DEPARTMENT OF THE INTERIOR
UNITED STATES GEOLOGICAL SURVEY

MISCELLANEOUS FIELD STUDIES
MAP MF-1358-D
PAMPHLET

MINERAL RESOURCE POTENTIAL OF THE DOLLY ANN ROADLESS AREA, ALLEGHANY COUNTY, VIRGINIA

By

Frank G. Lesure, U.S. Geological Survey
and
Jay G. Jones, U.S. Bureau of Mines
1983

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 some of them are presently being studied. The act provided that areas under consideration for wilderness designation should be studied for suitability for incorporation into the Wilderness System. The mineral surveys constitute one aspect of the suitability studies. The act directs that results of such surveys are to be made available to the public and be submitted to the President and the Congress. This report discusses the results of a mineral survey of the Dolly Ann Roadless Area (08-171), Virginia. The area, which is in the George Washington National Forest in Alleghany County, was classified as a further planning area during the Second Roadless Area Review and Evaluation (RARE II) by the U.S. Forest Service, January 1979.

MINERAL RESOURCE POTENTIAL SUMMARY STATEMENT

The Dolly Ann Roadless Area is in the George Washington National Forest, Alleghany County, Virginia, in the Valley and Ridge physiographic province. The area, which contains folded sedimentary rocks of Paleozoic age, has extensive inferred subeconomic iron resources in low-grade hematitic sandstone and limited inferred subeconomic iron resources in medium-grade sandy limonite. Other potential mineral resources include various rocks suitable for road metal, quartzite suitable for high-silica applications, limestone suitable for agricultural uses, and clay and shale suitable for structural clay products. A potential for natural gas exists but cannot be quantified from present knowledge. Thermal springs near the area suggest a potential for geothermal energy.

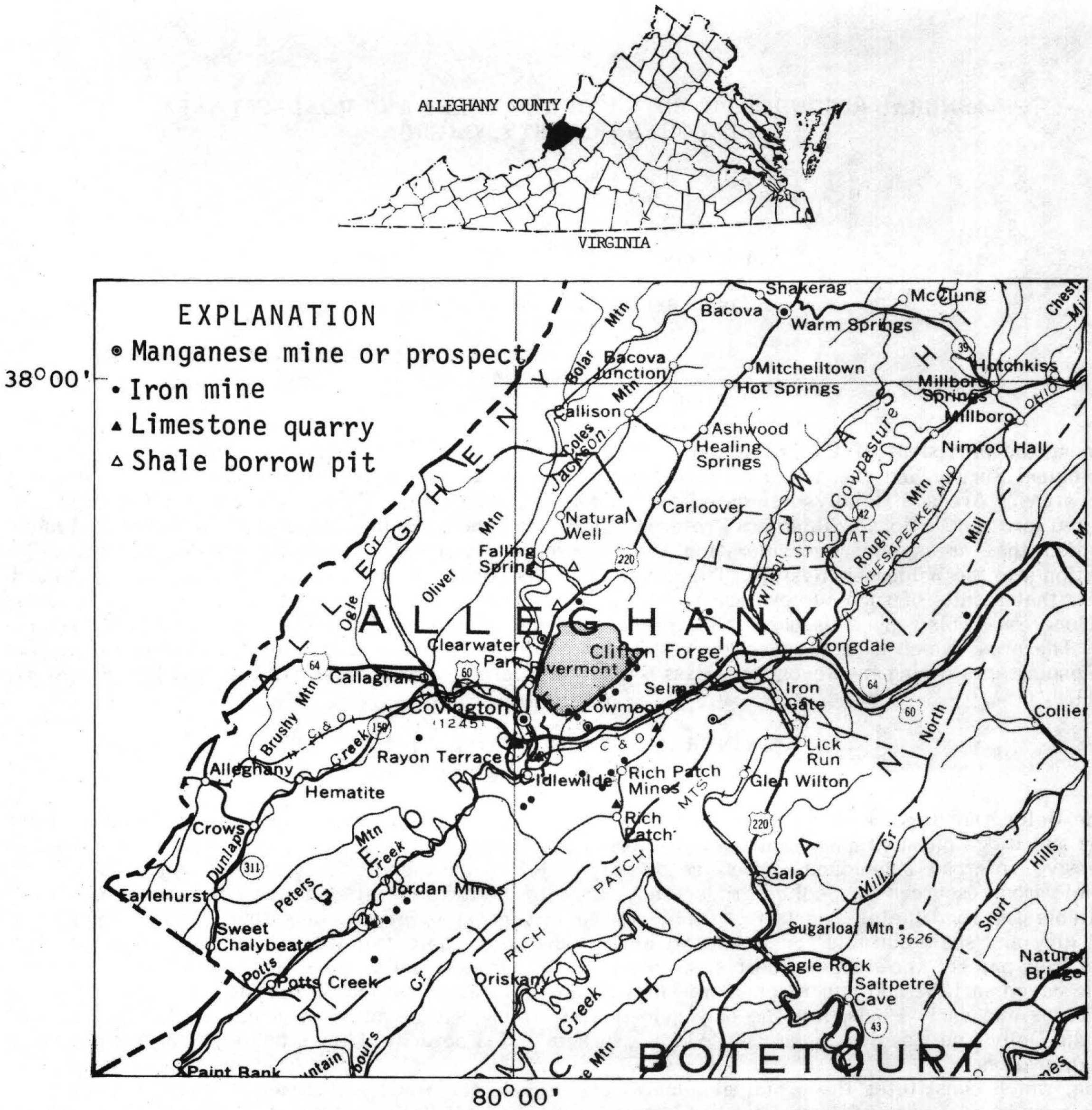
The caved surface and underground workings of the Dolly Ann and Iron Mountain iron mines, developed in the late 1800s and early 1900s, are the only evidence of mining within the study area. All surface and mineral rights in the Dolly Ann Roadless Area are Federally owned, and 15 percent of the study area has been leased for oil and gas exploration.

Iron, which constitutes the principal mineral resource in the Dolly Ann Roadless Area, is present both in low-grade primary deposits of hematitic sandstone in the Rose Hill Formation of Middle Silurian age, and in medium-grade secondary deposits of limonite in Lower Devonian limestone and sandstone. The area is estimated to contain total inferred subeconomic resources of 3 billion long tons of low-grade hematitic sandstone having as much as 540 million long tons of iron. Inferred subeconomic resources of 1.6 million long tons of medium-grade sandy limonite, containing possibly as much as 700,000 long tons of iron, may be present at the Dolly Ann and Iron Mountain mines. Because of the variable grade of iron-bearing material and present industry requirements, these iron resources in the study area would probably not compete with higher- and more uniform-grade iron resources elsewhere.

