520,000	230,000

60 percent, and calcium carbonate is generally less than 1 percent (Whitlow, 1962). The ore-grade material commonly is enclosed in or grades into hematitic sandstone or shale. Hematitic sandstone associated with the fossil and oolitic ores of the Birmingham, Ala., district contains 15–30 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 sedimentary iron deposit. The iron was precipitated from seawater and was concentrated as the sediments were deposited. In the Birmingham area, the oolitic and fossil ores probably were deposited as lagoonal sediments, and the hematitic sandstone as a barrier island (Sheldon, 1970, p. 110). In the study areas, the Rose Hill Formation also was probably deposited in a shallow marine environment (Diecchio, 1973, p. 57–62). Amorphous iron oxides and hydroxides deposited with the sediments formed the mineral hematite during compaction and lithification of the rocks. The primary deposition of the iron as a component of the sediments is of significance because such deposition suggests that the iron content of an ore bed or hematitic sandstone bed will be areally widespread throughout the bed and will persist down its dip.

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 (Gooch, 1954, p. 4; Lesure, 1957, p. 121); these deposits have not been important economically. Thin beds of fossil ore 1–2 ft thick containing 40–57 percent iron have been mined on the southeast side of Horse Mountain near Low Moor, 12 mi northeast and near Iron Gate, 18 mi to the northeast of the Barbours Creek study area (Lyman, 1886, p. 808; Harder, 1909, p. 228–233).

No oolitic or fossil ore beds were found in the Rose Hill Formation in the study areas, but hematitic sandstone similar to that associated with the ore beds in Alabama is common. The beds of hematitic sandstone range in iron content from less than 10 to as much as 28 percent but average only 15 percent (Lesure, 1987). The phosphorus content ranges from 0.08 to 0.45 percent. Where exposed along Virginia State road 621 along the northeast edge of the Hoop Hole Roadless Area, Botetourt County, 10 mi northeast of the Barbours Creek study area (fig. 1), the Rose Hill Formation is about one-half red hematitic sandstone interlayered with nonhematitic sandstone and red and green shale (Rader and Gathright, 1984, p. 42–43). The formation is 270 ft thick near Hoop Hole and 200–255 ft thick at Cliff Dale Chapel, Alleghany County, 3 mi northeast of Barbours Creek (Lesure, 1957, p. 34; Chen, 1981, p. 237). The thickness of the Rose Hill in the study areas probably ranges from 200 to 250 ft, and the thickness of hematitic sandstone is probably about 100–125 ft in beds 1–20 ft thick interlayered with shale and nonhematitic sandstone. The low iron and high phosphorus content of this material would not normally warrant economic consideration, but, because a large volume is present, a significant low-grade iron resource can be inferred. Recent studies suggest the possibility of economical methods of recovery of high-quality iron concentrates containing low phosphorus from the low-grade hematitic sandstone (Hanna and Rampacek, 1982).

Hematite Resources

Inferred low-grade subeconomic iron resources in the Rose Hill Formation can be estimated from available density, grade, and volume data. The average specific gravity of 15 samples of hematitic sandstone representing 67 ft of rock from the Barbours Creek and Shawvers Run study areas is 2.9 (Lesure, 1987). The grade of the hematitic sandstone ranges widely from 5 to 28 percent iron, but a weighted average for all samples containing 10 percent or more is about 15 percent iron (Lesure, 1987), which is less than the average of 18 percent for similar rock from the Dolly Ann Roadless Area, Alleghany County (Lesure and Jones, 1983), and less than the 18–22 percent iron in similar rocks from Giles County, Va. (Fish, 1967, p. 10; Lesure and others, 1982, p. 42). By using the geologic map of the study areas (pl. 1*A*), we can estimate by planimetric measurement that the Rose Hill is exposed in about 1,300 acres in the Barbours Creek study area and in 700 acres in the Shawvers Run area, is covered by 1–300 ft of younger rock in 1,600 acres in the Barbours Creek area and 900 acres in the Shawvers Run area, and is covered by more than 300 ft in 2,300 acres in the Barbours Creek area and 2,000 acres in the Shawvers Run area (pl. 1*B*). Assuming an average thickness of 100 ft of hematitic sandstone for the 6,800 acres of covered Rose Hill and 50 ft (because an average of one-half of the thickness is eroded) for the 2,000 acres of exposed Rose Hill, and an average specific gravity of 2.9 (181 lb/ft^3), the total inferred subeconomic iron resource is about 2.8 billion long tons of hematitic sandstone: Weight of rock in place (long tons) = acres × 43,560 ft^2/acre × thickness in feet × weight of rock per cubic foot ÷ 2,240 lb/long ton. At an average grade of 15 percent iron, this resource could contain as much as 410 million long tons of iron (table 2). Although this material is too low in average iron content to be considered economically important now, similar material was prospected in Giles County, Va., 18–25 miles southwest of the study areas in the 1950's and 1960's (Cooper, 1960; Fish, 1967; Lesure and others, 1982, p. 43–53).

