Geology and Mineral Deposits of the James River-Roanoke River Manganese District Virginia

GEOLOGICAL SURVEY BULLETIN 1008

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By GILBERT H. ESPENSHADE

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A description of the geology and mineral deposits, particularly manganese, of the James River-Roanoke River district

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CONTENTS

ILLUSTRATIONS

[All plates are in pocket]

TABLES

GEOLOGY AND MINERAL DEPOSITS OF THE JAMES RIVER–ROANOKE RIVER MANGANESE DISTRICT, VIRGINIA

By Gilbert H. Espenshade

ABSTRACT

This report presents the results of a study of the geology and mineral deposits, particularly the manganese deposits, of the James River–Roanoke River district, made by the Geological Survey during 1940–42 as part of its Strategic Mineral program. The area is in the Piedmont province of south-central Virginia, and it extends from Altavista, on the Roanoke River, for about 60 miles northeast to Howardsville on the James River. Lynchburg, the principal city in the region, is located a few miles west of the center of the mapped area.

The predominant rock types are metamorphosed sedimentary and igneous rocks that are probably late pre-Cambrian and early Paleozoic in age. The metamorphic rocks form three groups, as follows: the Lynchburg gneiss and associated igneous rocks (greenstone and altered peridotite) on the western border of the district, the Evington group (consisting of phyllite, mica schist, marble, quartzite, and greenstone) in the center of the area, and an unnamed group of biotite-garnet schists along the eastern edge of the district.

The Lynchburg gneiss and associated igneous rocks crop out in only a small part of the mapped area; the late pre-Cambrian age assigned to the Lynchburg gneiss by earlier workers is provisionally accepted here. The rocks which are called the Evington group in this report are the most extensive and the most important in the district. The oldest formation of the group seems to be the thick series of phyllite and mica schist, here called the Candler formation, that underlies much of the western half of the district. Successively younger formations appear to be the Archer Creek formation (consisting of a siliceous graphitic schist member and a blue marble member), the Mount Athos formation (composed of quartzite, conglomerate, calcareous quartzite, white marble, mica schist, and ferruginous mica schist beds), and an unnamed greenstone, made up largely of metamorphosed basaltic flows. The Evington group appears to be younger than the Lynchburg gneiss and is of late pre-Cambrian or early Paleozoic age; it may be similar in age to the Glenarm series in Maryland and Pennsylvania. The third group of metamorphic rocks, the biotite-garnet schists along the eastern side of the southern half of the district, are probably more highly metamorphosed schists of the Evington group, or possibly the Lynchburg gneiss.

Unmetamorphosed conglomerate, sandstone, and shale of Triassic age outcrop in five small areas at the northern end of the region; they are outliers of the Triassic rocks of the Scottsville basin, which extends about 11 miles northeast of Howardsville. Diabase dikes of probable Triassic age intrude the metamorphic rocks.

Alluvial gravel deposits of Pliocene or Pleistocene age occur as high as 220 feet above the level of the nearby rivers; the floodplain deposits in the present valleys of the rivers and larger streams are of Recent age.

The older rocks were highly deformed and metamorphosed prior to deposition of the Triassic sediments. Two generations of cleavage are widespread in the more schistose rocks, the older type usually is crumpled and sliced by the younger. The cleavages usually strike to the northeast and dip to the southeast. Lineations of two types are well developed. One group, represented by cleavage crinkles and the intersection of cleavages, is nearly horizontal and trends toward the northeast; the other includes drag folds, and elongated minerals and pebbles, and plunges steeply in a southern direction.

The formations of the Evington group trend northeasterly and are repeated several times from west to east across the strike. This pattern, together with the occurrence of numerous drag folds indicating anticlinal axes to the west, is taken as evidence that the major folds are isoclinal folds which have been sliced along the western limbs of anticlines by high-angle reverse faults. The rocks of the Evington group are thrust over the Lynchburg gneiss along the western border of the district by a fault which may be of relatively slight displacement (instead of a great overthrust sheet of 15 or 20 miles displacement, as previously thought). The youngest faults and fractures are represented by normal faults bordering the basins of Triassic sediments and by the fissures occupied by the Triassic diabase dikes. The formations composing the Evington group appear to lie in a long, narrow, deep synclinorium underlain by Lynchburg gneiss. In the southern part of the area, Lynchburg gneiss is exposed in three domal structures which are bordered by rocks of the Evington group.

The mineralogical changes induced by regional metamorphism, which has affected all rocks of pre-Triassic age, are best represented by the rocks of argillaceous composition in the Evington group. The different metamorphic types derived from these rocks are characterized by the following assemblages of index minerals: chlorite-muscovite (with chloritoid in places) in the western part of the area, biotite-muscovite in the center, and garnet (with staurolite locally) along the eastern edge in the southern part of the area. The low-grade chlorite-muscovite phyllites and schists have been considered by previous workers to be phyllonites formed by retrogressive metamorphism along the sole of a great overthrust. However, the writer has found no evidence for such profound thrusting and retrogressive metamorphism, and believes that the change from low-grade chlorite-muscovite schists on the west, through biotite-muscovite schists, to garnetiferous schists on the east is the result of progressive metamorphism.

The principal physiographic feature of the region is a rolling upland surface with dendritic drainage that passes near the rivers into areas of linear ridges and valleys with trellis drainage. The upland surface appears to be the remnant of an old peneplain that is being dissected by rejuvenated streams; some of the streams have incised northeasterly-trending valleys in the belts of marble and weaker schists. Rock exposures are scarce on the upland; the rocks commonly are weathered to depths of 50 feet or more. Several lines of evidence lead to the conclusion that the peneplain was formed during a prolonged period of chemical weathering in early Tertiary time, and that the deposits of manganese oxides were formed by ground waters either during this period, or during or immediately following uplift of the peneplain.

The manganese deposits consist of heavy manganese oxide minerals of the "psilomelane type" occurring principally in clay, chert, and decomposed schist and quartzite; and of mixtures of soft, lightweight wad and clay. Every man-

ganese deposit is associated with beds of the Mount Athos formation. The deposits of commercial interest typically consist of steeply dipping lenses of clay, with embedded lumps and masses of hard manganese oxides; one wall of the clay lens is usually quartzite, and the other wall is of marble or mica schist. The white marble beds of the Mount Athos formation have been found to carry a small content of manganese, presumably in the form of a sedimentary manganiferous carbonate; chemical analyses range from 0.11 to 0.85 percent MnO. Manganese was evidently leached from these calcareous beds and deposited as manganese oxides by circulating ground waters during or shortly following the period of peneplanation, because most of the deposits outcrop on the upland surface at elevations above that of present streams. Manganese oxides have been found to extend to depths of 312 feet at the Leets mine and to about 240 feet at the Piedmont mine (Campbell County).

Iron deposits of the district are of two distinct types, limonite or brown ore deposits, and specular hematite deposits. The limonitic deposits are surficial bodies of shallow depth, commonly associated with schists, and have been formed by ground waters in a manner similar to that of the manganese deposits. The specular hematite deposits are thin lenses, a few feet thick, interbedded with quartzite and schist of the Mount Athos formation; they are probably ferruginous beds of sedimentary origin that have been regionally metamorphosed.

Barite occurs as veins in the white marble member of the Mount Athos formation and as fragments and masses in the overlying residual and surficial clays derived from weathering of the marble and barite veins.

Minor amounts of copper sulfides and oxidized copper minerals have been found in altered peridotite, white marble, and in Triassic shales.

Quartz veins are very abundant in all the metamorphic rocks and range in size from short, thin lenses, less than an inch thick, to veins several hundred feet long and as much as 30 feet wide; most veins are essentially barren of other minerals.

The first manganese mining in the district was in 1868 and 1869 at the Cabell and Bugley mines, Nelson County. Mining activity and production were renewed in the eighties and nineties at numerous deposits in Campbell County and were practically continuous in the district until the end of World War I. Since then, production has declined and has been sporadic. Considerable prospecting, including drilling and sampling by the Bureau of Mines, was done in the district before and during World War II. Production from 1937 through 1945 was only 993 long tons of washed manganese ore, in comparison to the 1911–1918 production of 7,607 tons. Total recorded production of washed manganese ore from the district amounts to 26,107 long tons; 23,760 tons was produced prior to 1920. The total production of the district, including estimates of unrecorded production, amounts to 52,779 long tons of washed ore. Most of the operations have been small; over 90 percent of the total production of the district is believed to have come from 6 mines.

Nodular or lump ore has been the principal type mined, because the heavy, coherent lumps of manganese oxides are easily recovered from the enclosing clay by simple log-washing processes. The average grade of some washed ore has been 43.3 percent Mn (representing combined shipments of 1,021 long tons from 6 mines), and 12.3 percent SiO_2 (representing shipments totaling 863 tons).

Individual manganese mines and prospects are described in the text, and pertinent information is shown on large-scale maps and sections. Known reserves are judged to be no more than 10,000 long tons of washed lump ore. These reserves might be increased by new discoveries under the stimulation of very

high prices during a national emergency, but even under the most favorable conditions it is unlikely that a rate of production greater than several thousand tons annually could be maintained for longer than a few years. The soft wad ores have not been mined in the past because of difficulties in treating these ores.

Iron ore was mined at numerous places in the district for more than 100 years, beginning about the time of the Revolutionary War and ceasing about 1882. The records of iron ore production are very incomplete; the only recorded production concerns 1880, when 57,124 tons was produced. Reserves of iron ore are judged to be small. The limonite deposits are shallow and nearly mined out. The deposits of specular hematite interbedded with quartzite and schist are small, and the ore is highly siliceous.

Barite was mined between 1874 and 1935; about a dozen deposits are known. The Hewitt mine near Evington, which was closed down in 1935, was the largest producer in the state. Recorded production of Campbell County for the period 1911–1935, inclusive, amounted to 102,917 short tons of barite, much of which apparently came from the Hewitt mine. The potential reserves of barite in the district are difficult to appraise. Reserves in known deposits appear to be small, but it is possible that deposits comparable in size to the Hewitt deposit await discovery.

Copper ore is reported to have been mined in the Glades, Amherst County, and along Wreck Island Creek, Appomattox County, before the Revolutionary War. Work was done later in the Glades area and also at the old Bishop mine in Campbell County. Recorded production of copper ore from the district amounts to 15 tons, which was shipped from the Glades in 1880. Reserves of copper ore are judged to be insignificant.

Stone has been quarried at numerous places over a period of many years. White and blue marbles have been used mostly for making agricultural lime, as flux in the old iron furnaces, and in masonry construction; quartzite, greenstone, and Lynchburg gneiss have been quarried mainly for railroad and highway ballast, and for construction purposes. White marble and quartzite have been quarried in recent years in two quarries operated by the State, and could be quarried from other sites on a more extensive scale.

INTRODUCTION

LOCATION, ACCESSIBILITY, AND CULTURE

The area described in this report is in south-central Virginia, and is an elongated strip extending from Altavista on the Roanoke River, for about 60 miles northeast to Howardsville on the James River (fig. 1). Portions of the following counties, arranged from north to south, are included in the region: Nelson, Buckingham, Appomattox, Amherst, Campbell, and Bedford counties. Lynchburg, the principal city in this part of the state, lies a few miles west of the center of the mapped area. Three railway lines pass through Lynchburg, the Southern Railway System, the Norfolk and Western Railway Co., and the Chesapeake and Ohio Railway Co.; the southern part of the area is served also by The Virginian Railway Co. at Altavista. The region is easily accessible by paved highways; secondary roads, many with improved surfaces, lead to all parts of the district.

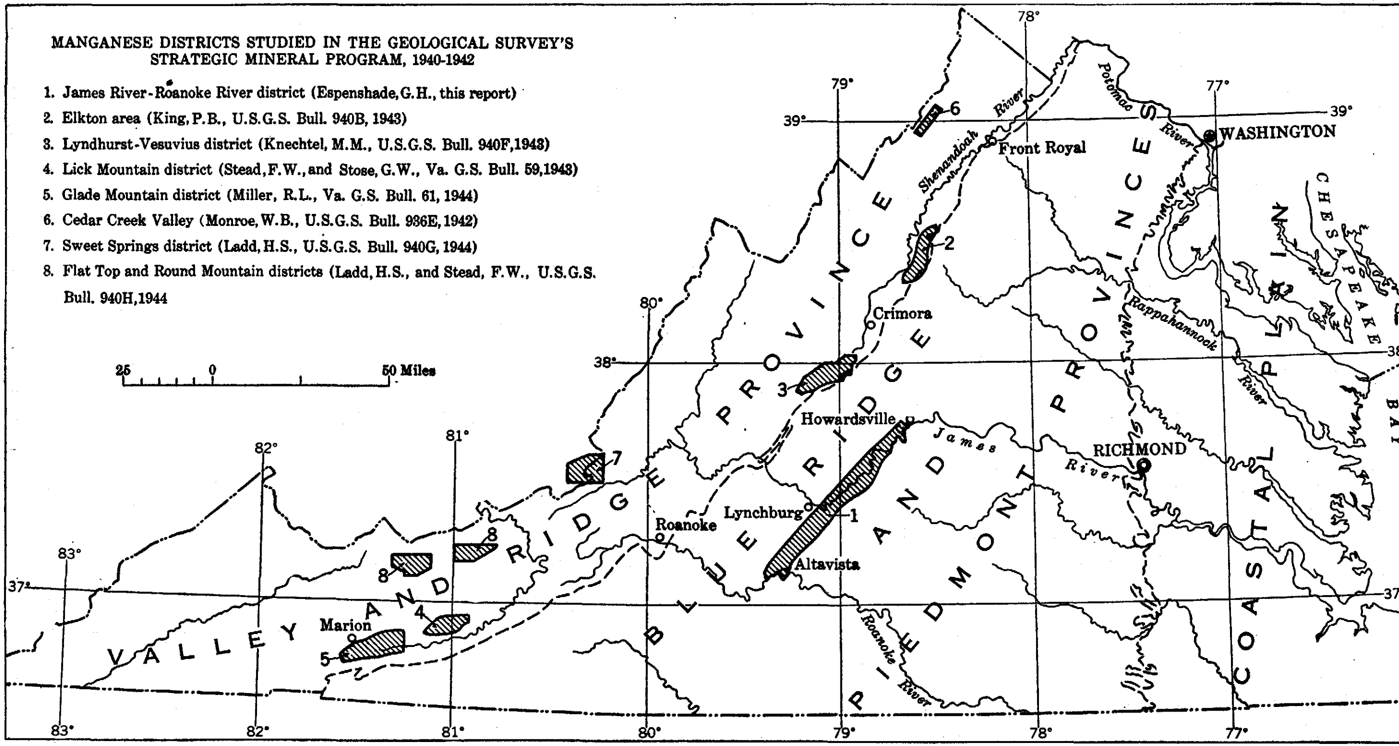

FIGURE 1. Index map of Virginia showing major geologic provinces and the manganese districts studied in the Geological Survey's Strategic Mineral program, 1940–42.