Sandstone, limestone, clay, and shale in the study area may be suitable for a variety of industrial materials. However, contaminants, limited occurrence, and the availability of similar or superior-quality material in nearby areas, limit the potential use of these commodities.

INTRODUCTION

The Dolly Ann Roadless Area comprises 7,900 acres (3,200 ha) in the George Washington National Forest in the Valley and Ridge physiographic province of west-central Virginia. The area is at the southern end of Warm Springs Mountain in Alleghany County just northeast of Covington, the county seat (index map). U.S. Highway 220 forms part of the western boundary, and U.S. Forest Service Road 125, which parallels Pounding Mill Creek, forms the eastern boundary. The principal streams draining the area are Pounding Mill Creek, Dry Run, and Roaring Run, all tributaries of the Jackson River. The highest point in the area is Big Knob at the north end, 4,072 ft (1241 m) above sea level; the lowest points, about 1,400 ft



Base from U.S. Geological Survey
Virginia State map, 1973

0 5 10 MILES

0 5 10 15 KILOMETERS

Dolly Ann Roadless Area

Index map showing location of Dolly Ann Roadless Area and some of the mines, prospects, and quarries in Alleghany County.

(427 m) above sea level, are at the south side, along Dry Run and Pounding Mill Creek. In general, the hill slopes are steep and heavily wooded with second- or third-growth hardwoods and scattered pine and hemlock. Dolly Ann Hollow near the east end of the area is a steep, boulder-strewn gorge, quite picturesque, but containing no good trails. A good trail up Dry Run connects a trail crossing the ridge between Bald Knob and Big Knob. No other trails cross the area.

Previous Studies

W. B. Rogers, the first State Geologist of Virginia, studied the geology of the general area between 1835 and 1838. In his annual report for 1835 (Rogers, 1836, p. 102-103) he described a section passing through Covington, and later he assigned numbers to the different rock units (Rogers, 1838, p. 21-23). His units III through VIII are exposed in the study area. J. L. Campbell (1880) described the geology of the Rich Patch Area just south of Dolly Ann, and N. H. Darton (1899) mapped the geology of the Monterey 30-minute quadrangle, which is north of the area. Among the numerous geologists who studied the so-called Oriskany iron ores while the deposits were being mined in the area are Benton (1886), Lyman (1886), Pechin (1896), Chance (1900), Eckel (1906), Holden (1907,1936), Harder (1909), and Weld (1915). The related manganese deposits were studied by Stose and Miser (1922). 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 by the U.S. Bureau of Mines (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).

In the early 1900s, several consulting engineers and geologists investigated the mining districts in and near the study area. Many of their reports, although unpublished, provide valuable information concerning the geology of the ore zone and resource estimates. The reports of Withrow (1910), Weld (1911a, 1911b, 1913, and 1926), and Burwell (1920) deal with extensive geologic explorations on the Iron Mountain and Dolly Ann mining tracts.

With the advent of World War II, the U.S. Bureau of Mines began resource investigations of the Virginia iron ores. These studies resulted in several War Minerals Reports (U.S. Bureau of Mines, 1943, 1944a, 1944b, 1945). Bureau of Mines Project 962, conducted in 1943-44 to determine reserves of iron ore as part of the strategic minerals program, included part of the Dolly Ann area (Morrison and Grosh, 1950). Additional unpublished articles written during the war include the Oriskany Report by Merrill (1943) and a report of iron-ore prospecting by Moomaw (1944).

Present work

Lesure, assisted by M. B. Longacre, mapped and sampled the area for the U.S. Geological Survey in May 1979. He field checked and resampled a few sample sites in April 1980, assisted by A. E. Grosz. Altogether 39 stream-sediment, 17 soil, and 120 rock samples were collected and analyzed in the U.S. Geological Survey laboratories, Denver, Colo. (Lesure and others, 1981).

The U.S. Bureau of Mines field investigation was conducted in April and May of 1980. Workings of the Dolly Ann and Iron Mountain iron mines were mapped and sampled (Jones and others, 1982; Jones, in press). A total of 26 large open cuts, three adits, 46 prospect pits and trenches, and two shafts were examined in the study area. Channel cuts were made to expose and sample the iron-bearing horizon; 19 samples were collected from the old workings. Other samples collected for analysis included sandstone, shale, and clay (Jones and others, 1982). TSL Laboratories, Ltd., Spokane, Wash., performed the spectrographic and chemical analyses. Clay and shale samples were submitted to the U.S. Bureau of Mines, Tuscaloosa Research Center, Tuscaloosa, Ala., for preliminary evaluation of ceramic properties and bloating characteristics.

Acknowledgments

Harry W. Webb, Jr., of the Virginia Division of Mineral Resources, provided background data on the geology of the area. Appreciation is extended to U.S. Forest Service personnel from the James River District Ranger Station, Covington, whose friendly cooperation and assistance greatly speeded up geologic mapping and sampling. William Leichter, District Ranger, provided valuable information concerning the history of the study area.

SURFACE- AND MINERAL-RIGHTS OWNERSHIP

The Federal Government owns all surface and mineral rights in the Dolly Ann Roadless Area. Oil and gas leases had been issued on approximately 1,200 acres (485 ha) in the study area as of January 1983 (fig. 1); applications for oil and gas leases for the rest of the study area are pending approval.

GEOLOGY

The rocks exposed in the Dolly Ann Roadless Area are chiefly marine clastic sedimentary rocks of Ordovician to Devonian age, which have an aggregate thickness of about 3,500 ft (1070 m) (table 1). The oldest formation present in outcrop is the Martinsburg Shale of Middle and Late Ordovician age, which is exposed in Dolly Ann Hollow and in Falling Springs Creek valley just north of the study area (Lesure, 1981). 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 in most of the study area. The Upper Silurian and Lower Devonian formations overlying these resistant units are poorly exposed along the western, southern, and eastern borders of the area. A few hundred feet of Middle Devonian Romney Shale are exposed along the western edge of the area.