Limonite Deposits

The only iron deposits prospected within the study areas are the secondary, or supergene, limonite deposits formed by weathering of the Lower Devonian Licking Creek Limestone. The ore mined in the Clifton Forge iron district was a sandy, cherty, and clayey limonite that formed as a replacement and cavity filling in the upper sandy limestone part of the Licking Creek. During weathering, ground water moving through black shale in the Romney Shale dissolved iron from disseminated iron sulfides and became acidic and iron rich (Holden, 1907, p. 408–410; Lesure, 1957, p. 102–103). This acidic ground water dissolved the calcium carbonate of the underlying rocks. As the ground water became less acidic, iron was precipitated as mixtures of iron oxides and iron hydroxides, commonly called limonite. The lower cherty part of the Licking Creek is generally less permeable during weathering and forms the footwall of the deposits. The calcareous cement of the overlying Ridgeley Sandstone also generally is replaced by iron minerals during weathering, and the resulting iron-cemented and brecciated sandstone forms the hanging wall of the deposits. In general, these limonite deposits are near-surface features that grade downward into unreplaced limestone within 100 ft or more of the surface. The largest deposits formed where the limestone beds dip 20°–75°; only a few deposits form in more steeply dipping or overturned beds, and thin sandy deposits form where the beds are flat or only gently dipping (Lesure, 1957, p. 94).

These ores have been called Oriskany iron ore for many years because of the correlation of the Licking Creek Limestone and Ridgeley Sandstone with the Oriskany Sandstone of Early Devonian age in New York State. A more complete discussion of the origin of the ores is given in Lesure (1957, p. 82–105).

Limonite Resources

Resource estimates for limonite, which is a secondary ore, are not made as easily as resource estimates of primary or bedded deposits because the limonite deposits are discontinuous masses that cannot be projected for any extended distance. Thickness of the mineralized zone is generally 10–35 ft, much less than the 50–60 ft of the unweathered upper part of the Licking Creek Limestone, and the iron content is highly variable within the deposit. The average thickness of ore mined at the Fenwick mine, 2 mi southeast of the Barbours Creek study area, was 20 ft (Morrison and Grosh, 1950, p. 12), and the grade 44.6

percent iron (Holden, 1907, p. 446). The depth to which the limonite can be projected is variable also but generally not more than a few hundred feet. The resource estimates given for each prospect or outcrop area are based on an assumed average thickness of 13 ft of limonite-cemented sandstone, an average grade of 44 percent iron, and a tonnage factor of 13 ft^3/t of rock in place (Morrison and Grosh, 1950, p. 13). A projection of 100 ft below existing outcrops or bottom of workings is made arbitrarily for each area. By using these figures, I estimate an average of 100 long tons of limonite-cemented sandstone for each linear foot of outcrop or projected mineralized zone, and this tonnage factor is used in the resource calculations (table 2). These deposits constitute inferred subeconomic resources as defined in U.S. Geological Survey Circular 831 (U.S. Bureau of Mines and U.S. Geological Survey, 1980).