The population is mainly rural. Altavista, the largest town within the mapped area, had a population of 3,332 in the 1950 census; Lynchburg, just outside the mapped area, the chief center of trade, listed 47,727 persons in the 1950 census.

Agriculture is the principal occupation, and the more important crops and products are tobacco, grain and forage, livestock and livestock products, pulpwood, and lumber. The major industries of Lynchburg are its dark-tobacco market, and the manufacture of shoes and clothing, iron pipes and castings, plows, wagons, paper boxes and tanning extracts. The manufacture of cedar chests and textiles are important industries in Altavista. Mining has been of importance to the economy of the region during various periods in the past when manganese, iron, and barite deposits were exploited, but mining activity in recent years has declined and is now largely confined to stone quarry operations.

TOPOGRAPHY, CLIMATE, AND VEGETATION

The region is characterized by a gently rolling upland surface, dissected by numerous streams, and having linear ridges that rise as much as several hundred feet above the general elevation of the upland. The James River, major drainage system of the region, flows in a meandering course northeasterly through the northern half of the area from its abrupt bend just east of Lynchburg. Streams in the southern part of the district drain into the Roanoke River or its tributary, the Otter River.

The mean annual rainfall at Lynchburg, as recorded over a period of 76 years to the end of 1947, is 40.53 inches. Mean monthly temperatures during the same period range from 35° F. for January to 76.1° F. for July.

The best farming lands are the alluvial floodplains of the main river valleys. Most of the soil in the rest of the region is not very fertile, and some is quite unsuited for cultivation; erosion of the top soil has damaged a large portion of the land. Although farming has been practiced for over 150 years, a large part of the region is woodland. Some areas, particularly the ridges, have never been cleared for farming, but scattered all through the country there are tracts that were cultivated at one time (as is readily apparent from old furrow marks) and have since reverted to woodland. The first trees to make their appearance on the abandoned land are yellow pines; they are gradually displaced by various hardwoods.

FIELD WORK AND ACKNOWLEDGMENTS

A comprehensive study of the geology and manganese deposits of this district was included in the Strategic Minerals program of the

Geological Survey, and in the spring of 1940, the writer and Warren R. Wagner were assigned to study the manganese deposits in a group of properties controlled by the Otter River Mining Co. near Altavista, which had been actively explored during the several preceding years. Seven weeks were spent during April and May, 1940, in the making of a topographic and geologic map to a scale of 1 inch equal to 500 feet of an area of approximately 2 square miles, and in mapping the geology of the accessible mine openings in that area.

In November 1940, the writer returned to the area to begin an investigation of the geology and manganese deposits of the entire district from Altavista to Howardsville. These field studies covered a period of 13 months, and were completed at the end of November 1941; John Rodgers participated in the geologic mapping during a period of 6 months in 1941. Mapping within the area of the Lynchburg 15-minute quadrangle was done on preliminary copies of the topographic base to a scale of 1:48,000. In the rest of the district, mapping was done on aerial photographs of the Soil Conservation Service to a scale of 1:20,000; planimetric maps had already been prepared from these same photographs by the Works Progress Administration for the State Department of Highways, and acetate tracings of these maps (scale, 1:20,000) were used for compilation of the geologic map as the field mapping progressed. The few accessible mine workings in the district were mapped also. From late April through June, 1942, an exploration program was carried on by the Bureau of Mines, chiefly on the basis of the geologic investigation, at the Cabell and Bugley mines in Nelson County, and the Piedmont, Bell, and Saunders mines in Campbell County. The writer participated in this program by making large-scale topographic and geologic maps at each mine by plane-table methods, by advising upon the location of drill sites, and by logging the drill core. At the close of this exploration campaign, a preliminary report on the geology and mineral deposits of the district, which had been started early in 1942, was completed and submitted for the use of the Geological Survey and other government agencies. This report was placed in open files, available for public inspection, in July 1944. A brief report and simplified geologic map giving the essential information on the geology and mineral deposits, particularly the manganese deposits, was published in 1952 (Espenshade, 1952).

John Rodgers contributed materially to the field work by mapping the geology of about one-third of the area. In the initial phase of the project, Warren R. Wagner mapped the topography, and the writer mapped the geology, of the properties of the Otter River Mining Co. The field work in 1940 and 1941 was accomplished under the supervision of D. F. Hewett, whose guidance and advice (based upon long

experience with manganese deposits in this district and elsewhere) were of great benefit to the writer. Previously unpublished information that Hewett had gathered at several of the mines is included in this report. Preparation of the preliminary report and participation in the Bureau of Mines' exploration program in 1942 was largely under the direction of T. A. Hendricks. Both H. D. Miser and T. L. Kesler of the Geological Survey visited the area once during the field work. The late Frank K. McIntosh, project engineer, was in charge of the exploration program of the Bureau of Mines.

The geology of part of the region described in this report was being mapped by W. R. Brown of the Virginia Geological Survey during the course of the writer's field studies; field conferences and discussions with Brown have contributed to a broader understanding of the general geologic problems.

The mine owners, operators, and miners of the district cooperated fully by granting access to their properties and furnishing information on past and current operations. Other local residents extended cordial interest and aid to the work. The National Paint and Manganese Co. of Lynchburg supplied records of the local manganese ores purchased by that concern between 1921 and 1941. Most of the preliminary report was written in the offices of the Virginia Geological Survey from December 1, 1941 to June 1, 1942; the facilities provided by that organization are gratefully appreciated.

PREVIOUS WORK

The earliest geological studies in this region were made by W. B. Rogers (1884) during the course of his geological survey of the state between 1835 and 1841. The first description of manganese deposits is that of Mills (1871) who worked the Cabell and Bugley deposits, Nelson County, in 1868 and 1869. A boom in iron mining in 1880 created wide interest in the iron deposits of this area, and the geology and iron deposits were described by Campbell (1882), Frazer (1883), and others. The mineral deposits of the district (iron, manganese, and barite) were briefly described by Watson (1907b) in a report on the mineral resources of the state. The manganese deposits were later studied and described in more detail by Harder (1910) and by Hewett (1916); the latter has kept in touch with developments in manganese mining in the district since that time.

The area was included by Jonas (1927) in her reconnaissance geologic studies in the southeastern Piedmont. The small areas of Triassic rock at the northern end of the district were mapped by Roberts (1928) in his study of the Virginia Triassic. The first detailed geological mapping in the region was done by Furcron (1935) from 1925 to 1929; this work resulted in a geologic map to a scale of 1:125,000 of the northern half of the region and a considerable part of the adjacent area, and also included a report on the geology and mineral deposits. The barite deposits of Campbell County were first described by Watson (1907a), and later by Edmundson (1938) in a treatise on the barite deposits of Virginia. The geology of the part of the Lynchburg 15-minute quadrangle lying south and east of the James River was mapped in the summers of 1940 and 1941 by W. R. Brown (1941, 1942a, 1942b) of the Virginia Geological Survey as a Ph.D. thesis at Cornell University; Brown (1953) has since mapped the rest of the quadrangle. The more important studies of geology and mineral deposits made of nearby areas in this part of the state are: to the west and northwest of this area, the Blue Ridge region by Bloomer and associates (1947, 1950), the titanium district of Nelson and Amherst Counties by Watson and Taber (1913), Moore (1940a, b), and Ross 1941), and to the east of the area, the James River gold belt by Taber (1913), and the kyanite region of Prince Edward, Buckingham, and adjacent counties by Jonas (1932).

GENERAL GEOLOGY

PRINCIPAL FEATURES

The James River-Roanoke River manganese district lies near the western side of the Piedmont metamorphic province in south-central Virginia, about 25 miles east of the crest of the Blue Ridge (fig. 1). The predominant rock types of the district are metamorphosed sedimentary and igneous rocks that are thought to be of late pre-Cambrian, and probably also early Paleozoic age. These metamorphic rocks form three different units whose absolute ages and whose age relationship to each other have not been determined with certainty: the Lynchburg gneiss and associated ignerous rocks (late pre-Cambrian ?), the Evington group, consisting of phyllite, mica schist, marble, quartzite, and greenstone of pre-Cambrian or Paleozoic age, and an unnamed group of biotite-garnet schists. Several small remnants of unmetamorphosed Triassic sedimentary rocks occur in the extreme northeastern part of the region. Triassic diabase dikes intrude the metamorphic rocks in the northern half, and also in the southernmost part of the area (pl. 1). Many of the mineral deposits in the district—manganese, iron, and barite—are associated with quartzite, calcareous quartzite, and marble beds of the Evington group.

The principal structure of the region is a trough of Lynchburg gneiss enclosing the rocks of the Evington group. This trough has a length of 60 miles within the mapped area, and extends well beyond to the northeast and southwest. The rocks of the region have been highly deformed by tight folding and faulting. The structural features developed in the rocks of the Evington group appear to be more complex than those in the Lynchburg gneiss; presumably, this is true because the Evington group is composed of an assemblage of comparatively thin rock units with different physical characteristics in contrast to the more uniform, massive character of the underlying Lynchburg gneiss. Throughout most of the district the rocks of the Evington group have been compressed into northeast-trending isoclinal folds which have been sliced by high-angle reverse faults of the same trend so that the formations are repeated several times across the strike. In some areas, the fault blocks themselves seem to have been folded. The degree of deformation and metamorphism increases gradually from west to east across the southern half of the region. Cleavage is well developed in the metamorphic rocks, and usually trends northeast and dips southeast parallel to the general strike and dip of bedding; two sets of cleavage are commonly present in schist. Small drag folds and other linear structural features are widespread, and generally plunge steeply southward. Numerous faults, most of which seem to be high-angle reverse faults with northeasterly trends, have been mapped in the rocks of the Evington group, and it is likely that other, unrecognized faults exist. The contact between the Evington group and the Lynchburg gneiss, along the western edge of the district, is interpreted as a persistent reverse fault that extends northeast and southwest beyond the mapped area. The several small areas of Triassic sedimentary rocks are bordered in part by normal faults trending parallel to the regional structure.

The pre-Triassic rocks have all undergone regional metamorphism. In the rocks of the Evington group, zoning of the metamorphic minerals has been developed in the southern half of the district; chlorite-muscovite phyllite and schist form the westernmost zone, biotite-muscovite schist is in the center, and garnetiferous schist (with staurolite locally) lies along the eastern border of the district. This mineral zoning has previously been interpreted as the result of retrogressive metamorphism, but the writer regards it as progressive metamorphism with increasing intensity toward the east.

The topography of the region is characterized by a rolling upland (believed to be the remnant of an old peneplain) and by parallel ridges and valleys where the old erosion surface has been most thoroughly dissected. The James River meanders across comparatively weak rocks, such as marble and mica schist, along most of its course through the district. A long period of peneplanation appears to have been a significant event in the physiographic history; the manganese deposits are believed to have been formed by ground-water action during this period, probably in early Tertiary time or shortly after regional uplift of the peneplain.

Geologic mapping was largely restricted to the narrow elongated belt in which the manganese deposits occur, and consequently the information gathered from this area, which is limited to a few miles in width, was not sufficient for an understanding of all the major geologic features. The order of stratigraphic sequence of the Evington group, its age, and its correlation with lithologically similar formations in other parts of the Piedmont province, particularly in Maryland and Pennsylvania, are important problems that have not been solved. Many of the structural features can be satisfactorily explained on the basis of the order of stratigraphic sequence proposed in this report. Certain structural features in the vicinity of domes of Lynchburg gneiss in the southern part of the area, however, are difficult to explain on the basis of available knowledge. Considerably more work is needed to settle these questions.

Because of the uncertainty in regard to the stratigraphic order of the Evington group, and because of the variation in mineral composition caused by differing degrees of metamorphism of certain beds, questions arose about the correlation of some of the rock units. In order to show clearly these areas in which correlations are dubious, all lithologically similar rock units are shown by the same pattern on plate 1, and each unit has an appropriate letter symbol to designate that identification of the unit is established or that it is uncertain.