The sedimentary rocks were deformed during late Paleozoic time into a series of upright to overturned folds forming the southwest-plunging end of the Hot Springs Anticline. The older formations are exposed in the center of the anticlines and the younger units are present in the centers of the synclines or on the flanks of the anticlines. Much of the area is

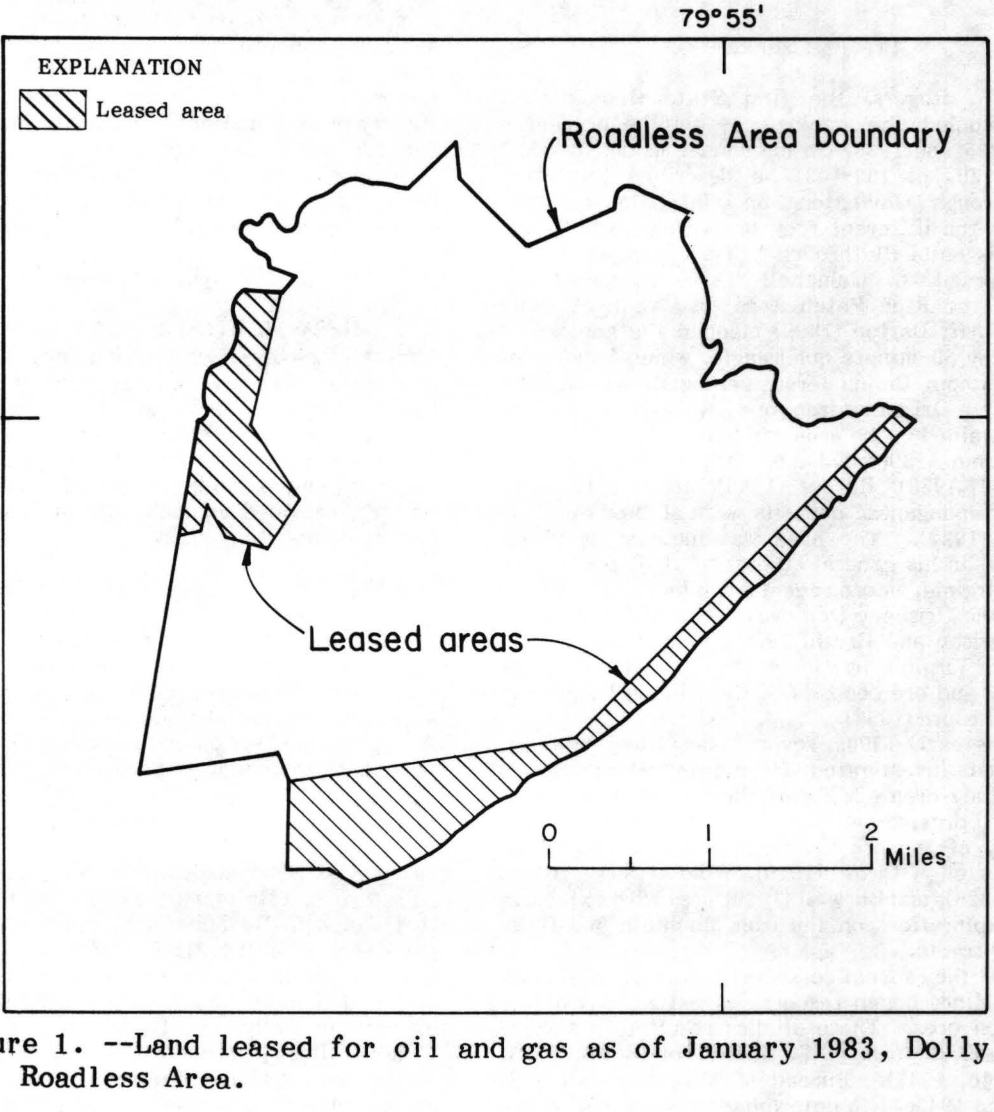


Figure 1. --Land leased for oil and gas as of January 1983, Dolly Ann Roadless Area.

Table 1. —*Summary of the geologic formations in the Dolly Ann Roadless Area*
[Modified from Lesure, 1957, p. 20.]

Age			Name	Thickness in feet	Lithologic character
CENOZOIC	QUATERNARY	Holocene	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	Middle	Romney Shale Upper part (correlates with Millboro Shale)	600-1150	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)	15-100	Medium to light olive-gray shale; poorly exposed
		Lower	Ridgeley Sandstone	20	Medium- to coarse-grained calcareous sandstone; where cemented with iron oxides forms hanging wall of many of the Oriskany iron deposits
			Licking Creek Limestone	105	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	20	Medium-grained calcareous sandstone
			New Creek Limestone	20	Coarse-grained crinoidal limestone
	SILURIAN	Upper	Keyser Limestone	100	Upper part nodular limestone; lower part calcareous sandstone
			Tonoloway Limestone	150	Thin-bedded argillaceous limestone
			Williamsport Sandstone(?) or Wills Creek Shale (?)	50	Thin-bedded argillaceous limestone and shale; poorly exposed
		Middle	Keefer Sandstone	250	Resistant quartzitic sandstone; a few thin beds of dark shale
			Rose Hill Formation	250-300	Dark-red hematitic sandstone and greenish-gray shale; some medium-gray sandstone and red shale
		Lower	Tuscarora Quartzite	100	Resistant quartzitic sandstone; thin lenses of pebble conglomerate
	ORDOVICIAN	Middle and Upper	Juniata Formation	250	Grayish-red sandstone and shale; some medium-gray to greenish-gray sandstone and shale in the east
			Martinsburg Shale	1200	Dark-gray calcareous shale and thin-bedded argillaceous limestone; some interbedded coarse crystalline limestone

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 of large parts of the study area, especially where the Upper Silurian and Lower Devonian formations would otherwise be exposed (Lesure, 1981).

GEOCHEMICAL SURVEY

Iron is the only metallic mineral resource reported for the Dolly Ann area. Reconnaissance geochemical sampling in the area did not find evidence of any indistinct or unexposed metallic mineral deposits that might be recognized by their geochemical halos. Zinc is a trace constituent (0.04-0.6 percent) in the limonitic iron-ores (Lesure, 1982) and sediment samples from many streams draining areas that include the iron deposits have higher-than-background zinc content.

MINING ACTIVITY

Only iron ore has been mined in the Dolly Ann Roadless Area, but manganese ore was mined nearby (index map). Limestone was quarried at Low Moor, 3 mi (5 km) southeast of the area, and sandstone and shale have been mined for crushed rock and fill in several small open cuts in nearby areas.

Iron mines

Dolly Ann Roadless Area is in the northwestern part of the Clifton Forge iron district, a region of many abandoned iron mines. Iron production in the district began prior to 1800 (Bruce, 1931, p. 454), and peaked during the period 1890 to 1920 when most mines in the district were in operation. Total production from some 20 mines was more than 6 million long tons of iron ore, but by 1925, all mining operations had ceased (Lesure, 1957, p. 81-82; Jones, in press, table).