Barbours Creek study area.—Boulders of iron-cemented sandstone were found for 1,000 ft southwest and 500 ft northeast of the prospect in the Barbours Creek study area (pl. 1*C*, locality E). By using the tonnage factor of 100 long tons per linear foot of outcrop, the inferred resources in this prospect area are estimated at 150,000 long tons of subeconomic limonite-cemented sandstone. The potential for additional resources along strike to the northeast for about 3 mi and to the southeast for 1.5 mi is moderate because iron-cemented sandstone, which has a lower iron content than that of locality E (pl. 1*C*), is present in several scattered outcrops.

Shawvers Run study area.—Outcrop areas containing limonite-cemented sandstone are more abundant in the Shawvers Run study area than in the Barbours Creek area. At the northern edge of the study area, limonite-cemented sandstone and chert breccia is scattered for about 500 ft along strike east and west of locality A (pl. 1*C*). By using a tonnage factor of 100 long tons per linear foot, inferred resources are estimated to be 50,000 long tons of subeconomic limonite-cemented sandstone.

The ore-bearing zone is poorly exposed for 1.5 mi to the southwest of locality A and is covered by colluvium for part of that distance. This part of the ore-bearing zone has a low potential for additional resources.

About 0.8 mi southwest of locality A, a sandstone breccia, partly limonite-cemented, crops out for about 1,000 ft along strike. This breccia is probably in the Keefer Sandstone and is several hundred feet stratigraphically below the ore zone. A chip sample representing 4 ft of this rock contains only 5 percent iron (Bailey and others, 1986, table 1, sample VSR 140). This breccia is too low grade to have resource potential.

Near locality F in the western part of the study area, limonite-cemented sandstone breccia containing 31 percent iron is poorly exposed for about 200 ft across a small ridge. Inferred resources in this area may amount to 20,000 long tons or more. Potential for additional resources northeast of locality F is considered moderate because of the presence of limonite-cemented sandstone containing less than 10 percent iron. The lack of boulders or outcrops of iron-cemented sandstone along strike to the southwest of locality F suggests a low potential for additional resources. One outcrop of limonite-cemented sandstone at locality G, west of F (pl. 1*C*), suggests a moderate potential for additional resources in a limited area. No iron-cemented sandstone was seen in other nearby areas of Lower Devonian rocks.

Just north of the thrust fault in the eastern part of the Shawvers Run study area, limonite-cemented sandstone and chert breccia is exposed for 1,000 ft intermittently along a small ridge between localities B and C (pl. 1*A* and *C*). Inferred resources in this area are 100,000 long tons of subeconomic limonite-cemented sandstone. There is a moderate potential for additional resources for at least 1,000 ft southwest of locality C and adjacent to the fault.

Limonite-cemented sandstone and chert breccia is present as scattered boulders for 1,500 ft southwest of locality D (pl. 1*C*). The inferred resources for this area amount to 150,000 long tons of subeconomic low-grade limonitic sandstone. The favorable zone extends for 2,000 ft to the southwest, and additional resources are possible. However, a lack of small knobs characteristic of iron-cemented sandstone and the presence of steeply dipping to possibly overturned beds, which are not as likely to be mineralized (Lesure, 1957, p. 104), indicate that the potential for these resources is probably low.

Northwest of locality D and on the northwest limb of the syncline is another outcrop area of the ore zone (pl. 1*C*, locality H). Limonite-cemented sandstone and chert breccia crops out on two small knobs for at least 2,000 ft. The inferred resources in this area are 200,000 long tons. An additional 1,500 ft along strike to the southwest has a low potential for additional resources.

The favorable zone is also present northeast of the small cross fault just northeast of locality D. There is a low potential for iron resources in this area for about 2,500 feet to the north of the study area boundary along USFS road 176.

Economic Assessment of Limonite Resources

Economic potential is small for the limonite resources in the study areas. Because distribution of iron in western Virginia is sporadic, iron resources cannot be considered a viable commodity in the foreseeable future. The following reasons for the decline and eventual demise of iron mining in Virginia, as pointed out by Morrison and Grosh (1950, p. 4), are still applicable in dismissing any present-day potential: (1) competition from Great Lakes ores and from other markets, (2) unfavorable freight rates, and (3) more stringent iron ore requirements for modern furnaces.