METAMORPHIC ROCKS

GENERAL STATEMENT

Three distinct groups of metamorphic rocks are present in the region. Bordering the northwestern edge of the area is an assemblage of gneiss and schist, known as the Lynchburg gneiss, and associated igneous rocks—greenstone and altered ultrabasic rocks. This group of rocks is thought to be of late pre-Cambrian age (Jonas and Stose, 1939, p. 577–578, 589–90). The central portion of the mapped area is underlain by a series of phyllite, mica schist, marble, quartzite, and greenstone[1] (pl. 1). This group of rocks apparently forms a stratigraphic succession, in which the greenstone is thought to be the youngest formation. These rocks have previously been correlated on the basis of lithologic similarity with the Glenarm series of Pennsylvania and Maryland by Jonas (1927) and Furcron (1935, p. 22–37) and heretofore have been called Glenarm. However, because of the uncertainty of lithologic correlations between places some miles apart in meta-

[1] The term "greenstone" is applied in this report to schists and gneiss composed essentially of hornblende, epidote, and albite, with biotite and chlorite in some varieties. These metamorphosed rocks of basaltic composition have been called "metabasalt" by previous geologists in the district. Although most bodies of this rock probably represent basaltic flows, some may have originally been diabasic intrusions, and for this reason, the non-genetic term of "greenstone" is adopted in this report.

morphic terranes, and because the stratigraphic sequence is interpreted in this report as being the reverse of Furcron's interpretation, a new name—the Evington group—is here applied to these rocks throughout the area. The Evington group structurally overlies the Lynchburg gneiss and its associated rocks and is believed to be younger than the Lynchburg gneiss, possibly of very late pre-Cambrian or early Paleozoic age; the contact between the Evington group and the Lynchburg gneiss is faulted. The third group of metamorphic rocks is along the southeastern edge of the belt, in the southern half of the area, and consists of biotite-garnet schists that carry staurolite locally. Their age and their structural relationship to the Lynchburg gneiss and the Evington group are obscure, but these garnetiferous schists are probably the more highly metamorphosed equivalents of some of the schists of the Evington group, or possibly of the Lynchburg gneiss.

LYNCHBURG GNEISS AND ASSOCIATED IGNEOUS ROCKS

The Lynchburg gneiss crops out in an extensive northeast-trending belt about 5 miles wide lying west of the James River—Roanoke River district (Stose and others, 1928; Jonas and Stose, 1939, p. 577–578; Fureron, 1935, p. 20–22); within the area shown in plate 1, it appears only in a narrow strip bordering the northwestern side of the district, and in three fairly small areas in the southern part of the region. The formation is well exposed along the James River near Lynchburg, and was named by Jonas (1927, p. 845) after this locality.

The typical Lynchburg gneiss is a fine- to medium-grained, gray gneiss composed chiefly of quartz, feldspar, and biotite, with scattered garnets. It is a uniformly foliated massive rock with widely spaced cleavage planes. In places the gneiss contains large grains of feldspar and blue quartz, as much as a quarter of an inch in size, and resembles a gritty arkose. Layers of mica schist, containing abundant large flakes of muscovite, are common. Thin layers of micaceous or chloritic marble are exposed in a quarry 1 mile west of Evington, and at the bend of Buffalo River, a mile northwest of Norwood. The entire formation evidently represents a metamorphosed group of clastic sedimentary rocks with a few, thin calcareous beds.

Greenstone, or chlorite-hornblende schist and gneiss, is intercalated with the Lynchburg gneiss as layers several hundred feet thick along the western border of the district, and surrounds the domes of Lynchburg gneiss in the southern part of the area. It has previously been correlated with the Catoctin metabasalt of northern Virginia and Maryland (Jonas, 1927, p. 844–845; Furcron, 1935, p. 44–45; Jonas and Stose, 1939, p. 582–591). The relationship of this greenstone to the Lynchburg gneiss in the James River region is not clear, and it is not known whether the several narrow parallel belts of greenstone shown in the Lynchburg gneiss on plate 1 are basaltic flows at different horizons, whether there is one flow that has been repeated by folding or faulting, or whether some greenstone may have been intruded as diabasic sills into the Lynchburg gneiss.

Greenstone schist of similar character is also associated with the Evington group in this region, and seems to be the youngest formation in that group. Thus, there appear to be at least two greenstone formations of distinctly different ages. The greenstone associated with Lynchburg gneiss is designated the "older greenstone" on plate 1, and the greenstone associated with rocks of the Evington group is called the "younger greenstone." In the vicinity of the domes of Lynchburg gneiss in the southern part of the area, greenstone is associated both with Lynchburg gneiss and with rocks of the Evington group, and its age and structural relations have not been determined; this uncertainty is indicated on plate 1. Because of these correlation problems and the uncertainty in regard to the stratigraphic order of the Evington group, formational names are not applied to the greenstone units in this report.

The Lynchburg gneiss is cut by ultrabasic intrusions, now largely altered to soapstone, at a number of places along the western side of the region and also in the larger dome of Lynchburg gneiss at the southern end of the district. The largest area of soapstone (pl. 1) forms a long swampy belt, known as the Glades, along the west foot of Buffalo Ridge. Important deposits of soapstone to the northeast along the strike of this belt have been quarried for many years at Schuyler, about 5 miles northwest of Howardsville. These deposits have been described and their origin discussed by Burfoot (1930), Hess (1933), and others. The soapstone varies in color from tan, to mottled blue gray, to dark green, and usually weathers brown. It has a fine to medium grain, with scattered relict phenocrysts of pyroxene and olivene as large as an inch in size, and commonly has a poorly developed cleavage. It typically forms numerous, large rounded outcrops. The most abundant minerals in the few thin sections examined are chlorite, of which two varieties are usually present, and a colorless amphibole. Relict crystals of olivene and pyroxene are present locally and are accompanied by a carbonate mineral. Talc is rather abundant in places, especially where pyroxene and olivene have been destroyed. Accessory metallic minerals are common.

Originally, the Lynchburg gneiss was thought to be the oldest pre-Cambrian formation in the Catoctin-Blue Ridge anticlinorium, because the Lynchburg gneiss seemed to be intruded by granitic gneisses (Jonas, 1927, p. 844–845, and 1929, p. 507–508; and Furcron, 1935, p. 20, 56). However, at the base of the Lynchburg gneiss Nelson (1932) has found a conglomerate horizon containing pebbles of granite gneiss, thus showing that the Lynchburg gneiss is the younger.

Jonas and Stose (1939, p. 589–590) now consider the Lynchburg gneiss to be late pre-Cambrian in age.

EVINGTON GROUP

The phyllites, mica schists, marbles, quartzites, and greenstones that underlie most of the district to the east of the area of Lynchburg gneiss appear to be members of the metamorphosed stratigraphic sequence, which is here called the Evington group. These formations—Candler (oldest), Archer Creek, Mount Athos, and greenstone (youngest)—are well exposed near the village of Evington. The age of this group has not been established, because of the absence of fossils, and because of uncertainty in regard to the structural and stratigraphic relationship of these rocks to the Lynchburg gneiss. The Evington group seems to occupy a synclinorium underlain by Lynchburg gneiss, and it seems to be thrust over the Lynchburg gneiss along the western side of the district. In this report, it is tentatively concluded that the Evington group is younger and is of late pre-Cambrian or Paleozoic age. The different formations of the Evington group are repeated from west to east across the strike by folding and faulting.

On the geologic map (pl. 1), the lithologic units represent stratigraphic members and formations of the Evington group. However, because of varying degrees of metamorphism of the argillaceous rocks, the stratigraphic identity of certain bodies of these rocks could not be definitely established.

Although the order of succession of the formations has not been conclusively determined, various structural features (discussed in detail under the section on structural geology) suggest that phyllite and mica schist are the oldest units of the group and that the greenstone is the youngest; this order is favored in this report. The reverse order of sequence was proposed by Furcron (1935, p. 22–37), who correlated the rocks of the Evington group with the Glenarm series of Pennsylvania and Maryland because of lithologic similarities. Furcron regarded the thick sequence of phyllite and mica schist in the James River area to be the youngest formation, because he believed it to be equivalent to the Wissahickon schist, which forms the top of the Glenarm series. The greenstone was considered to be the oldest formation of the sequence.

The stratigraphy of the Evington group is summarized in table 1, and is described later in detail.

CANDLER FORMATION

The thick series of phyllite and mica schist, with thin lenses of quartzite and white and blue marble, that seems to form the base of the Evington group and underlies a large part of the district, is

TABLE 1.—*Stratigraphy of the Evington group* [1]

Formation	Thickness (feet)[2]	Lithology and remarks
Greenstone (youngest formation?).	1,000+	Hornblende-epidote-albite-chlorite schist and gneiss. The original volcanic features are usually entirely destroyed. Believed to lie at the top of the Evington group, and to be distinct in age from the greenstone associated with the Lynchburg gneiss.
Mount Athos [3]	50–900	White to gray micaceous quartzite and conglomerate, with widespread beds of calcareous quartzite, white to cream marble, and quartz-muscovite schist. The basal member of the formation, as much as 400 feet thick, is a tan to gray, siliceous muscovite schist, with biotite porphyroblasts in areas of middle grade metamorphism. Ferruginous muscovite schists, carrying hematite and martite, are interbedded with quartzite, and occur in upper part of formation in places. The quartzitic beds usually form ridges. The manganese, barite, and most of the iron deposits of the region occur in the Mount Athos formation.
Archer Creek [4]	50–900	Green to blue-gray, siliceous graphitic schist member, as much as 500 feet thick, forms lower part of formation. Bluish, fine-to medium-grained marble member, as much as 400 feet thick, lies in upper part of formation and is interbedded with the graphitic schist member. Marble usually forms valleys.
Candler (oldest formation?).[1]	3,000–5,000	Silvery to green, fissile sericite-chlorite phyllite and muscovite schist, with thin quartzite and marble beds locally. Commonly forms ridges.

[1] The names Evington and Candler have been used by the writer and by W. R. Brown since about 1942 in their mutual discussions of these rocks. These names appear in recent papers by Brown (1951, 1953).
[2] Thickness is approximate; accurate measurements are not possible because of close folding and faulting.
[3] Name introduced by A. S. Furcron.
[4] Name proposed in this report.

called the Candler formation in this report because of the occurrence of these strata along Candler Mountain, a prominent ridge to the east of Lynchburg.

The phyllites and mica schists are typically silvery green to gray, fine-grained, and very fissile. Sericite, chlorite, quartz, and albite are the principal constituents. Porphyroblasts of chloritoid are common, and tiny biotite flakes are present occasionally. Tourmaline, rutile, zircon, and apatite are accessory minerals.

Thin lenses of white quartzite and white marble (similar to the quartzite and white marble members of the Mount Athos formation) and lenses of blue marble (similar to the marble of the Archer Creek formation) are locally interbedded with phyllite. Calcareous schists are common along the James River in the northern third of the area. The schists in the eastern part of the region are usually more siliceous and somewhat less fissile than those to the west, and contain epidote and numerous magnetite crystals. Cleavage is characteristically well-developed in the phyllites and schists, and cuts across the bedding which is still visible in places. In some parts of the area two sets of cleavage are present. Quartz veins are very common along cleavage surfaces and range in size from thin stringers to lenticular pods several feet thick. Where thoroughly weathered, the rocks of the Candler formation are decomposed to a tan to pinkish, micaceous, clayey soil, which is not very fertile. Much of the area underlain by schist and phyllite forms wooded ridges and hills.

The phyllite and schist of the Candler formation, as well as the garnetiferous schists along the eastern border of the southern part of the district, were considered by Furcron (1935, p. 27–37) to be equivalent to the Wissahickon schist of Maryland and Pennsylvania.

ARCHER CREEK FORMATION

The Archer Creek formation is made up of a siliceous graphitic schist member in the lower part of the formation, and a bluish marble member that forms the upper part of the formation. Some marble is also interbedded with the graphitic schist. Maximum thickness of the formation is estimated at 900 feet. The formation is exposed most extensively along the James River valley to the southwest of Allen Creek, in the neighborhood of Jack Mountain and Chestnut Mountain, and southeast of Evington.

Graphitic schist and blue marble are exposed along Archer Creek about 1¼ miles above its confluence with the James River. The formation is named after this locality and includes the Joshua schist and Arch marble of Brown (1951, 1953).

The graphitic schist member is greenish to blue gray, hard, siliceous schist, composed of quartz and albite arranged in a mosaic pattern, with interstitial muscovite and chlorite, and prominent porphyroblasts of biotite. A considerable amount of fine-grained opaque mineral, apparently graphite, is evident under the microscope. Pyrite is a common constituent and is present in such abundance in many places that, after weathering, it yields a characteristic yellowish stain on the rock. Tourmaline and apatite are widespread accessory minerals, and garnet occurs locally. Manganese is usually present in the schist in very small amounts, as shown by blowpipe tests,[2] but no deposits of manganese oxides are known to be associated with the graphitic schists. Pink, manganiferous garnet is present in the graphitic schist belt lying between Wreck Island Creek and David Creek (pl. 1).