Mining in the Dolly Ann area began in 1848 (Lesley, 1859, p. 71), and was accelerated following acquisition of leases by the Low Moor Iron Company of Virginia in 1893. Ore from the mines was originally smelted at the Dolly Ann charcoal furnace (Lesley, 1859, p. 71) and later shipped to the company's Covington furnace. Company records listed the combined total iron ore production from the Dolly Ann and Iron Mountain mines between 1893 and 1921 as 897,239 tons (Low Moor Iron Company of Virginia, 1923; Lesure, 1957, p. 107). Production figures from individual workings within the study area are not available.

The iron ore in the Dolly Ann area is along a syncline paralleling Pounding Mill Creek, and abandoned workings are distributed on both sides of the syncline for a distance of 4.5 mi (7.2 km) along the southeastern boundary of the roadless area (Lesure, 1957, plate 17). Most of the workings are outside the study area boundary, but those parts of the Dolly Ann and Iron Mountain mines within the study area, mapped as part of this study, are shown in figures 2 and 3. Two isolated small pits, referred to as the Bull Pen Cuts, are also located inside the study area along the same geologic trend (Jones, in press).

Manganese mines

Although no evidence of manganese mineralization was found in the study area, two nearby localities described by Stose and Miser (1922, p. 106-108) have produced limited quantities of manganese associated with iron deposits. The Covington prospect is about one-quarter mile (0.4 km) west of the study area boundary, just west of U.S. Highway 220. The Vowles mine is an abandoned manganiferous iron mine about 1.5 mi (2.4 km) south of the study area (index map).

ASSESSMENT OF MINERAL RESOURCE POTENTIAL

Low-grade iron deposits, abundant rock for common building stone and crushed rock, limestone and quartzite for special uses, and limited amounts of shale and residual clay suitable for common building brick are potential mineral resources in the Dolly Ann Roadless Area. A possibility exists for the presence of natural gas, but no drilling has been done in the area to substantiate gas potential. Thermal springs just north of the area suggest a potential for geothermal energy.

Iron

The study area contains two types of iron deposits, hematite and limonite. Low-grade hematitic sandstone beds and lenses in the Rose Hill Formation extend throughout most of the study area (fig. 4). Limited areas of higher-grade limonite deposits in the Licking Creek Limestone have been largely mined out in the Dolly Ann mine and the Iron Mountain mine, at the southern and northeastern ends, respectively, of the study area.

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). In Virginia, these deposits are in the Rose Hill Formation.

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 either oolitic or fossil, 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 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

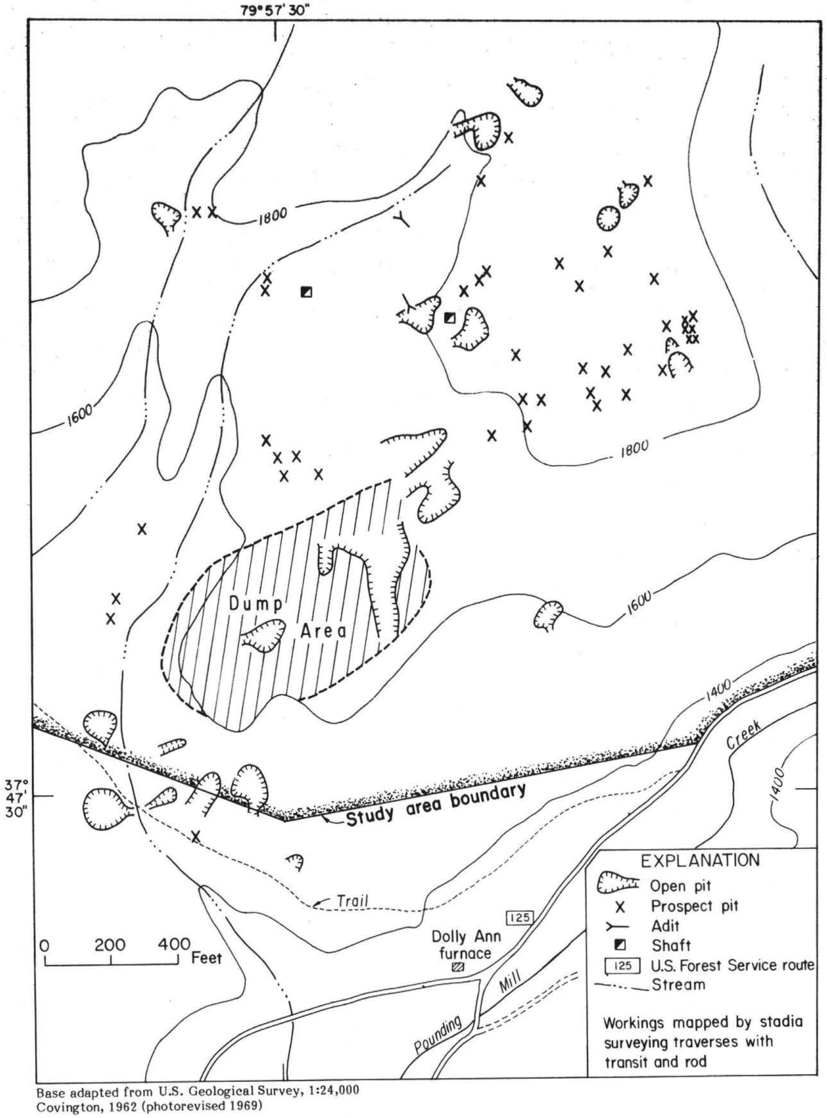


Figure 2.--Sketch map of the northern workings of the Dolly Ann mine. Modified from Jones and others (1982, fig. 5).