Stone

The Juniata Formation, Tuscarora Quartzite, Rose Hill Formation, and Keefer Sandstone (pl. 1*A*) contain abundant rock suitable for crushed rock and rough building stone. Similar rock is exposed abundantly throughout the general region, and the rocks of the study areas have no special properties that could increase their value.

The Tuscarora Quartzite and Keefer Sandstone contain silica-rich sandstone that may be suitable for use in various sand products. Chemical analyses indicate that contaminants, especially iron (Lesure, 1987), limit the commercial potential for glass sand and other high-silica sand products. Some of this sandstone, however, may be suitable for use as furnace, molding, engine, and construction sand and for the manufacture of ganister and abrasives. More accessible materials of similar quality are widely available elsewhere in the region.

Limestone

The Licking Creek Limestone is a relatively clean limestone that may be suitable for crushed stone and for agricultural uses. It is poorly exposed and generally deeply weathered but is probably present at depth along the southeastern part of the Barbours Creek study area and in the northwestern and eastern parts of the Shawvers Run study area. The Licking Creek has been mined near Low Moor, about 12 mi northeast of the Barbours Creek study area. The only potential for unweathered limestone in the study areas is at depth. Resources of unweathered limestone in the study areas are probably not large; higher quality, more accessible material is exposed along the highway southeast of Paint Bank.

Shale and Residual Clay

Large amounts of shale are present in the Romney Shale and Jennings Formation, which are poorly exposed along some of the small streams in the study areas. Tests show that similar material from adjacent areas is suitable for structural clay products and lightweight aggregate (Ries and Somers, 1920, p. 78–82; Calver and others, 1964, p. 16–35, 84–85, 126–134, 217–221). Ceramic properties of shale and clay from the study areas are untested but should not differ greatly from those of shale and clay located in greater abundance elsewhere in the region.

Oil and Gas Potential

Recently, major petroleum companies and independent operators have become interested in the possibility of new gas discoveries in the eastern overthrust belt of the Appalachian Mountains from New York to Alabama. Geologic and geophysical exploration, including seismic work, currently is being conducted in the Valley and Ridge province of Virginia. Cambrian to Mississippian strata underlying the province may contain potential natural gas reservoirs and a lesser potential for large-scale petroleum reserves (LeVan, 1981).

Although the study areas contain source beds of organic-rich black shales of Ordovician and Devonian age and reservoir rocks in the sandstones of Silurian and Early Devonian age, the areas have a low potential for natural gas and no potential for commercial accumulations of oil (Wallace de Witt, Jr., U.S. Geological Survey, written commun., 1981). The degree of thermal maturation (the temperature to which the source beds have been heated) is too great for the presence of oil; however, the rocks are within the temperature range favorable for the presence of dry natural gas (Harris and others, 1978). The anticlinal structures of Potts Mountain and the other anticlines to the northwest permit the good sandstone reservoir rocks in the near-surface clastic sequence to crop out within the study areas. Thus, any accumulation of natural gas in these rocks probably has escaped to the atmosphere in the 250 million years since the rocks were folded and faulted during the Alleghany orogeny. Extensive fracture porosity, however, may be associated with buried thrust faults in the general vicinity of the study areas (Harris and Milici, 1977, p. 8–11; Milici, 1980). Natural gas has been produced from rocks having fracture porosity to the north and northwest in the Allegheny Plateau and in the Valley and Ridge province.

A test hole was started by Atlantic Richfield Co. in Hanging Rock Valley on the northwest flank of Potts Mountain 2.5 mi southwest of the Shawvers Run study area. According to press releases by the company, the hole was plugged after drilling more than 2,000 ft because of abnormal drilling problems and increased costs involving, in part, contamination of ground-water supplies and danger to the State fish hatchery at Paint Bank. The proposed target area was not reached, and the gas potential of the area is still untested.