Blue marble, which has a fine- to medium-grained texture and resembles unmetamorphosed limestone, overlies and is interlayered with the graphitic schist member. The blue marble is distributed throughout the region, but exposures are usually restricted to stream valleys. Wide exposures of marble near the village of Allen Creek, along Wreck Island Creek, and Otter River, north of Scott Mountain, are due to the repetition of beds by folding and faulting. The marble commonly contains disseminated cubes of pyrite and large flakes of brown biotite, partly altered to chlorite. Tiny sericite flakes impart a silky luster to cleavage surfaces. Thin siliceous or schistose beds occur,

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[2] The presence of manganese in these schists was pointed out to the writer by W. R. Brown, and it was confirmed by blowpipe determination of samples from different parts of the region.

and are well displayed in a quarry at the mouth of Opossum Creek, where beds of marble containing abundant small grains of blue quartz alternate with phyllitic layers. The marble resembles the graphitic schist in the blue color and in the presence of biotite flakes and pyrite. It is probable that the parent sediments of the marble represent a highly calcareous facies of the sediments from which the graphitic schist originated. The blue marble, however, does not contain manganese in amounts detectable by blowpipe tests, as does the graphitic schist. The marble typically weathers to a blue-gray or greenish, micaceous, clayey soil, which carries irregular fragments of vein quartz with rhombohedral cavities from which calcite has been leached.

The calcareous beds of the Archer Creek formation, together with the white marble member of the overlying Mount Athos formation, were correlated with the Cockeysville marble of the Glenarm series by Furcron (1935, p. 27–31). This correlation, based solely on lithologic similarity, is not followed in this report.

MOUNT ATHOS FORMATION

The Mount Athos formation, as originally defined by Furcron (1935, p. 22–27) for its occurrence at Mount Athos, east of Lynchburg, included the quartzite and schist beds described below, but it did not include the beds of white marble, which were grouped with the underlying blue marble and placed in the Cockeysville marble. The present study has demonstrated that the white marble is associated nearly everywhere with quartzite or calcareous quartzite of the Mount Athos formation, and that it is stratigraphically distinct from the blue marble.

The Mount Athos formation comprises quartzite, conglomerate, calcareous quartzite, marble, siliceous mica schist, and ferruginous mica schist. The quartzitic beds usually form long ridges which rise as much as several hundred feet above the surrounding country. The Mouth Athos formation is of particular economic interest because deposits of manganese, iron, barite, and marble are associated with it at many places in the region. The quartzite beds have also been quarried for road metal at several localities.

At many places, the lowest beds of the Mount Athos formation are composed of a characteristic siliceous muscovite schist, tan to greenish-gray in color. It typically carries porphyroblasts of black biotite, about a sixteenth of an inch in diameter, that lie transverse to the cleavage. The matrix of the rock is a fine-grained mosaic mixture of quartz and muscovite. Tourmaline, zircon, and epidote are common accessory minerals; garnet and magnetite also are present. This type of schist generally lies on the flanks of ridges formed by the quartzite member. Good exposures occur in the Chesapeake and Ohio railroad cut near Six Mile Bridge, at the mouth of Archer Creek. In the central part of the region, this schist has been mapped as a separate unit and termed the biotite-muscovite schist member of the Mount Athos formation. Brown (1951, 1953) has given the name, Pelier schist, to this siliceous muscovite schist with biotite porphyroblasts. In the northern and southern parts of the district, however, the schists in the lower part of the Mount Athos formation are generally more fissile and lack biotite, and usually they cannot be distinguished from the muscovite schists of the Candler formation. Consequently, they have been represented by the same pattern on plate 1.

The quartzite of the Mount Athos formation is white to light gray in color, and weathers gray with occasional brown or pink stains. The texture ranges from a fine-grained porcelaneous type to conglomerate with flattened blue quartz or feldspar pebbles up to a quarter-inch in size. Quartz and minor amounts of microcline and albite, form an interlocking mosaic with sutured grain boundaries. Silvery to pearly-green muscovite is abundant. Epidote, apatite, martite, and biotite are the more common accessory minerals; chlorite, zoisite, zircon, garnet, and tourmaline are present in some mylonitized (highly crushed) quartzite along the eastern side of the area.

The calcareous quartzite superficially resembles the varieties described above, but may contain as much as 40 percent of white to tan carbonate. Weathering of the calcareous variety of quartzite results in characteristic blocks of porous, honeycombed rock whose irregular, leached cavities are stained black with manganese oxide or filled with red clay.

The calcareous quartzite grades into white to tan marble at several places within the region. The marble has been mapped as a separate member of the Mount Athos formation. Doubtless, it is considerably more widespread than is shown in plate 1 because it weathers rapidly. The few outcrops are mainly along streams and in quarries and mines. The more prominent outcrops of marble are located near Warminster, along the James River between Allen Creek and Gladstone, on Wreck Island Creek, at Little Beaver Creek near the Piedmont mine, along Beaver Creek, near the McGehee mine southeast of Lawyer, and at several places along Otter River. The marble is generally coarse- to medium-grained, but some dolomitic varieties in the northern part of the district are rather fine-grained. Biotite, muscovite, and chlorite are not uncommon constituents. Small amounts of metallic minerals are present in places. In the State limestone quarry on Wreck Island Creek, several thin veins of sulfides—pyrite, chalcopyrite, sphalerite, and bornite—cut the marble. Veinlike deposits of barite occur in the marble in the southern part of the district.

Chemical analyses, supplemented by blowpipe tests for manganese of a considerable number of samples, show that the marble uniformly carries a small content of manganese, probably in the form of carbonate. All of the manganese deposits in the region occur within the Mount Athos formation, and it is believed that the manganese was dissolved from the calcareous beds and was concentrated as manganese oxides during a period of prolonged weathering in early Tertiary time. These features are fully discussed in the section on the origin of the manganese deposits. The marble typically weathers to a chocolate-colored, loamy soil, whose color doubtless is due to the formation of manganese oxide during weathering.

Gray, hematite-magnetite-quartz schist with thin seams of lustrous black, micaceous, specular hematite occur with conglomerate beds on the west side of the James River, north of Round Mountain. These ferruginous beds were worked for iron ore many years ago near Riverville and also in areas farther to the north. Thin beds of tan to greenish martite-bearing schist occur in the formation at many places, and in a few places are at the top of the Mount Athos formation in sufficient thickness to be mapped as a separate member. These ferruginous beds may represent a tuffaceous gradation to the overlying greenstone.

GREENSTONE

Greenstone, which includes hornblende-epidote-albite-chlorite schist and gneiss, is widespread throughout the district in narrow belts that are usually flanked on the west side by quartzite of the Mount Athos formation. As already pointed out, certain structural features suggest that this greenstone is the youngest formation of the Evington group, and hence distinct from greenstone associated with Lynchburg gneiss. Although it seems reasonably certain that greenstone occurs at two different stratigraphic horizons, no characteristics other than association with the Mount Athos formation or with the Lynchburg gneiss were recognized which would permit distinctions between the two greenstone formations. As a result, it was not possible to determine whether greenstone surrounding the three domes of Lynchburg gneiss in the southern part of the region belonged to the greenstone horizon of the Evington group or to the Lynchburg gneiss. Furthermore, several areas of greenstone in the southern part of the district underlie the Mount Athos formation structurally. As discussed below, it is possible that some bodies of greenstone in the southern part of the region are basaltic flows occurring at an intermediate stratigraphic position, or may have been intrusive rather than extrusive. Because of these uncertainties in determining the relative age of some bodies of greenstone, all greenstone in the area is shown by the same pattern on plate 1, and no formational names are used. Bodies of greenstone considered to be stratigraphically associated with the Lynchburg gneiss are distinguished as the "older greenstone", those bodies that apparently are flows at the top of the Evington group as the "younger greenstone," and the bodies of uncertain correlation as simply "greenstone". The greenstone that is interpreted here as overlying the Mount Athos formation was considered by Furcron (1935, pp. 47–49) to be lying beneath the Mount Athos formation. Brown (1951, 1953) uses the name "Slippery Creek greenstone volcanics" for the "younger greenstone".

The greenstones include a variety of schists and gneiss and are composed principally of hornblende, epidote, albite, and chlorite. The rocks range from light green to dark green or greenish gray in color, and from fine-grained schist to coarse gneiss. Biotite is generally present as ragged flakes, partly altered to chlorite. Magnetite and apatite are common accessory minerals. Hornblende needles generally have strong linear orientation. The greenstone is usually so mylonitized that no traces of its primary volcanic features are preserved, although epidote-filled amygdules still remain in a few places.

The greenstone areas are generally rolling uplands, and are underlain by a red to red-brown clayey soil that is characteristic of the formation.

DISTRIBUTION OF FORMATIONS OF THE EVINGTON GROUP

All formations of the Evington group occur throughout most of the mapped area, but in the northern section, phyllite and mica schist predominate and the other rock units occur mainly as thin, discontinuous lenses. The graphitic schist member of the Archer Creek formation was not recognized to the north of Greenway. The abundance of phyllite and mica schist at the northern end of the district may mean that the trough containing the Evington rocks is more shallow here, and that most of the Archer Creek formation, the Mount Athos formation, and the greenstone have been eroded. Another explanation may be that the original conditions of sedimentation progressively changed toward the northeast, with deposition here mainly of argillaceous material, and lesser amounts of sand, lime, and greenstone than in areas to the southwest.

The quartzite and white marble members of the Mount Athos formation show some variations in their distribution that possibly reflect original differences in the composition and conditions of deposition of the sediments and may have some bearing on the distribution of manganese and specular hematite deposits. Between Otter River and Wreck Island Creek, white marble seems to be most abundant with quartzite near the eastern border of the district, whereas there is little marble in the westernmost quartzite belts. No marble is known in the thick beds of quartzite that underlie Jack Mountain and Round Mountain. This suggests that the Mount Athos sediments originally became more limy toward the east in this part of the district. On the other hand, in the northern part of the district, marble is most abundant in the westernmost quartzite belt, and seems to be absent from the thick beds of quartzite associated with greenstone on the eastern side of the district between Wreck Island Creek and Bent Creek. Specular hematite of probable sedimentary origin is associated with quartzite at several places between Round Mountain and Greenway.

If the present distribution and thickness of the quartzite and white marble members, and lenses of specular hematite of the Mount Athos formation are reflections of the original conditions of deposition, it is suggested that the depositional basin was elongated in a northeasterly direction nearly parallel to present structural trends, and that thick beds of sand with a small amount of lime mud were deposited along the margins of the basin or trough while a large amount of lime with thinner layers of sand was being deposited in the center. Thin, lenticular ferruginous beds were deposited locally in various parts of the basin, but are found most abundantly in a rather small area west of the thickest lime deposition.

Narrow belts of quartzite and white and blue marble in the phyllite of the Candler formation have been mapped as members of the Candler formation. These thin beds of quartzite and marble could be thin lenses of sandy and calcareous sediments that were deposited with the argillaceous Candler sediments, or they may be thin or highly sheared beds of the Mount Athos and Archer Creek formations that were folded or faulted with schists of the Candler formation.

BIOTITE—GARNET SCHIST

Garnetiferous schists and gneisses occur along the southeastern edge of the district between Rustburg and Altavista (pl. 1). The structural and age relations of these higher grade metamorphic rocks to the other formations of the region are not clear, but they are probably strongly metamorphosed equivalents of the Evington group. To the northeast of this belt, the garnet-bearing schists associated with quartzite and marble members of the Mount Athos formation between Archer Creek and the headwaters of Beaver Creek are probably more highly metamorphosed schists of the Mount Athos formation. Garnet-bearing schist that occurs in discontinuous narrow strips around the largest dome of Lynchburg gneiss is garnetiferous Lynchburg gneiss.

The garnet schists between Rustburg and Altavista usually are gray to greenish in color, medium- to coarse-grained, and are schistose to gneissic. Quartz and albite, with variable amounts of muscovite, make up the matrix. Biotite, partly altered to chlorite, and garnet crystals are characteristic; tourmaline and epidote are accessory minerals. Staurolite, forming crystals as large as 2 centimeters in size, is a common constituent.

AGE RELATIONSHIPS OF THE METAMORPHIC ROCKS WITHIN THE DISTRICT

The various problems regarding the relative ages of the different metamorphic rock units in this area are summarized and discussed below. The discussion is limited to rock units within the mapped area; the broader problems of correlation with formations in other localities are treated in the following section.

AGE OF LYNCHBURG GNEISS AND ASSOCIATED GREENSTONE AND SOAPSTONE

No new information on the absolute age of the Lynchburg gneiss and its associated igneous rocks was gathered in the limited area comprising this study. Greenstone occurs in the upper part or at the top of the Lynchburg gneiss. Several belts of greenstone are exposed, but it was not evident whether one basaltic flow occurred that was repeated by folding or faulting, or that several flows occurred, or that some greenstone bodies were basaltic flows and others were diabasic intrusions. The late pre-Cambrian age for the Lynchburg gneiss and the greenstone, as proposed by Jonas and Stose (1939), is provisionally accepted in this report; it had formerly been called early pre-Cambrian by Jonas (1927). The soapstone bodies represent altered peridotite intrusions in the Lynchburg gneiss, and hence, although they are younger than the Lynchburg gneiss, their age is unknown; they may be either late pre-Cambrian or Paleozoic in age. The absence of ultrabasic intrusives from the Evington group is assumed to mean either that the Evington rocks are younger than the ultrabasic intrusives (in which case the peridotite may have been intruded in late pre-Cambrian time) or that the Evington rocks are overthrust onto the area of Lynchburg gneiss and peridotite (in which case, the ultrabasic rocks may have been intruded either in late pre-Cambrian or Paleozoic time, prior to overthrusting of the Evington group).