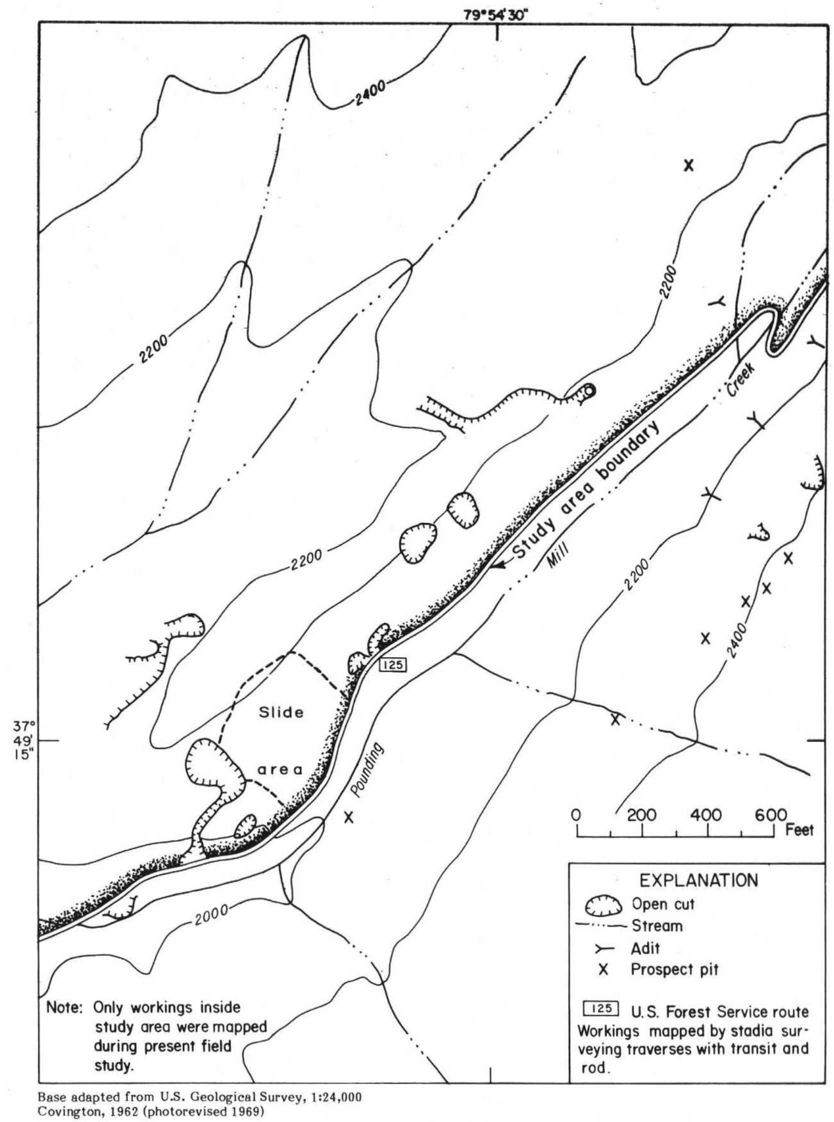


Figure 3.--Sketch map of the northwestern workings of the Iron Mountain mine. Modified from Jones and others (1982, fig. 6).

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 seawater and was 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 Dolly Ann area, the Rose Hill Formation was also probably deposited in a shallow marine environment (Diecchio, 1973, p. 57-62). The mineral hematite formed in the sediments during compaction and lithification of the rocks. The primary deposition of the iron as a component of the sediments is of significance because it suggests that the iron content of an ore bed or hematitic sandstone bed will be fairly consistent throughout the bed and will persist to depth.

Oolitic and fossil ore beds have been found in the Rose Hill Formation in Lee and Wise Counties, in the far southwestern part of Virginia, and near Iron Gate and Low Moor in Alleghany County (Gooch, 1954, p. 4; Lesure, 1957, p. 121). These ore beds have never been important economically. Thin beds of fossil ore 1 to 2 ft (0.3-0.6 m) thick containing 40 to 57 percent iron have been mined on the southeast side of Horse Mountain near Low Moor, 2.5 mi (4 km) southeast of the Dolly Ann area, and near Iron Gate, 7 mi (11.2 km) to the east (Lyman, 1886, p. 808; Harder, 1909, p. 228-233).

No oolitic or fossil ore beds were found in the Rose Hill Formation in the Dolly Ann area, 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 (Lesure, 1982; Jones and others, 1982, p. 19-20). The phosphorus content ranges from 0.2 to 0.9 percent. The Rose Hill Formation where exposed at Iron Gate is about two-thirds red hematitic sandstone interlayered with red and green shale (Lesure, 1957, p. 36). The formation may vary in thickness from 200 to 300 ft (60-90 m) in the Dolly Ann area, and the thickness of hematitic sandstone may range from 150-200 ft (45-60 m). The low grade 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.

Hematite Resources

Inferred low-grade subeconomic iron resources in the Rose Hill Formation can be estimated from the weight, grade, and volume data available. The average specific gravity of 39 samples of hematitic sandstone representing 165 ft (50 m) of rock from the Dolly Ann area is 2.9 (Lesure, 1982). The weight of a cubic foot of average hematitic sandstone is the specific gravity, 2.9, multiplied by the weight of a cubic foot of water, 62.4 lbs, which equals 181 lbs/ft^3. The grade of the hematitic sandstone ranges widely from 10 to 28 percent iron, but a weighted average for all samples is about 18 percent iron (Lesure, 1982; Jones and others, 1982, p. 19) which compares well with data on similar rock from Giles County, Va. (Fish, 1967, p. 10; Lesure and others, in press). Using the geologic map of the Dolly Ann area (Lesure, 1981), we can estimate that the Rose Hill is exposed in about 2,700 acres (1,090 ha), is covered by 5-200 ft (1.5-60 m) of younger rock in 2,800 acres (1,130 ha), and is covered by more than 200 ft (60 m) in 1,300 acres (530 ha) (fig. 4). Assuming an average thickness of 150 ft (45 m) of hematitic sandstone for the 4,100 acres (1,660 ha) of covered Rose Hill and 75 ft (23 m) for the 2,700 acres of exposed Rose Hill, the total inferred subeconomic iron resource is about 3 billion long tons of hematitic sandstone:

Acres x 43,560 ft^2 per acre x thickness

x weight per ft^3

÷ 2240 lbs per long ton = weight of rock in place

At an average grade of 18 percent iron, this resource could contain as much as 540 million long tons of iron. Although this material is too low in average iron content to be considered economically important now, similar material was seriously prospected in Giles County, Va., in the 1950s and 60s (Cooper, 1960; Fish, 1967; and Lesure and others, in press).

Limonite Deposits

The only iron deposits mined within the study area are the secondary or supergene limonite deposits in the Lower Devonian Licking Creek Limestone (Lesure, 1957, p. 105-108). The ore mined was a sandy and clayey limonite that formed as a replacement and cavity filling in the upper sandy limestone part of the Licking Creek. During weathering, groundwater 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 groundwater dissolved the calcium carbonate of the underlying rocks. As the groundwater 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 is also generally 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 a hundred or a few hundred feet of the surface. The largest deposits formed where the limestone beds dip 20 to 75 degrees; a few deposits formed in steeper dipping or overturned beds; and thin sandy deposits formed 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

In the Dolly Ann area only the Dolly Ann mine and Iron Mountain mine have resource potential for limonite iron deposits (fig. 4 and table 2). The upper sandy part of the Licking Creek Limestone, in which most of the limonite ore is found, lies along Pounding Mill Creek outside the study area for much of the distance between the two mines. The only exception is an isolated mass of limonite, explored at the Bull Pen Cuts, on a low spur of Peters Ridge. Along the western boundary of the study area, the Licking Creek is steeply dipping to overturned, and poorly exposed. The formation is in an unfavorable structural position for iron-ore deposition, although some limonite-cemented sandstone is exposed along U.S. Highway 220, and the Covington manganese prospect is in this stratigraphic interval immediately west of the study area. Between the Dolly Ann mine and Covington, the Licking Creek lies outside the study area.