Another test hole, drilled in 1981 by Columbia Gas Transmission Corp., in Botetourt County about 16 mi northeast of Barbours Creek, was also plugged and abandoned. Only gas shows were encountered in fractured zones in Middle Ordovician limestone, and the hole is listed as dry (Patchen and others, 1983, p. 1573–1586). Because available data indicate that even favorably developed fractures may not be gas filled, the potential for natural gas in the study areas must be rated as low. The areas are certainly one of high-risk drilling but cannot be excluded from the list of possible gas-producing areas. Hydrocarbon potential in the study areas presently remains untested and speculative.

Uranium

Marine black shales, which may contain more uranium than other types of shale, have been studied extensively as possible sources of uranium (Swanson, 1961). Thirteen samples of black and greenish-gray shale collected from the Romney Shale and Jennings Formation in the study areas contain 0.8–11 ppm uranium (Bailey and others, 1986, p. 4), and similar samples from 4–25 mi away contain from less than 1 to as much as 24 ppm uranium (Hasson, 1977, appendix III; Lesure, 1982, 1986). This uranium content is lower than that of the upper part of the Chattanooga Shale, Late Devonian to Mississippian age, which averages 60 ppm uranium in Tennessee (Swanson, 1961, p. 3). The U.S. Department of Energy (1980, p. 7) classifies the Chattanooga as a low-grade uranium resource and uses a lower cutoff of 85 ppm uranium for resource assessments (1980, p. 4). The average grade of uranium ore mined in the United States in the first half of 1980 was 1,000 ppm uranium (U.S. Department of Energy, 1980, p. 124). These data further support Hasson (1977, p. 41), who concluded that "the Millboro (upper Romney) Shale of Virginia contains too little uranium to be a potential source."

REFERENCES CITED

Bailey, E.A., Sanchez, Robin, Lesure, F.G., Fairfield, R.J., and Laudon, L.S., 1986, Analyses and descriptions of geochemical samples, Barbours Creek and Shawvers Run Wilderness Study Areas, Craig County, Virginia: U.S. Geological Survey Open-File Report 86–591, 15 p.

Benton, E.R., 1886, Notes on the samples of iron ore collected in Virginia: U.S. 10th Census, v. 15 (Mining industries), p. 261–288.

Bruce, Kathleen, 1931, Virginia iron manufacture in the slave era: New York, Century Co., 482 p.

Butts, Charles, 1933, Geologic map of the Appalachian Valley of Virginia, with explanatory text: Virginia Geological Survey Bulletin 42, 56 p.

———1940, Geology of the Appalachian Valley in Virginia: Virginia Geological Survey Bulletin 52, 568 p.

Calver, J.L., Smith, C.E., and LeVan, D.C., 1964, Analyses of clay, shale, and related materials—West-central counties: Virginia Division of Mineral Resources Report 5, 230 p.

Campbell, J.L., 1882, The Clinton and Oriskany iron ores near Richmond & Alleghany RR.: The Virginias, v. 3, p. 126–129.

Chance, H.M., 1900, The Rich Patch iron tract, Virginia: American Institute of Mining Engineers Transactions, v. 29, p. 210–223.

Chen, Ping-fan, 1981, Lower Paleozoic stratigraphy, tectonics, paleogeography, and oil/gas possibilities in the Central Appalachians (West Virginia and adjacent States), pt. 2, Measured sections: West Virginia Geological and Economic Survey Report of Investigations RI-26-2, 300 p.

Cooper, B.N., 1960, Preparation of iron ore concentrates of commercial grade from iron-bearing sandstone in western Virginia: Mineral Industries Journal, v. 7, no. 2, p. 1–5.

Crane, W.R., 1926, Red iron ores and ferruginous sandstones of the Clinton Formation in the Birmingham district, Alabama: U.S. Bureau of Mines Technical Paper 377, 41 p.

Darton, N.H., 1894, Description of the Staunton quadrangle [Virginia–West Virginia]: U.S. Geological Survey Geologic Atlas Folio 14, 4 p.

———1899, Description of the Monterey quadrangle [Virginia–West Virginia]: U.S. Geological Survey Geologic Atlas, Folio 61, 12 p.