STRATIGRAPHIC SEQUENCE AND AGE OF EVINGTON GROUP

Despite careful mapping of the Evington group over a fairly large area, the age and stratigraphic order of these rocks were not established with certainty. The Evington group overlies Lynchburg gneiss structurally wherever the two groups are in contact within the area, and although there appears to have been thrusting along the main contact on the western border of the district, the writer thinks that the rocks of the Evington group were originally deposited upon the Lynchburg gneiss, and hence are of late pre-Cambrian or early Paleozoic age. Furcron (1935, p. 22, 52–53) assigns pre-Cambrian age to the rocks included in the Evington group, and interprets the contact between the Evington rocks and the Lynchburg gneiss to be a thrust along which normal faulting later took place. Brown (1942b) has suggested that the rocks called the Evington group represented a deeper-water facies which were deposited at about the same time that the Lynchburg sediments were laid down; thus, both units would be essentially equivalent in age.

The stratigraphic order of the Evington group is regarded as greenstone (youngest), Mount Athos formation, Archer Creek formation, and Candler formation (oldest). This view is based largely upon structural features, which are essentially the determination of nature and the position of major fold axes by means of drag folds, and similar repetition of formations in adjacent fault blocks. This evidence, which is not conclusive, is treated at greater length in the section on structural geology. Brown (1941) was the first to propose this order of sequence and his reasons for considering the greenstone to be the youngest formation are:

1. Coarsening of grain size in the quartzite member of the Mount Athos formation at many places near its contact with the biotite-muscovite schist member at the base of the formation. (The writer, however, has observed pebble or grit beds at different horizons within the quartzite members, even near the greenstone contact at a number of places, but has not seen definite graded bedding).
2. Nature of drag folds.
3. Apparent dip of the Candler formation (Wissahickon schist in Brown's 1941 paper) under both sides of the belt of greenstone, quartzite, and marble suggests a synclinal structure for the belt.
4. Absence of greenstone pebbles in quartzite of the Mount Athos formation.
5. Simpler explanation of structures and regional age relationships.

Nearly all structural features in the region can be explained satisfactorily on the basis of this stratigraphic order, except in the vicinity of the domes of Lynchburg gneiss near Altavista and Rustburg. If the stratigraphic order of the Evington group is the reverse of the sequence just discussed, then the greenstone would be the oldest formation of the group (Furcron, 1935), and could be equivalent to the greenstone associated with the Lynchburg gneiss. The structures of the domed areas might be explained more readily by this sequence.

Other possible explanations for the distribution of greenstone in the domed areas are:

1. Some greenstone bodies may be intrusive, cutting across formation boundaries.
2. Basaltic flows may occur locally at intermediate stratigraphic horizons.
3. Basaltic flows may be younger than some of the deformation of Lynchburg gneiss and the Evington group, and may rest unconformably on both units in the southern part of the area.
4. The Lynchburg gneiss may be a shallow water facies and the sediments of the Evington group may be a deeper water facies that were deposited about the same time, as suggested by Brown (1942b). The final stage of deposition could then have been extrusion of basaltic flows over both groups.

AGE OF BIOTITE—GARNET SCHISTS

The probable equivalence of garnetiferous schists in different areas to formations of the Evington group or to the Lynchburg gneiss has been discussed above.

REGIONAL CORRELATION PROBLEMS OF THE METAMORPHIC ROCKS

In the small area of Lynchburg gneiss mapped in this study, no new information was discovered in regard to the age relationships of the formation to underlying rocks, inasmuch as the base of the formation lies several miles to the west of the district. The Lynchburg gneiss and associated greenstone are considered by some geologists to be representative of a series of clastic sediments and volcanics deposited at different places in the Great Smoky Mountains and Blue Ridge areas in late pre-Cambrian time; the various views are sketched briefly below. The correlation problems of the Lynchburg gneiss and associated greenstone have been discussed by Jonas and Stose (1939). According to them, the base of the Lynchburg gneiss rests uncomformably upon an injection complex of gneiss and granodiorite northwest of the James River area. They correlate the Lynchburg gneiss with the tuff that rests upon the early pre-Cambrian injection complex at Swift Run Gap on the western side of the Catoctin-Blue Ridge anticlinorium. They consider this tuff, later named the Swift Run tuff (Stose, G. W. and Stose, A. J., 1944), to be of late pre-Cambrian age, and conclude that the Lynchburg is the same age. They also assign late pre-Cambrian age to the Catoctin metabasalt, overlying the Swift Run tuff, and correlate the Catoctin with the greenstone associated with the Lynchburg gneiss. More recently, the Stoses have extended their studies of the Cambrian and late pre-Cambrian formations to the southern Appalachians; they conclude that the Ocoee series of conglomerate, graywacke, shale, etc. in the Great Smoky Mountains and vicinity is of late pre-Cambrian age, and probably correlative with the Lynchburg gneiss (Stose and Stose, 1944; 1949). The same conclusions have also been reached by King (1949b) as a result of extensive field work by himself and associates at several places in the Blue Ridge of Virginia and Tennessee and in the Great Smoky Mountains.

Another view on the age of volcanics and clastic sedimentary rocks beneath known Cambrian rocks and resting on the injection complex in central Virginia has been reached by Bloomer and Bloomer (1947). They conclude that the Catoctin metabasalt in the Blue Ridge in the Buena Vista quadrangle, about 20 miles northwest of Lynchburg, is basal Cambrian, and suggest that the Lynchburg gneiss is also of the same age. Bloomer (1950) has since discussed more fully the distribution, characteristics, and ages of the rocks of the Catoctin-Blue Ridge anticlinorium; he concludes that there is a continuous sequence from the base of the Lynchburg gneiss up through the clastic rocks that lie above the Catoctin metabasalt and below known Cambrian rocks. However, he is undecided about the ages of these rocks, and states that the boundary between pre-Cambrian and Cambrian rocks may be as low as the base of the Lynchburg gneiss, or as high as the non-fossiliferous rocks above the Catoctin metabasalt.

The formations making up the Evington group of this report were correlated by Jonas (1927) and Furcron (1935) with the Glenarm series of Maryland and Pennsylvania because of lithologic similarities. The Glenarm series was considered by Jonas and others to be pre-Cambrian in age, and the order of sequence of formations (from oldest to youngest) in the Glenarm series was determined as Setters quartzite (resting upon Baltimore gneiss), Cockeysville marble, and Wissahickon gneiss and schist. Furcron believed that a similar stratigraphic sequence was represented in the James River area. He thought that the Mount Athos formation (resting on greenstone) was the oldest sedimentary formation, the marble (both the blue and white types that are clearly members of two distinct formations) to be equivalent to the Cockeysville marble, and the mica schist to be the youngest formation and correlative with the Wissahickon formation.

Inasmuch as the writer believes that the stratigraphic order of the Evington group is the reverse of that proposed by Furcron, correlation with the Glenarm series would seem to be uncertain. Nevertheless, there is reason to believe that the Evington group may be correlative with metamorphosed sedimentary and volcanic rocks in the Piedmont of Maryland and southeastern Pennsylvania. Solution of the problem is severely handicapped by the fact that the two regions are nearly 150 miles apart, and in much of the intervening area the metamorphic rocks are covered by younger Triassic sediments. An area of extremely complex geology in Frederick and Carroll Counties, Maryland, involves several varieties of marble, metamorphosed volcanic rocks (basalt, rhyolite, and tuffs), quartzite, and mica schist. Stose and Stose have studied these formations in some detail here (Stose and Stose, 1946) and farther northeast in the Hanover-York district, Pennsylvania (Stose and Stose, 1944); although they were unable to establish the relationship of this series of rocks to the Setters quartzite, Cockeysville marble, and Wissahickon formation farther east in the Maryland Piedmont, they believe that the two series may be correlative.

Correlation of the Evington group with the lithologically similar series of marble-volcanic rocks, and quartzite-mica schist of possible Glenarm age in Frederick and Carroll Counties, Maryland, is proposed by the writer as a possibility.

The geologic structure and age of the Glenarm series in Pennsylvania and Maryland has been the subject of much investigation over a long period of time. Although most of the area in the Piedmont between the Potomac River and the Schuylkill has been mapped to the scale of 1 inch to the mile, many of the fundamental problems remain unsolved. These studies will not be reviewed here; the interested reader will find summaries of investigations and interpretations in papers by Cloos and Hietanen (1941) and by Stose and Stose (1944; 1946). One of the controversial questions has been the age of the Glenarm series, whether it is pre-Cambrian in age (as long held by the Stoses and others), or whether it is Paleozoic, representing the metamorphosed, near shore, argillaceous and arenaceous facies of early Paleozoic calcareous rocks (as believed by Cloos and others). Although the question is far from settled, the most recent view expressed by the Stoses (1946, p. 83) is that the Setters quartzite and Cockeysville marble may be of Early Cambrian age, and the Wissahickon formation may be an argillaceous facies of Early Cambrian to Ordovician age (possibly including some rocks of pre-Cambrian age) that is thrust upon the Setters, Cockeysville, and other formations. The writer believes that the Evington group is probably of early Paleozoic age, and that the formations included in the Evington group were deposited together in the same basin of sedimentation.

The possible relationship of formations of the Evington group to two areas of Ordovician rocks in the Virginia Piedmont must be kept in mind. A belt of calcareous rocks, termed the Everona limestone, lies 15 miles northeast of Howardsville on the strike. These rocks are separated from the Evington group by a basin of Triassic rocks and extend 60 miles farther northeast (Jonas, 1927, p. 842). About 17 miles east of Howardsville is the syncline of quartzite and fossiliferous slate of the Arvonia slate belt (Stose and others, 1928; Stose and Stose, 1948).

Very little detailed geologic study has been devoted to the large area of the Piedmont province southwest of the James River-Roanoke River district, and information on which to base suggested correlations of the Evington group is correspondingly scarce. One area having an assemblage of rocks somewhat similar to this district is the Gaffney-Kings Mountain region in South Carolina and North Carolina. Greenstone, quartzite, mica schists (some varieties of which are manganiferous), graphitic schists, and marble (both blue and white varieties) are among the metamorphic rocks in this region; barite, iron, and residual manganese deposits also occur (Keith and Sterrett, 1931). The possibility of correlation between the Evington group and the lithologically similar group of rocks in the Gaffney-Kings Mountain region should be recognized. One or more types of rock lithologically similar to members or formations of the Evington group, such as quartzite, marble or graphitic schist, are present at numerous places in the southern Piedmont, but their stratigraphic and structural characteristics have not been determined.

If the stratigraphic order of the Evington group should be the reverse of the order favored in this report, then the greenstone formation of the Evington group would be the oldest formation and might be equivalent to the Catoctin metabasalt. In that case, the Mount Athos, Archer Creek, and Candler formations would be younger and might be regarded as Cambrian in age. The manganiferous marble and calcareous quartzite members of the Mount Athos formation might therefore be considered as equivalent to the manganiferous Tomstown (Shady) dolomite of early Cambrian age along the west flank of the Blue Ridge, and the residual manganese deposits in the two districts would thus have been derived from beds of comparable age.

UNMETAMORPHOSED ROCKS

The only rocks in the region that have not undergone metamorphism are the sedimentary and igneous rocks of Triassic age. In the northern end of the district, red, tan, and greenish shale, sandstone, and conglomerate rest unconformably upon phyllite in five isolated areas (pl. 1). The green shale is fine-grained and composed mostly of quartz and feldspar grains with some epidote in a matrix of chlorite and sericite; coarse-grained, tan sandstone and conglomerate layers with pebbles of phyllite and vein quartz occur with the shale. Red shale and conglomerate containing pebbles of greenstone and vein quartz are abundant.

Although no fossils were found in these rocks, they are outliers of the Scottsville basin of Triassic rocks that extends for about 11 miles northeast of Howardsville, and are similar in character to Triassic sedimentary rocks elsewhere in Virginia (Roberts, 1928). The outliers south of Howardsville are bounded on one side or on both sides by normal faults that drop the Triassic rocks against phyllite. During the present study, several areas of Triassic rocks were mapped that are not shown on the geologic maps of Roberts (1928, pl. 4) or Furcron (1935, pl. 1).

The metamorphic rocks in the northern and southern parts of the district are intruded by diabase dikes considered to be of Triassic age because they are unmetamorphosed and similar to the diabase bodies intruded into Triassic sediments farther north. The dikes in this area, however, do not cut Triassic sediments. The larger and most persistent dikes are 100 to 150 feet thick and usually trend slightly northwest, although the courses of some dikes are irregular and branching. The intruded rocks have been metamorphosed for a distance of a few feet from the larger dikes. Diabase has usually weathered more readily than the enclosing rocks, and the course of a dike is typically marked by northerly trending depressions that make gaps in the transected quartzite and schist ridges. Blocks of diabase rounded by weathering lie on the surface of the ground along the dikes. The texture of the diabase in the larger dikes is coarse-grained, and becomes fine-grained at the walls of the dike and in the thinner dikes. Large crystals of andesine and pyroxene, with scattered olivine crystals, occur with interstitial crystals of finer-grained plagioclase and pyroxene; shreds of brown biotite are present, and accessory metallic minerals are abundant. Olivine is partly altered to serpentine, pyroxene is partly replaced by hornblende, and olivine, pyroxene, and plagioclase are partly replaced by pale-green chlorite.