Resource estimates for this type of secondary ore are not made as easily as resource estimates of primary or bedded deposits because limonite deposits are discontinuous masses that cannot be projected for any extended distance. Thickness of the ore is generally 10 to 35 ft (3 to 10 m), much less than the 50-60 ft (16-19m) of the unweathered upper part of the Licking Creek Limestone, and the iron content is highly variable within the deposit. With these restrictions in mind, we have made resource estimates based on available data (table 2).

Iron Resources at Dolly Ann Mine

Inferred subeconomic iron resources can be estimated for an area of 75 acres (30 ha) enclosed by mine workings and prospect pits in that part of the Dolly Ann mine inside the study area (figs. 2 and 4). Little of the ore zone is presently exposed, although iron-rich Ridgeley Sandstone of the hanging wall is found in the old pits and cuts. According to Weld (1911b), average thickness of ore mined at the Dolly Ann mine was 12 ft (3.6 m), but three samples collected by the U.S. Bureau of Mines from the presumed ore zone in three abandoned pits range in thickness from nearly 2 to about 5 ft (0.6-1.6 m) and in grade from 50 to 58.8 percent iron (Jones and others, 1982, p. 20). The thinness of ore in these pits may be one reason that mining here was discontinued. Harder (1909, p. 249) reported an analysis of Dolly Ann ore containing 44.32 percent iron, which is probably a realistic figure for rock in place. A tonnage factor of 13 ft^3 per long ton of ore for rock in place was estimated by Morrison and Grosh (1950, p. 13).

Presence of limestone pinnacles in the ore zone on the south side of the Dolly Ann workings, near the study area boundary, suggests that mining had reached the bottom of the ore in this area when the Low Moor Iron Company abandoned the mine in 1921 (Lesure, 1957, p. 107). The ore zone in the valley area west of the larger cuts (fig. 2) must be low dipping or nearly flat, which is unfavorable for ore formation. Some of this area, therefore, may have only ferruginous sand in the ore zone.

Inferred subeconomic iron resources of about 800,000 long tons of sandy limonite containing possibly as much as 350,000 long tons of iron can be calculated for that part of the Dolly Ann mine within the study area. This tonnage is for a mineralized area of 75 acres (30 ha) minus 4 acres (2 ha) previously mined, an average thickness of mineralized rock of 3.5 ft (1 m), a tonnage factor of 13 ft^3 per long ton, and an average grade of 44 percent iron. The U.S. Bureau of Mines classifies 20,000 long tons of this material present within a hundred-foot (30-m) radius of the three sample sites as demonstrated subeconomic iron resources (table 2; Jones and others, 1982, p. 24).

An additional, larger tonnage of iron in the ferruginous sandstone hanging wall can also be inferred, but this material would probably be low grade, ranging from 10 to 40 percent iron.

Iron Resources at Iron Mountain Mine

The small part of the Iron Mountain mine in the study area includes about 50 acres (20 ha) in which are seven large cuts, several pits, and one adit, all on a small anticline in the Licking Creek Limestone and Ridgeley Sandstone. Drilling by the Low Moor Iron Company (Weld, 1926) and the U.S. Bureau of Mines (Morrison and Grosh, 1950, p. 13-14) did not show material of ore grade or minable thickness. Seven samples from the ore zone collected by the U.S. Bureau of Mines (Jones and others, 1982, p. 26), show ore-zone thicknesses of 2 to about 14 ft (0.6-4 m) and iron contents of 40 to 54 percent. The average thickness of ore is 5 ft (1.6 m) and the average grade is 48 percent iron. Merrill (1943, p. 8) reported, however, an average of 43.27 percent iron in ore from the Iron Mountain mine. We calculate that the inferred subeconomic iron resources in the 50 acres (20 ha), minus about 3 acres (1 ha) that have been mined out, are 800,000 long tons of sandy limonite that might contain 340,000 long tons of iron. The U.S. Bureau of Mines classifies 56,000 long tons of the sandy limonite present within a hundred-foot (30-m) radius of the seven sample sites as demonstrated subeconomic iron resources (table 2; Jones and others, 1982, p. 26). In addition, as at the Dolly Ann mine, a larger amount of limonite-cemented sandstone in the hanging wall is classified as lower grade subeconomic iron resources.

Little iron-rich material is exposed in the study area for 4,000 ft (1200 m) northeast of the workings of the Iron Mountain mine. The Licking Creek Limestone and Ridgeley Sandstone are poorly exposed in an area about 500 ft (160 m) wide along the study area boundary. Drilling southeast of U.S. Forest Service Road 125 and outside the study area by the Low Moor Iron Company and U.S. Bureau of Mines (Weld, 1926; Morrison and Grosh, 1950, p. 14) suggests the presence of some limonite on the southeast limb but none in the trough of the syncline. The small anticline present at the Iron Mountain workings in the study area probably dies out to the northeast in this covered area. Because of the low dips to be expected in the ore zone along the axis of the syncline and the lack of iron-rich material along the outcrop area of the host limestone, the possibility of significant amounts of limonite is small.

Assessment of Limonite Resources

There is little potential for the limonite resources in the Dolly Ann Roadless Area. Distribution of iron in western Virginia is sporadic, and iron resources here cannot be considered a viable commodity in the foreseeable future. The 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: competition from Great Lakes ores and from other markets, unfavorable freight rates, and more stringent iron-ore requirements for modern furnaces.