Diecchio, R.J., 1973, Lower and Middle Silurian ichnofacies and their paleoenvironmental significance, central Appalachian basin of the Virginias: Durham, N.C., Duke University, Department of Geology, unpub. M.S. thesis, 100 p.

Eckel, E.C., 1906, The Oriskany and Clinton iron ores of Virginia: U.S. Geological Survey Bulletin 285, p. 183–189.

Fish, G.E., Jr., 1967, Clinton hematitic sandstone deposits, Butt Mountain area, Giles County, Va.: U.S. Bureau of Mines Report of Investigations 6966, 39 p.

Gooch, E.O., 1954, Iron in Virginia: Virginia Division of Geology, Mineral Resources Circular 1, 17 p.

Hanna, H.S., and Rampacek, Carl, 1982, Recovery of high quality iron-ore products from the Appalachian region area: Mining Engineering, v. 34, no. 4, p. 395–403.

Harder, E.C., 1909, The iron ores of the Appalachian region in Virginia: U.S. Geological Survey Bulletin 380, p. 215–254.

Harris, A.G., Harris, L.D., and Epstein, J.B., 1978, Oil and gas data from Paleozoic rocks in the Appalachian basin—Maps for assessing hydrocarbon potential and thermal maturity (conodont color alteration isograds and overburden isopachs): U.S. Geological Survey Miscellaneous Investigations Series Map I–917–E, scale 1:2,500,000.

Harris, L.D., and Milici, R.C., 1977, Characteristics of thin-skinned style of deformation in the southern Appalachians, and potential hydrocarbon traps: U.S. Geological Survey Professional Paper 1018, 40 p.

Hasson, D.O., 1977, Uranium potential of the Chattanooga Shale, northeast Tennessee and Millboro Shale, southwest Virginia—A reconnaissance study: Johnson City, Tenn., Environmental and Regional Research Associates, Inc., Project Final Report, Project No. 75–8–UY, 69 p.

Holden, R.J., 1907, Iron, *in* Watson, T.L., Mineral resources of Virginia: Virginia Jamestown Exposition, Lynchburg, J.P. Bell Co., p. 402–491.

———1936, Origin of the Oriskany iron and manganese ores: Virginia Geological Survey Bulletin 46–D, p. 29–34.

Ladd, H.S., 1944, Manganese deposits of the Sweet Springs district, West Virginia and Virginia: U.S. Geological Survey Bulletin 940–G, p. 199–217.

Lesley, J.P., 1859, The iron manufacturer's guide to the furnaces, forges, and rolling mills of the United States, with discussions of iron as a chemical element, an American ore, and a manufactured article in commerce and history: New York, John Wiley, 772 p.

Lesure, F.G., 1957, Geology of the Clifton Forge iron district, Virginia: Virginia Polytechnic Institute Bulletin, Engineering Experiment Station Series 118, 130 p.

———1982, Geochemical survey of the Dolly Ann Roadless Area, Alleghany County, Virginia: U.S. Geological Survey Miscellaneous Field Studies Map MF–1358–B, scale 1:48,000.

———1986, Geochemical survey of the Rich Hole Roadless Area, Alleghany and Rockbridge Counties, Virginia: U.S. Geological Survey Miscellaneous Field Studies Map MF–1760–B, scale 1:48,000.

———1987, Geochemical survey of Barbours Creek and Shawvers Run Wilderness Study Areas, Craig County, Virginia: U.S. Geological Survey Miscellaneous Field Studies Map MF–1914–B, scale 1:48,000.

Lesure, F.G., Estabrook, J.R., and Linden, M.A., 1987, Geologic map of Barbours Creek and Shawvers Run Wilderness Study Areas, Craig County, Virginia: U.S. Geological Survey Miscellaneous Field Studies Map MF–1914–A, scale 1:48,000.

Lesure, F.G., and Jones, J.G., 1983, Mineral resource potential map of Dolly Ann Roadless Area, Alleghany County, Virginia: U.S. Geological Survey Miscellaneous Field Studies Map MF–1358–D, scale 1:24,000.