ALLUVIAL DEPOSITS

Two types of alluvial deposits of different ages are found along and near the rivers and streams. The older deposits are gravels composed of pebbles and cobbles of quartzite resting on terraces, bluffs, and intermeander spurs along the river valleys at elevations as much as several hundred feet above river level. These gravels are distributed along the James River in isolated patches. Evidently, they are erosion remnants of extensive sheets of gravel that were deposited in the river flood plain at an earlier stage or stages of the river's development when its valley was at a higher elevation. The ground surface is littered with quartzite pebbles and cobbles, but exposures of the gravel in place were not seen, and it is uncertain how much downslope migration of gravels may have taken place during progressive down-cutting of the river valley. Certainly, there has been some movement of the gravel in some places, particularly on some of the lower intermeander spurs of the James River where cobbles and pebbles are scattered over the surface down to the present flood plain. Gravels on the flat-topped bluffs along the river just east of Lynchburg are probably nearer their original levels of deposition; the upper surface of these patches of gravel ranges from 150 to 220 feet above the river. Deposition of gravel may have taken place at different stages of downcutting over a long period of time. The age of these gravels has not been determined, but they are probably Pliocene or Pleistocene; the question is discussed in the section on Physiographic History.

The younger alluvial deposits are made up of fine-grained sediments that form flood plain deposits in the present valleys of the rivers and larger streams. The flood plain in the James River valley is composed of several broad terraces, 10 to 20 feet above the adjacent lower terrace. Several terraces are present along some of the larger stream valleys. These terraces evidently represent successive stages in the lowering of the drainage systems and are judged to be of Recent age.

STRUCTURAL GEOLOGY

GENERAL STATEMENT

The strong deformation that the pre-Triassic rocks of the region have undergone has folded and faulted the rocks in a complex fashion and has imposed cleavages upon them which have obscured or destroyed the bedding. Structural trends prevail in a northeasterly direction; bedding, cleavages, faults, and the axial planes of folds usually dip toward the southeast. Lineations of several types and ages are widespread. One group, represented by cleavage crinkles and the intersection of cleavages, is nearly horizontal and trends toward the northeast; the other group, including drag folds and elongated minerals and pebbles, plunges steeply in a southerly direction. Most of the major folds appear to be isoclinal, faulted by high-angle reverse faults that have sheared out the western limbs of anticlines. Axes of many of these folds appear to be nearly horizontal; some large folds plunge toward the south. Low-angle thrust faults parallel to the regional strike are present in addition to high-angle reverse faults. The contact between the phyllite of the Candler formation and Lynchburg gneiss along the western border for a distance of 60 miles coincides with a fault; the displacement along this fault may be relatively slight, and not a distance of 15 or 20 miles as previously had been thought. The latest faulting and fracturing is represented by normal faults that cut the Triassic sediments and by fractures filled by the Triassic diabase dikes. The most complex structure in the district is in the area of Wreck Island Creek and Riverville where a complex of faulted folds seems to have been refolded along a northerly trending cross structure and in the southern part of the area where rocks believed to be Lynchburg gneiss are exposed in three domes that are surrounded by rocks of the Evington group. The major structural feature of the belt of formations composing the Evington group is believed to be a long, narrow, deep synclinorium underlain by Lynchburg gneiss.

BEDDING, CLEAVAGE, AND JOINTS

The original sedimentary and igneous features of the pre-Triassic rocks have been largely destroyed by the development of cleavage and the formation of new minerals during regional metamorphism. Bedding is still apparent locally in some phyllite of the Candler formation where it is represented by color banding, or by limy or sandy layers. It is also evident in some outcrops of the marble member of the Archer Creek formation as siliceous or micaceous layers and at places in the quartzite member of the Mount Athos formation as differences in grain size between layers. The bedding, particularly in phyllite or marble, is commonly crumpled into tight, small folds that are sliced by the cleavage. However, on a larger scale, bedding and cleavage are nearly parallel in many places; this is indicated by the fact that the principal strike and dip of many of the lithologic units nearly coincide with main trends of cleavage. No bedding was recognized with certainty in the Lynchburg gneiss or in the higher grade biotite-garnet schists along the eastern edge of the area. Relicts of vesicular structure in greenstone are found in place as light-colored, elongate amygdules.

Cleavage is well developed, in variable manner and degree, in all of the metamorphic rocks of the region. In the more massive rocks, such as quartzite and the Lynchburg gneiss, usually only a single set of cleavage planes with a rather uniform strike and dip is present. In marble, cleavage is generally apparent as lustrous surfaces on which numerous tiny muscovite flakes are visible. Cleavage is most strongly developed in mica schist and phyllite, and several sets of cleavage of two general types are commonly present in these rocks. In one type, that is rather widespread in the western belt of phyllite of the Candler formation, the several cleavages seem to be about equally developed and have about the same northeasterly strike, but dip southeasterly at different angles, so that in exposures normal to the strike the rock appears to be sliced into lenticular blocks by the intersecting surfaces. In the other type, a well-developed cleavage is present that is sliced by later cleavage planes. All degrees of deformation of the early cleavage and its displacement along the younger cleavage may be observed. In some places, the early cleavage shows little or no crumpling and displacement and is merely sliced by later cleavage. Commonly, the older cleavage is tightly crumpled and slightly displaced by movements along the younger surface; the two sets of cleavage usually have nearly the same strike, but may dip in the same general direction or in the opposite direction. Crumpled early cleavage with general westerly dips that is sliced and displaced by cleavage with easterly dips is found in the phyllite and schist of the Candler formation near its contact with Lynchburg gneiss along the western edge of the area and in the region of Bent Creek and David Creek on the eastern border of the district. Small quartz lenses and stringers are very common along the cleavage surfaces in phyllite and schist and may have a crumpled or folded shape conformable with the cleavage.

The late cleavage in these rocks resembles types that have been called "fracture cleavage" by many geologists in the past. Recently, White (1949) has described and discussed two types of cleavage in Vermont metamorphic rocks, schistosity or flow cleavage (the older), and slip cleavage (the younger). The early schistosity is commonly crumpled into numerous tiny crinkles whose axial planes are paralleled by the later slip cleavage that slices the rock. In parts of the Vermont area, the slip cleavage has become so prominently developed that the early schistosity is obscured, or even wholly obliterated. The late cleavage of the James River area seems to be very similar to the slip cleavage described by White, and the term "slip cleavage" (originally introduced by T. N. Dale) can be appropriately applied to the late cleavage in this area. Very close crumpling of the early cleavage and slicing by the slip cleavage, gives a "herringbone tweed" appearance in cross section at places on the eastern border of the district. Complete destruction of the early cleavage was not noted by the writer, but such a condition might be easily overlooked.

The writer feels that the several sets of cleavage present in schist and phyllite at many places were developed during different stages of a single orogenic period; thus, several cleavages were formed in these incompetent rocks while a single cleavage was being formed in quartzites and other competent rocks. Jonas (1932, p. 32–37) and others believe that these rocks have undergone two periods of deformation, the earlier cleavage formed in a pre-Cambrian period of metamorphism, and the younger cleavage formed during metamorphism in the late Paleozoic. However, the writer concludes that the facts point to a single period of metamorphism.

Cleavage in this area generally trends toward the northeast; the trends are quite irregular in the tightly folded area along Wreck Island Creek. Dips are usually toward the southeast at angles of 60 degrees or more; however, rather gentle easterly dips, from 20 to 30 degrees, prevail along the eastern side of the district between Wreck Island Creek and Bent Creek. Westerly dipping cleavage prevails along the southeastern edge of the district, and is found in the western phyllite belt of the Candler formation in the northern part of the region. In the domes of Lynchburg gneiss near Rustburg and Altavista, the cleavage dips outward from the center, and becomes more closely spaced near the borders of the domes; broad folds in the cleavage are indicated in the northern half of the larger dome.

The most prominent system of joints in the district trends northwesterly and usually dips rather steeply toward the northeast. This joint system is well reflected in the rectilinear drainage pattern in the Candler Mountain area.

LINEATION

Linear structures, or lineations, of several different kinds are prominent in all of the metamorphic rocks; they are represented by small-scale folds of bedding, cleavage, or quartz stringers, by tiny cleavage crinkles, intersection of two cleavage surfaces, elongation and alinement of such minerals as biotite, muscovite, and hornblende, elongation of pyrite crystals in marble and graphitic schist of the Archer Creek formation, and stretched pebbles in conglomeratic beds. Orientation of the linear structure is variable, but there are two general trends. One group of lineations trends nearly parallel to the regional strike and plunges rather gently northeasterly or southwesterly; this group is represented chiefly by crumpled cleavage and intersections of several cleavage surfaces. The other group of lineations plunges rather steeply in a southerly direction; it is represented by elongated minerals and pebbles, and also by some small-scale drag folds, particularly of siliceous beds in marble. This trend seems to be represented by at least one of the manganese deposits of the district, the Stonewall deposit, which has an elongate form that apparently plunges steeply southwest; the Piedmont deposit (Campbell County) is also elongated downward, but plunges steeply westward.

Interpretations of the significance of these lineation trends in terms of direction of movement must be used with caution, because information on the trends and age relationships of these structures is inadequate, due to the fact that the relative ages of cleavage and lineation were not distinguished and recorded in the field mapping. More careful observation and more complete statistical analyses of these structural elements are needed for satisfactory interpretation of the structural movements. Nevertheless, it is probably safe to assume from the present data that the lineation trending nearly parallel to the regional strike and plunging gently northeast or southwest is approximately parallel to the regional fold axes, or the tectonic axis, *b*. The more steeply plunging lineation represented by elongated minerals and pebbles that streak the cleavage planes and by the axes of some small folds is doubtless parallel to at least one direction of movement. However, this group of steeply plunging lineations is not at right angles to the gently plunging lineation, as seems to be the case in many areas (see the treatise on lineation by Cloos, 1946), but is usually at an angle of 40° to 60° in the plane of cleavage. This relationship suggests that during one stage of the regional deformation, the compressive stresses were directed toward the major structural trends in an oblique direction.

FOLDS AND FAULTS

Recognition of faults and most of the major folds of the region is based mainly upon the regional strike and dip, the outcrop pattern of lithologic units, and the juxtaposition of lithologic units in such a manner as to indicate a fault; few large-scale folds and faults have been observed directly in the field. The general structure of the Evington rocks is interpreted to consist of tight, isoclinal folds that have been faulted by high-angle reverse faults which have sheared out the western limbs of the anticlines. This conclusion is based upon the distribution of lithologic units of the Evington group along persistent northeast-trending belts with southeasterly dips, the repetition of these lithologic units from west to east across the strike several times in the following sequence—members of Archer Creek formation, members of the Mount Athos formation, and greenstone, and the common occurrence of small-scale drag folds which indicate that each repeated group of formations is on the eastern limb of an anticline.

If this structural interpretation is correct, the rock units on the eastern side of most faults (commonly members of the Archer Creek formation) are older than the rocks on the western side of the faults (usually greenstone). The interpretation of the stratigraphic sequence of the Evington group is based upon this assumption. Structural features and age relations of this character are rather typical of the folded belts of known Paleozoic rocks in the Appalachians and lend support to the interpretation of apparently similar structures in the Evington group. Nevertheless, the writer realizes that the small drag folds, upon which are based the structural and stratigraphic interpretations, may have a completely false relationship to the larger folds. It is quite possible that these small drag folds, nearly all of which indicate anticlinal axes to the west, were superimposed indiscriminatingly on eastern and western limbs of folds alike in the late stages of deformation. The structural and stratigraphic interpretations favored by the writer may be incorrect; the Candler formation may be the youngest in the Evington group, and the greenstone the oldest. Structural interpretations based upon the two possible orders of stratigraphic sequence are shown in plate 1.

The axial planes of the major folds, and the reverse faults probably dip southeasterly at high angles. Without doubt, the axes of some of these large folds are nearly horizontal over long distances, because the limbs of the folds are essentially straight for several miles. On the other hand, it is probable that broad areas of quartzite are formed by plunging folds; examples are Cove Mountain, Round Mountain, Chestnut Mountain, Jack Mountain, and Scott Mountain (pl. 1).

Rather small, tight folds in the bedding (with axial planes several inches to 5 or 10 feet apart and with steeply plunging fold axes) are fairly common, particularly in the blue marble member of the Archer Creek formation and in the folded complex of quartzite and greenstone on Wreck Island Creek. In this latter area, the tight minor folds present in nearly all outcrops show a consistent relationship between the strike direction of the limbs and axes of individual folds (northerly) and the directional trend of the bedding within a group of folds (northeasterly). These patterns in individual outcrops are the basis for the inferred zig-zag nature of the contacts between quartzite and greenstone, as shown in plate 1. The contacts are quite definitely offset between exposures, and close folding instead of cross faulting seems the most logical explanation. Similar zig-zag contacts caused by steeply plunging, tight folds are inferred in the Riverville area, in blue marble near the head of Flat Creek, and in quartzite in the vicinity of the Bell mine. Small scale recumbent folds with nearly horizontal axes are found on the eastern edge of the area along Troublesome Creek in the southern part of the district, and along Bent Creek, within a mile of its mouth, in the northern part of the area.