Table 2.--*Inferred, demonstrated, and hypothetical limonite iron resources, Dolly Ann Roadless Area.*

[Data in long tons[1]]

	Dolly Ann mine	Iron Mountain mine
Inferred resources	800,000	800,000
Grade	44 percent iron[2]	43 percent iron[3]
Iron tonnage	350,000	340,000
Demonstrated (original)[4]	25,000	79,000
Previously mined [5]	5,000	23,000
Remaining resources	20,000	56,000
Grade (weighted)	54.6 percent iron[6]	48.1 percent iron[7]

1 One long ton (2240 lbs) is nearly equal to one metric ton (2204 lbs).
2 Harder, 1909, p. 249
3 Merrill, 1943, p. 8
4 Calculated by U.S. Bureau of Mines for 100-ft (30-m) radius from sample sites (Jones and others, 1982, p. 24-26)
5 Estimated from size of workings at sample site (Jones and others, 1982, p. 24-26)
6 Weighted average, three samples (Jones and others, 1982, p. 20)
7 Weighted average, seven samples (Jones and others, 1982, p. 20)

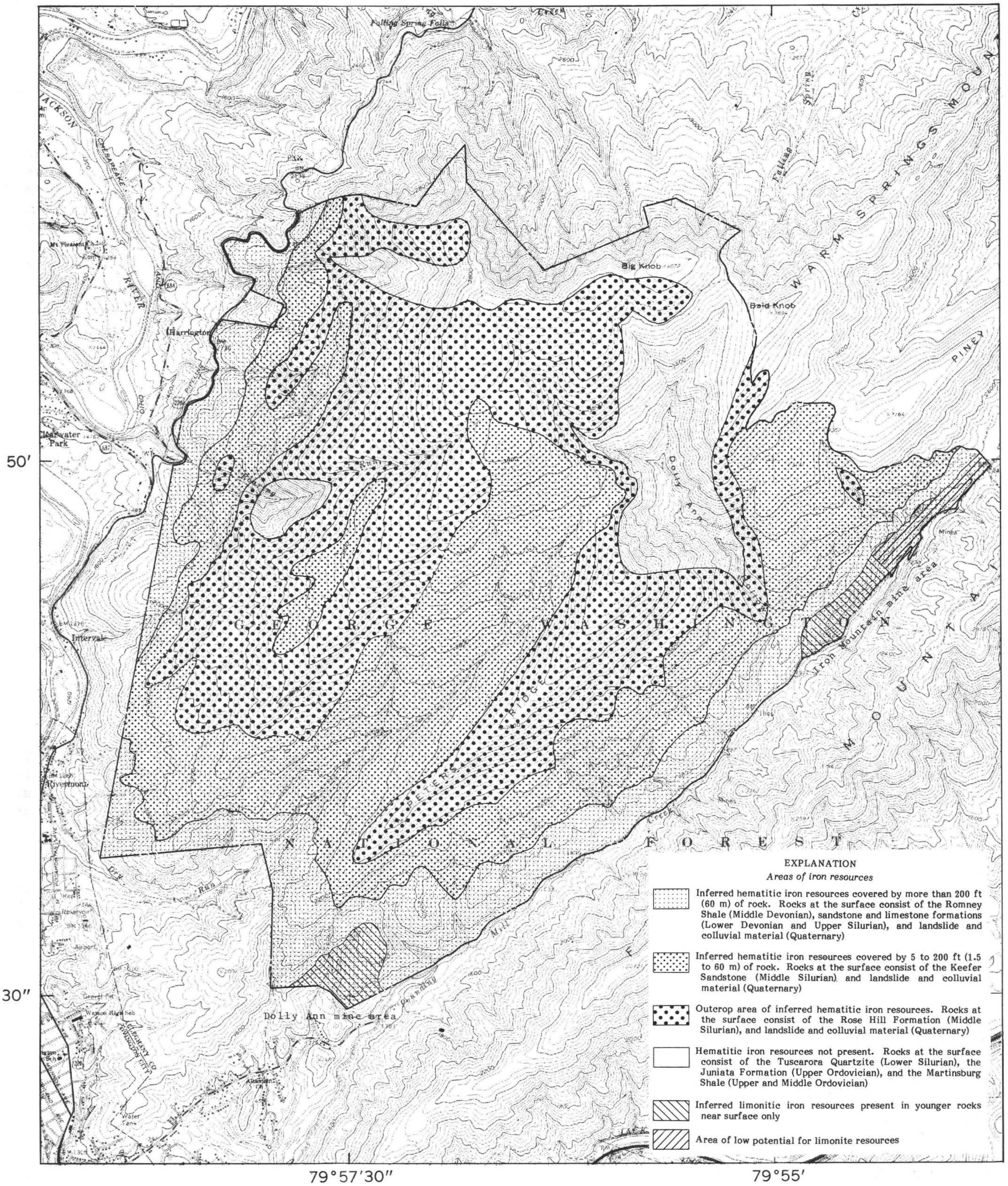


Figure 4.--Areas containing iron resources in the Dolly Ann Roadless Area.

Stone

The Juniata Formation, Tuscarora Quartzite, Rose Hill Formation, and Keefer Sandstone contain abundant rock suitable for crushed rock and rough building stone. Similar rock is abundantly exposed throughout the general region, and the rocks of the study area 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 and others, 1981), 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. Similar-quality and more accessible materials are widely available elsewhere in the region.

Limestone

The New Creek and Licking Creek Limestones are relatively clean limestones that could be suitable for crushed stone and for agricultural uses. Both are poorly exposed, and generally deeply weathered, but are probably present locally along the western edge of the study area. The Licking Creek has been mined near Low Moor, about 3 mi (5 km) southeast of the study area. The only potential for unweathered limestone in the study area is at depth. Some boulders of New Creek Limestone are in the dump material at the Dolly Ann mine. Resources of unweathered limestone in the study area are probably not large; better and more accessible material is exposed near Low Moor.

Shale and Residual Clay

Minor amounts of shale are poorly exposed along U.S. Highway 220 on the western edge of the study area, and residual clays of limited extent are present in some of the iron mines. Tests show that some of this material is suitable for structural clay products and lightweight aggregate (Ries and Somers, 1920; Calver and others, 1964, p. 30-31; Jones and others, 1982, p. 31). Ceramic properties of this shale and clay are in no respect superior to similar material located elsewhere in the region.

Oil and Gas Potential

Although the Dolly Ann Roadless Area contains both source beds and reservoir rocks, it has 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 structure of Warm Springs Mountain permits all of the good sandstone reservoir rocks in the near-surface clastic sequence to crop out within the Dolly Ann area. Thus, any considerable accumulation of natural gas in these rocks would have escaped to the atmosphere in the 200 million years since the rocks were folded and faulted during the Alleghenian orogeny. Extensive fracture porosity, however, may be associated with buried thrust faults in the general vicinity of the Dolly Ann area (Milici, 1980; Harris and Milici, 1977, p. 8-11), and natural gas has been produced from rocks having fracture porosity to the north and northwest in both the Allegheny Plateau and in the Valley and Ridge province. Because available data indicate that even if favorably developed the fractures may not be gas filled, the potential for natural gas in the Dolly Ann area must be rated as low. The area is certainly one of high-risk drilling, but it cannot be excluded from the list of possible gas-producing areas.