Lesure, F.G., Williams, B.B., and Dunn, M.L., Jr., 1982, Mineral resources of the Mill Creek, Mountain Lake, and Peters Mountain Wilderness Study Areas, Craig and Giles Counties, Virginia, and Monroe County, West Virginia: U.S. Geological Survey Bulletin 1510, 76 p.

LeVan, D.C., 1981, Natural gas in Virginia: Virginia Minerals, v. 27, no. 1, 8 p.

Lyman, B.J., 1886, Geology of the Low Moor, Virginia, iron-ores: American Institute of Mining Engineers Transactions, v. XIV, p. 801–809.

Milici, R.C., 1980, Relationship of regional structure to oil and gas producing areas in the Appalachian basin: U.S. Geological Survey Miscellaneous Investigations Series Map I–917–F, scale 1:2,500,000.

Morrison, G.A., and Grosh, W.A., 1950, Investigation of Oriskany iron-ore deposits, Alleghany, Bath, Botetourt, and Craig Counties, Virginia: U.S. Bureau of Mines Report of Investigations 4668, 59 p.

Patchen, D.G., Schwarz, K.A., Debrosse, T.A., Bendler, E.P., McCormac, M.P., Harper, J.A., Kelly, W.W., Jr., and Avery, K.L., 1983, Oil and gas developments in Mid-Eastern States in 1982: American Association of Petroleum Geologists Bulletin, v. 67, no. 10, p. 1570–1592.

Pechin, E.C., 1891, The iron-ores of Virginia and their development: American Institute of Mining Engineers, Transactions, v. XIX, p. 1016–1035.

———1896, The Oriskany iron ores at Rich Patch mines, Virginia: Engineering and Mining Journal, v. 61, p. 113, 134, 159–160.

Rader, E.R., and Gathright, T.M., II, 1984, Stratigraphy and structure in the thermal springs area of the western anticlines: Virginia Division of Mineral Resources, 16th Annual Virginia Geologic Field Conference, October 13–14, 1984, Guidebook, 55 p.

Ries, Heinrich, and Somers, R.E., 1920, The clays and shales of Virginia west of the Blue Ridge: Virginia Geological Survey Bulletin 20, 118 p.

Rogers, W.B., 1836, Report of the geological reconnaissance of the State of Virginia: Philadelphia, Pa., Desilver, Thomas and Co., 144 p.

———1838, Report of the progress of the geological survey of the State of Virginia for the year 1837 (Document 45): [Richmond, Va.], 24 p.

Sheldon, R.P., 1970, Sedimentation of iron-rich rocks of Llandovery Age (Lower Silurian) in the southern Appalachian basin, *in* Berry, W.B.N., and Boucot, A.J., eds., Correlation of the North American Silurian rocks: Geological Society of America Special Paper 102, p. 107–112.

Stose, G.W., and Miser, H.D., 1922, Manganese deposits of western Virginia: Virginia Geological Survey Bulletin 23, 206 p.

Swanson, V.S., 1961, Oil yield and uranium content of black shales: U.S. Geological Survey Professional Paper 356–A, 44 p.

U.S. Bureau of Mines and U.S. Geological Survey, 1980, Principles of a resource/reserve classification for minerals: U.S. Geological Survey Circular 831, 5 p.

U.S. Department of Energy, 1980, An assessment report on uranium in the United States of America: U.S. Department of Energy, Grand Junction Office, Colorado, GJO–111(80), 150 p.

Weld, C.M. 1915, The Oriskany iron ores of Virginia: Economic Geology, v. 10, no. 5, p. 399–421.

Whitlow, J.W., 1962, Red iron-ore beds of Silurian age in northeastern Alabama, northwestern Georgia, and eastern Tennessee: U.S. Geological Survey Mineral Investigations Field Studies Map MF–175, scale 1:250,000.

Wright, W.B., Guild, P.W., Fish, G.E., Jr., and Sweeney, J.W., 1968, Iron and steel, *in* Mineral resources of the Appalachian region: U.S. Geological Survey Professional Paper 580, p. 396–416.