The rocks of the Evington group have undergone considerable faulting during deformation; certain contacts between lithologic units are obvious faults, and certain other contacts are interpreted as faults (pl. 1). The high-angle reverse faults that slice the isoclinal folds have been discussed above. Gently dipping contacts between schist and underlying quartzite and greenstone along the eastern side of the district, between Wreck Island Creek and David Creek, are probably low-angle thrusts. It is probable that the contact east of the mouth of Bent Creek dips about 5 to 15 degrees southeast, because its irregular trace conforms to the rolling topography. This probable thrust is well exposed in a road cut on U. S. Highway 60, east of Bent Creek; the contact is undulating, and crushed quartzite with greenstone lenses is infolded in the mica schist.

Faulting has undoubtedly taken place along the contact between the fissile phyllite of the Candler formation and the massive Lynchburg gneiss, throughout the 60-mile extent of that contact along the western edge of the district. The phyllite typically becomes more highly deformed as the contact is approached; this is obvious at various places, especially along the northern bank of the James River, east of Lynchburg, and along the Otter River, where early cleavage in the phyllite is strongly folded and sliced by slip cleavage near the contact. However, it is uncertain whether the phyllite has been thrust for a great distance onto the Lynchburg gneiss, as postulated by Jonas and Furcron, or whether the amount of movement may have been much less. Jonas (1929, p. 507–508; 1932, p. 3–4, 32–34, pl. 1) believes that the formations here called the Evington group (her Glenarm series), have been thrust westward 15 to 20 miles as a great nappe upon the Lynchburg gneiss and other rocks of the Catoctin-Blue Ridge anticlinorium; this view is evidently accepted by Furcron (1935, p. 52). This great thrust sheet is judged by Jonas to be the southwestern extension of the Martic thrust block originally mapped in southeastern Pennsylvania. To the northeast of Lynchburg, the Martic thrust sheet is considered by Jonas and Furcron to have later been faulted downward against Lynchburg gneiss by the Catoctin Border fault; Jonas (1932, pl. 1) shows the Martic overthrust to be unaffected by normal faulting southwest of Lynchburg.

So far as the writer has been able to determine from study of this contact between the phyllite of the Candler formation and Lynchburg gneiss along a distance of 60 miles, this contact is structurally uniform over the entire distance. No evidence was found to support the view that it is disturbed by normal faulting northeast of Lynchburg but not to the southwest. Jonas' conception of a nappe, thrust westward for 15 or 20 miles, depends to a large extent upon her interpretation that the belt of phyllitic rocks (Candler formation in this report), lying structurally upon the Lynchburg gneiss, represents gneisses and schists (originally of fairly high metamorphic grade) that were reduced to a lower metamorphic grade by retrogressive metamorphism resulting from profound movement along the sole of a great thrust. Therefore, she views these rocks as phyllonites, formed by mylonitization. The writer, on the other hand, has found no evidence that the rocks of the Candler formation are phyllonites in this sense, but instead, believes them to be normal phyllites of low metamorphic grade, and doubts very much that vast thrust movements have taken place within the area. It seems quite probable that the parent muddy sediments of the Candler formation were originally deposited on the Lynchburg gneiss. If so, the amount of fault movement between the Candler formation and Lynchburg gneiss may have been relatively slight, and in the nature of large-scale bedding faults or slippage between lithologic units of contrasting competency during deformation.

The evidence of a later period of faulting and fracturing after the major deformation of the region is indicated by normal faults cutting the Triassic sedimentary rocks and by Triassic diabase dikes. Each of the five areas of Triassic sedimentary rocks at the northern end of the district is bordered on the west side, and several are bordered on the east side, by a normal fault. The fault along the west side of the largest area of Triassic rocks is exposed along a small tributary of the Rockfish River. Green Triassic shales and phyllite of the Candler formation are mashed and deformed within 25 feet of the fault, and gash veins, 1 foot thick, of quartz with carbonate masses, occur in the Triassic rocks. The normal faults bordering the Triassic basins have the same northeasterly trends as the structures of the metamorphic rocks, and it seems probable that normal faulting has occurred here along ancient faults or zones of structural weakness.

Diabase dikes occur in two groups, one in the northern part of the district, and the other in the southern part. Their trend is usually a little west of north; this direction is a common trend for Triassic diabase dikes in the Piedmont province and is probably the result of certain unknown structural conditions of wide extent. No offset is discernible between beds on the two sides of the dikes. The fissures now occupied by the dikes apparently were tension fractures that were widened by intrusion of the diabase magma. The dikes do not cut the Triassic sedimentary rocks within the area of plate 1, but a diabase dike intruding Triassic sedimentary rocks near Boiling Springs, about 7 miles northeast of the Rockfish River, is mentioned by Roberts (1928, p. 44; pl. 4), and diabase intrusions in the Triassic sedimentary rocks are very extensive in northern Virginia (Roberts, 1928, pl. 1). It is reasonable to assume, therefore, that the diabase dikes in this area south of the Rockfish River are younger than the Triassic sedimentary rocks. It is quite probable, also, that the dikes are younger than most of the normal fault movements that affected the Triassic sedimentary rocks. In the vicinity of Norwood, along the strike of the normal faults bordering the Triassic basins, the faults in the metamorphic rocks are cut at numerous places by dikes. Only one dike in the area (near Buffalo Springs) shows any signs of displacement by faulting, and this dike could be along a fracture that had previously been offset by faulting. A number of dikes end abruptly at faults, whereas other nearby dikes extend across the same faults.

Furcron (1935, p. 52–53, pl. 1) concluded that diabase dikes in the area are commonly offset by normal faults, but the writer's observations are definitely contrary to this view. Furcron also shows a number of normal faults cutting across the strike of the metamorphic rocks, and states (1935, p. 53) that the most conspicuous example of this type of fault is near Galts Mills. No large-scale cross faulting was recognized in the present study; the disappearance of the Mount Athos formation and greenstone south of Galts Mills seems to be due to a plunging fold with thrust faults along its limbs (pl. 1).

One of the most structurally complex places in the area is in the region of Wreck Island Creek and Riverville. Some of the details of this area shown on plate 1 involve considerable interpretation, and may be incorrect, but it is believed that the general nature of the area and many of the details are correctly shown. Broadly speaking, it appears that the complexity of this area is due to localized cross-folding along trends more northerly than the older regional strike on which it was superimposed. Thus, extensive folding and thrusting seem to have taken place prior to the cross-folding. This folded belt athwart the general strike is not continuous between the Wreck Island Creek area and the Riverville area, but is interrupted by the quartzite belt of Gowans Hill which is not folded. No cross folding was recognized northwest of the Riverville area in the Candler formation or in the Lynchburg gneiss.

The structure in the southern part of the district between Evington and Altavista is also complicated and incompletely understood. Rather fine-grained gneissic rock, believed to be Lynchburg gneiss, is exposed in two domal structures, each surrounded by greenstone (pl. 1). Cleavages in the gneissic rock and in the overlying greenstone dip outward from the centers of the domes. Decipherment of the structure is dependent upon determination of the true age relationship between the greenstone and the gneiss, and between the greenstone and the schist and quartzite lying between the domes and to the north of them. If the stratigraphic sequence here favored is correct, the structures may be as shown in sections CC′, and DD′, and EE′ in the left hand column of plate 1. The greenstone around the domes would then be the youngest formation of the Evington group, and the Lynchburg gneiss would have been thrust or punched up through all the older formations of the Evington group. If the reverse stratigraphic order is correct, the greenstone would then be overlying the Lynchburg gneiss of the domes in normal sequence, and should be older than the quartzite composing Scott Mountain. However, due to the fact that greenstone overlies the quartzite on the southwestern side of the mountain, this would mean that the quartzite and the schist and marble north of the mountain were in a recumbent fold (pl. 1, sections CC′ and DD′, right hand column); no features to suggest the existence of such a large recumbent fold were found in mapping this area. It will be noted that, in accordance with the structural interpretation following either stratigraphic order, the larger dome of Lynchburg gneiss is thrust westward over phyllite of the Candler formation (pl. 1, sections EE′). Either interpretation makes it possible that the greenstone arch 3½ miles east of Evington is underlain at depth by Lynchburg gneiss (pl. 1, sections CC′).

The greenstone surrounding the arch of Lynchburg gneiss northwest of Rustburg (pl. 1, secs. BB′) is interpreted in both sections to be lying on the gneiss with normal depositional contact; the interpretation that the gneiss is punched up into greenstone (the youngest formation of the Evington group) could also have been made in the left hand section BB′, plate 1.

The stratigraphic interpretations of the extrusive origin and possible ages of the greenstone overlying the domes and archs of Lynchburg gneiss represent the simplest relationships. As pointed out under the discussion of the age of the Evington group, the greenstone surrounding the domes might either be intrusive, or extrusive, with stratigraphic relationships different from those considered in plate 1. Such conditions would require modification of the structural interpretations made in plate 1.

REGIONAL STRUCTURE

The general structure of the entire district is probably synclinal, with the belt of rocks of the Evington group occupying a trough underlain by Lynchburg gneiss. This idea was originally expressed by Brown (1941). The three domes of Lynchburg gneiss lend support to this view that Lynchburg gneiss underlies the belt. Furthermore, tight buckling of the rocks of the Evington group within a long, narrow, and relatively deep synclinorium would seem to be one of the most likely mechanisms by which the long isoclinal folds, sliced by high-angle reverse faults, could have originated. If the regional structure is synclinal, and if the phyllites and schists of the Candler formation form the base of the Evington group, then the occurrence of abundant phyllite and schist at the northern end of the district suggests that the axis of the syncline is rising toward the northeast.

Jonas and Stose (1939) have concluded that the Lynchburg gneiss, and the complex of igneous and metamorphic rocks that makes up the Blue Ridge farther west are exposed in a large anticlinal structure which they call the Catoctin Mountain-Blue Ridge anticlinorium. The probable syncline enclosing the Evington group lies along the eastern side of this anticlinorium.

METAMORPHISM

CHARACTERISTICS OF REGIONAL METAMORPHISM

The principal mineralogical changes induced in the rocks by regional metamorphism consist of recrystallization of some of the original sedimentary minerals, such as carbonates and detrital quartz and feldspar, and the formation of such new minerals as muscovite, chlorite, chloritoid, biotite, garnet, staurolite, epidote, and hornblende. The factors that have primarily determined what new minerals were formed in these rocks have been the bulk chemical compositions of the rocks and the temperature and pressure conditions during metamorphism. The effects of mineral zoning, due to variations in the intensity of temperature and pressure conditions that accompanied metamorphism in this region, are best displayed in the rocks of argillaceous composition, which are the most abundant and widespread class. The different metamorphic types derived from argillaceous rocks are characterized by the following assemblages of index minerals: chlorite-muscovite (with chloritoid in places), biotite-muscovite, and garnet (with staurolite locally). Rocks with the chemical composition of quartzite, marble, and greenstone have little variety in their mineral content, and zonal arrangement of the mineral assemblages has not been developed, or has been developed very poorly. These last-named rocks are therefore less important than the argillaceous rocks for an understanding of the metamorphic history of the region; they are described below, prior to discussion of the argillaceous rocks.

In rocks of quartzitic composition, the varying intensity of the metamorphic processes is best recorded in the texture. Recrystallization of quartz has taken place universally, most commonly to a mosaic texture with sutured grain boundaries; original pebbles are still preserved in some of the least deformed conglomeratic rocks, whereas the most highly deformed quartzite beds are essentially mylonites. Muscovite is the most common mineral accompanying quartz and has formed from the argillaceous material of the original sediment. Chlorite is a rare constituent of some quartzite beds, and garnet is found in small quantities in other quartzite beds. Variable amounts of feldspar (usually albite) and carbonates are present depending upon the primary composition of the sediment. The accessory minerals, apatite, tourmaline, and zircon, appear to be of detrital origin.

In marbles, the intensity of deformation is again most commonly recorded by textural or structural features. Bedding persists, and the texture is fine-grained in the least deformed beds of the blue marble member of the Archer Creek formation; highly deformed marble of the Mount Athos formation is coarse grained and has irregular color streakings that are relicts of bedding. Calcite has been recrystallized, and muscovite is the most widespread new mineral developed. Light brown biotite and chlorite may be present in the same rock; tremolite is found in some areas of higher metamorphism. Original detrital minerals are quartz, apatite, and zircon. Small amounts of sulfides (usually pyrite in blue marble) and chalcopyrite (in white marble) are common.

The greenstones are mostly fine- to medium-grained hornblendic schists. with some moderately coarse gneisses. All types are characterized by hornblende, epidote, and albite; chlorite is also an essential mineral of some greenstone. Ragged flakes of biotite are very common, and are nearly always altered or partly altered to chlorite. Apatite, magnetite, and ilmenite are characteristic accessory minerals.

Only incidental mention can be made here of metamorphism in the Lynchburg gneiss and associated soapstone because of the very limited studies made of these rocks. In the Lynchburg gneiss, biotite is a characteristic mineral, and garnet is common. Along the northeastern and southern contact of the largest dome of Lynchburg gneiss, quartz-muscovite schist, with garnets sheathed in chlorite, is exposed at intervals. Numerous chlorite flakes in the schist are relict from biotite, but it is not certain whether the chlorite surrounding the garnets has replaced garnet, or whether it has replaced biotite that previously enveloped garnet. Principal minerals in the metamorphosed peridotite or soapstone are tremolite and chlorite (usually two varieties); talc and carbonate are abundant in some of the soapstones.