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, are currently being conducted in the Valley and Ridge province of Virginia. Cambrian to Mississippian strata underlying the province may contain potential natural-gas reservoirs, with a lesser possibility for large-scale petroleum reserves (LeVan, 1981). Leases for oil and gas have been issued for several tracts of land, parts of which lie in the study area, containing possible gas-bearing horizons (fig. 1). Applications for leases have also been filed for the rest of the study area.

Hydrocarbon potential in the Dolly Ann Roadless Area presently remains untested and speculative.

Geothermal Resources

Thermal springs in Warm Springs Valley northeast of the Dolly Ann area have been used as medicinal and recreational attractions for two hundred years (Hobba and others, 1979, p. E3). Falling Spring, the southernmost thermal spring in Warm Springs Valley, is less than one mile north of the study area. This spring discharges 65° to 74° F water at a rate of 6,000 to 7,000 gallons per minute (Reeves, 1932, p. 16). Studies of water chemistry in Warm Springs Valley indicate a geothermal resource of approximately 250° to 300° F (Dean Pilkington, AMAX Exploration, Inc., oral commun., 1981).

The principal aquifer for the thermal springs is Middle Ordovician limestone, which is present only at depth in the study area. A geothermal lease on 4,928 acres less than a mile north of the Dolly Ann area was allowed to terminate in 1980 after geophysical studies were performed. Previous studies indicate that warm springs in the area may constitute a geothermal resource for low-temperature application such as space heating (Costain, 1976). Additional data, however, would be required to determine geothermal-energy potential for the study area.

REFERENCES CITED

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

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

Burwell, E. B., 1920, Consultant report on the Iron Mountain mining property: U.S. Bureau of Mines, unpublished file material, Eastern Field Operations Center, Pittsburgh, Pa., 8 p., with map.

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., 1880, The geology, etc., of the Richpatch, Virginia, iron region: The Virginias, v. 1, p. 185, 188-189, 192-193.

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

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.

Costain, J. K., 1976, Geology and geophysical study of the origin of the Warm Springs in Bath County, Virginia: Virginia Polytechnic Institute and State University, Department of Geological Sciences, 44 p.

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., 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 No. 1, 17 p.

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.

Hobba, W. A., Jr., Fisher, D. W., Pearson, F. J., Jr., and Chemerys, J. C., 1979, Hydrology and geochemistry of thermal springs of the Appalachians—Geohydrology of geothermal systems: U.S. Geological Survey Professional Paper 1044-E, 36 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.

Jones, J. G., in press, Maps showing mines, prospects, and mineral localities in and near the Dolly Ann Roadless Area, Alleghany County, Virginia: U.S. Geological Survey Miscellaneous Field Studies Map MF-1358-C.

Jones, J. G., Piros, M. E., and Hammack, R. W., 1982, Mineral resources of Dolly Ann RARE II Further Planning Area, Alleghany County, Virginia: U.S. Bureau of Mines Open-File Report MLA 61-82, 37 p.

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 no. 118, 130 p.

_____1981, Geologic map of the Dolly Ann Roadless Area, Alleghany County, Virginia: U.S. Geological Survey Miscellaneous Field Studies Map MF-1358-A, scale 1:24,000.

_____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.

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.

Lesure, F. G., Arbogast, B. F., Meier, A. L., Motooka, J. M., and Siems, D. F., 1981, Analyses and descriptions of geochemical samples, Dolly Ann Roadless Area, Alleghany County, Virginia: U.S. Geological Survey Open-File Report 81-1126, 18 p.

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

Low Moor Iron Company of Virginia, 1923, Brief historical sketch of the Low Moor Iron Company of Virginia from July 5, 1873 to December 31, 1923: U.S. Bureau of Mines unpublished file material, Eastern Field Operations Center, Pittsburgh, Pa., 9 p.

Lyman, B. J., 1886, Geology of the Low Moor, Virginia, iron-ores: American Institute of Mining Engineers Transactions, v. 14, p. 801-809.

Merrill, P. C., 1943, Oriskany report: U.S. Bureau of Mines unpublished file material for war minerals report, Eastern Field Operations Center, Pittsburgh, Pa., 17 p.

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.

Moomaw, B. C., Jr., 1944, Brief of information in support of a request for extensive prospecting for iron ore in the Covington-Clifton Forge area of Virginia: U.S. Bureau of Mines unpublished file material, Eastern Field Operations Center, Pittsburgh, Pa., 11 p.

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.

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

Reeves, Frank, 1932, Thermal springs of Virginia: Virginia Geological Survey Bulletin 36, 56 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 No. 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.

U.S. Bureau of Mines, 1943, The Iron Mountain area, Alleghany County, Virginia, Regional File No. E-739: Unpublished file material for war minerals report, Eastern Field Operations Center, Pittsburgh, Pa., 15 p.

_____1944a, Douthat survey, Alleghany and Bath Counties, Virginia, Regional File No. E-591: Unpublished file material for war minerals report, Eastern Field Operations Center, Pittsburgh, Pa., 7 p.

_____1944b, The Oriskany and Tredegar Mines—Botetourt County, Virginia, and the Iron Mountain area—Alleghany County, Virginia (Interim Report, Project 962), Regional File No. E-592a: Unpublished file material for war minerals report, Eastern Field Operations Center, Pittsburgh, Pa., 12 p.

_____1945, Oriskany iron deposits, Alleghany, Botetourt, and Bath Counties, Virginia (Final Report, Project 962), Regional File No. E-592b: Unpublished file material for war minerals report, Eastern Field Operations Center, Pittsburgh, Pa., 72 p.

Weld, C. M., 1911a, Report on Iron Mountain: U.S. Bureau of Mines unpublished file material, Eastern Field Operations Center, Pittsburgh, Pa., 9 p.

_____1911b, Report on the iron properties of the Low Moor Iron Company: U.S. Bureau of Mines unpublished file material, Eastern Field Operations Center, Pittsburgh, Pa., 24 p.

_____1913, Report on the Douthat survey: U.S. Bureau of Mines unpublished file material, Eastern Field Operations Center, Pittsburgh, Pa., 15 p.

_____1915, The Oriskany iron ores of Virginia: Economic Geology, v. 10, no. 5, p. 399-421.

_____1926, Report on the mineral reconnaissance of the Douthat survey, Alleghany and Bath Counties, Virginia: U.S. Bureau of Mines unpublished file material, Eastern Field Operations Center, Pittsburgh, Pa., 23 p.

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, 2 sheets, scale 1:250,000.

Withrow, A. E., 1910, Report on Dolly Ann and Iron Mountain iron ore zones: U.S. Bureau of Mines unpublished file material, Eastern Field Operations Center, Pittsburgh, Pa., 3 p.

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.