Consideration is now directed toward the argillaceous rocks, represented mainly by the phyllites and schists of the Candler formation, the mica schists of the Mount Athos formation, and the biotite-garnet schists with some staurolite that are on the eastern edge of the mapped area between Altavista and Rustburg; the graphitic schists are also included as a special variety. Mineral zoning in these rocks is best developed in the central part of the district in the latitude of Lynchburg and Rustburg, where argillaceous rocks along the western side of the district are characterized by chlorite-muscovite (indicative of low-grade metamorphism), those in the middle by biotite, and those along the eastern side by garnet, and locally staurolite. Similar zoning appears to be developed in the southern end of the district, but the picture is obscured by the domes of Lynchburg gneiss and by the fact that the biotite zone is not as distinct. In the northern third of the district, argillaceous rocks predominate, but the chlorite-muscovite zone extends the full width of the district. Thus, the characteristic biotite-bearing schist member (the Pelier schist of Brown, 1951) of the Mount Athos formation, which is widely developed in the central part of the district, is not found in the area of low-grade metamorphism to the north.

The phyllites and schists in the chlorite zone are typically composed of chlorite, muscovite, quartz, and albite forming a fine-grained matrix; some varieties have abundant epidote or zoisite. Accessory minerals are tourmaline, zircon, and apatite, probably all of detrital origin; magnetite, leucoxene, and tiny rutile crystals may be present. Chloritoid is a common constituent of some beds, usually as small crystals 1 to 2 millimeters in size, but occasionally as large as 5 to 8 millimeters, lying transverse to the cleavage. This mineral is commonly developed in low-grade metamorphic rocks of argillaceous composition. Various workers have pointed out that chloritoid is probably formed in those rocks with an abundance of alumina and a high iron oxide content, and that staurolite may form in beds of similar composition under more intense conditions of metamorphism (Harker, 1932, p. 213–214, 224–227). The formation of chloritoid in chlorite-muscovite schists of the Pennsylvania Piedmont may have been partly favored by shearing stresses, as well as by chemical composition, according to Hietanen (Cloos and Hietanen, 1941, p. 119–123, 152).

Argillaceous rocks in the biotite zone are characterized by a matrix of quartz, albite and muscovite, and by porphyroblasts of biotite lying transversely to cleavage and generally partly altered to chlorite. Epidote and zoisite are commonly present, and minor amounts of chlorite may be found in the matrix. The usual accessory minerals of probable detrital origin are tourmaline, zircon, and apatite; leucoxene and magnetite were not recognized and have possibly been destroyed during the formation of biotite. Small red garnets are occasionally present, and mark the appearance of the garnet zone; such rocks with very minor garnet content, however, are not designated as garnet schists on plate 1. The graphitic schists have similar mineral composition, but are characterized by abundantly disseminated, very fine-grained graphite; pyrite is also usually present. Garnets are more common than in the argillaceous rocks, but appear to be the pinkish manganiferous variety that is formed under conditions of lower grade metamorphism than almandite, according to Harker (1932, p. 217–218) and others.

Crystals of red garnet 3 to 5 millimeters in size, with quartz, muscovite, and biotite, are abundant in the higher grade garnet zone along the eastern side of the district; here also, the biotite may be partly or wholly altered to chlorite. Staurolite is present in some beds in the form of crystals as large as 2 centimeters.

PROGRESSIVE METAMORPHISM OR RETROGRESSIVE METAMORPHISM

The mineralogical changes in the argillaceous rocks (described above) from chlorite-muscovite phyllites and schists on the west, through biotite-muscovite schists, to garnet-staurolite schists on the east, have been interpreted by earlier workers, Jonas (1932, p. 7–11, 32–37) and Furcron (1935, p. 55), as the result of retrogressive metamorphism. They regard the low grade chlorite-muscovite schists along the entire western side of the district as having been formed from higher grade schists and gneisses by retrogressive metamorphism induced by profound movement along the base of a great thrust sheet. According to their views, the effects of retrogressive metamorphism diminished eastward from the base of the supposed thrust sheet; the biotite-muscovite schists would thus have been less affected by retrogressive metamorphism than the chlorite-muscovite schists. Their interpretations are based on the assumption that the two sets of cleavage commonly present in the schists were formed during two different periods of regional metamorphism, the earlier cleavage during pre-Cambrian time, and the later cleavage accompanying overthrusting during the Appalachian revolution. Observed alteration to chlorite and muscovite of biotite, garnet, and staurolite are interpreted as the result of retrogressive metamorphism attending the late Paleozoic thrusting.

The writer, on the other hand, has not found evidence for such large-scale thrusting, and interprets the mineral zoning as indicative of progressive metamorphism. Several sets of cleavages are commonly developed in regionally metamorphosed terranes, and do not necessarily signify several periods of deformation or metamorphism of widely different ages. Two sets of cleavage are present in much of the Piedmont area of Pennsylvania and Maryland studied by Cloos and Hietanen (1941, p. 72, 135–136, 182–185); they concluded that only one period of deformation and metamorphism had taken place. In the James River area, the development of two cleavages seems to be primarily a function of the physical properties of the rocks, because two cleavages are commonly present in phyllite and schist, but usually only one cleavage is developed in quartzite, marble, and greenstone. Therefore, it seems doubtful, that the two sets of cleavage in the schists mentioned in this discussion were formed during two widely separated orogenic periods, that is, in pre-Cambrian and late Paleozoic time.

The other evidence of retrogressive metamorphism cited by Jonas and Furcron, alteration of high-grade metamorphic minerals to lower grade minerals, has been observed in this district by the writer as alteration of biotite to chlorite (a rather common and widespread feature), and as garnet crystals sheathed in chlorite (found only locally in a restricted part of the district). These mineralogical changes are indeed retrogressive in character, but the cause need not necessarily be related to very large-scale thrusting, as advocated by Jonas and Furcron. Instead, the widespread alteration of biotite to chlorite in this district, and the local alteration of garnet (or possibly biotite sheaths surrounding garnet) to chlorite, might have been caused by hydrothermal solutions, as suggested by Hietanen in the Pennsylvania-Maryland area (Cloos and Hietanen, 1941, p. 135–136), or might represent adjustments to lower temperatures in the waning stages of regional metamorphism, as discussed by Harker (1932, p. 348–349).

Strong evidence in favor of progressive metamorphism is the fact that at numerous places within the chlorite and biotite zones of metamorphism, bedding is preserved as siliceous layers in blue marble and as color banding in the phyllites; no bedding was seen in staurolite-garnet schists. The presence of bedding in low-grade phyllites, schists, and marbles, and its absence in high-grade schists is convincing proof that the low-grade rocks had never attained a higher grade of metamorphism. If the low-grade rocks were phyllonites retrogressive from high-grade schists, their bedding would certainly have been destroyed at the higher stages of metamorphism and would no longer be visible.

The retrogressive metamorphism that has occurred therefore appears to have been a relatively mild process that has slightly modified the minerals and mineral zoning developed during progressive metamorphism. A full understanding of the metamorphic history of these rocks requires study of a much larger region than the area concerned here. Granitic intrusions are found about 12 miles east of the district, and pegmatite and kyanite deposits are numerous 10 to 15 miles farther east (Jonas, 1932). The metamorphic features of the James River district can be completely understood only in the light of the metamorphic history of this larger region.

CONTACT METAMORPHISM

Contact metamorphism is restricted to the country rocks in a narrow zone along the Triassic diabase dikes. Because of poor exposure, the effects have been observed at only a few localities; the best exposed locality is on the road along Partridge Creek, about half a mile northwest of Stapleton. The diabase dike here is about 100 feet thick. Phyllite at a distance of 1½ feet from the dike is tan in color, dull in luster, and has a poor schistosity. Abundant dark greenish-brown spots, 1 to 2 millimeters in size, are present; some of the spots were determined under the microscope to be composed of sericite, and others were determined to be of chlorite and biotite. Similar spots are developed in the rock 11 feet from the contact, but the rock is darker in color and has the typical lustrous sheen of the phyllites. No effects of contact metamorphism were observed at a distance of 20 feet from the dike.

PHYSIOGRAPHY

DESCRIPTION OF PHYSIOGRAPHIC FEATURES

The physiography of the area is characterized by two varieties of surface forms and drainage patterns. The surface of part of the region is a dissected, rolling upland with dendritic drainage, occasionally grading into areas of elongated ridges and valleys having rectilinear or trellis drainage. These different kinds of surface and drainage features are thought to be reflections of two stages in the sculpturing of the land surface by stream action. The rolling upland seems to represent an old erosion surface or peneplain that has been uplifted and is now partly dissected by present streams. Where erosion has been sufficiently vigorous since uplift, linear ridges and valleys with northeasterly trends have been carved in the belts of Evington rocks in which beds of contrasting resistance to erosion alternate across the strike. Quartzite and some types of schist form ridges, and marble and the weaker schists are cut into valleys.

The widespread, rolling upland is the most prominent physiographic feature of the district, and is well shown on the old 30-minute sheet of the Lynchburg quadrangle with 100-foot contour intervals. On the new 15-minute sheet of the Lynchburg quadrangle (having 20-foot contours and showing the northeast quarter of the area of the old map) the rolling upland is not as readily apparent in the belt of Evington rocks. Linear ridges and valleys are common in the area draining into James River, but in the area of Lynchburg gneiss farther west, dendritic drainage prevails and linear ridges and valleys are absent. The upland ranges from altitudes of about 700 to 1,000 feet; quartzite and schist ridges rise above the surface, and streams and rivers are dissecting it. Altitudes of the upland surface reach a maximum, between 900 and 1,000 feet, along that part of the watershed of the James and Roanoke Rivers that extends west and northwest of Rustburg. The nature and extent of the rolling upland are easily determined when one travels the old country roads that follow the interstream divides.

Exposures of fresh rock are scarce on the upland. The soil mantle is commonly no more than a few feet thick, and passes downward through red clay into the clayey residuum of highly weathered rocks. Fragments of the most resistant types of rock are present in the soil, such as iron-stained pieces of quartzite, vein quartz, tough mica schist, and pieces of limonite and hard manganese oxides. The highly weathered rock beneath the soil cover has usually been altered to a clayey material, in which the structures of the parent rock are usually well preserved. These relict structures and other characteristics may serve as aids in the identification of the parent rock. Mica schists are usually weathered near the surface to a schistose, pinkish mixture of clayey material and interspersed fine mica, passing downward into tan or gray decomposed schists. White marble commonly yields a residue of chocolate-brown clayey loam, and the blue marble weathers to a stiff blue-gray or greenish, micaceous clay. The original foliation of the two kinds of marble generally is absent in the weathering residuum. Greenstone weathers, as a rule, to light green or brown, punky material that breaks into blocky fragments with surfaces covered with very thin manganese oxide coatings. Calcareous quartzite weathers to characteristic porous blocks stained with limonite or manganese oxides. This highly weathered rock material that generally retains some of the structures and textures of the original rock is known as "saprolite." It is a distinctive geologic feature of the southern Piedmont province, and the geologist working in the region must learn to recognize the different kinds of saprolite and correlate them with the rocks from which they were derived. A general account of saprolite in the region is given in the paper by Pardee and Park (1948, p. 24–27) on gold deposits in the Piedmont.

The depth to which weathering extends is highly variable, and is the result of a number of factors, such as the original mineral composition of the rock, its structure and texture, and the action of ground water and erosion processes during different stages of the physiographic history. In this area, decomposed schists are exposed to depths of 30 to 50 feet in numerous railroad and highway cuts. Mining operations have shown that weathering extends still deeper, because weathered rock and residual clay have been found at depths of over 200 feet at the Piedmont mine (Campbell County), and more than 300 feet at the Leets mine; however, within a few hundred feet of each mine fresh marble is exposed at higher elevations in the stream beds. The decayed rock found with the manganese deposits in depth was probably formed by ground waters circulating along deep, restricted channelways.

Some of the most prominent and persistent ridges in the district are composed of phyllite and schist of the Candler formation; best examples are the series of three ridges along the western side of the district (Johnson Mountain, Candler Mountain, and Buffalo Ridge), and a series of unnamed lower ridges along the eastern border of the district between Beaver Creek and Bent Creek. Most of the quartzite belts form ridges or mountains rising above the upland surface; the more prominent ones are Mount Athos, and Jack, Round, Chestnut, and Scott Mountains. Linear valleys are usually cut into the upland along belts of marble, either as short tributary streams, or as northeasterly trending intervals several miles long in the courses of major streams, such as stretches along the course of Beaver, Opossum, Flat, and Stonewall Creeks. Exposures of fresh rock are found in nearly all stream valleys.

One of the most interesting physiographic features in the region is the abrupt change in the course of the James River a short distance east of Lynchburg where it turns from the southeasterly course it had taken for 25 miles from the Blue Ridge, and flows northeasterly for nearly 50 miles (airline distance) to Scottsville, where it again turns toward the southeast. The northeasterly course of the river here has obviously been controlled by the northeastern trending belts of weak and strong rocks of the Evington group, across which the river swings in broad meanders. The course of the river is first deflected toward the northeast by the quartzite ridge at Mount Athos, and for over 15 miles (airline distance) to the northeast, the river meanders back and forth across schist, marble, and greenstone to the west of the Mount Athos belt of quartzite, and cuts into that quartzite belt at only three places. Beyond Allen Creek, the river cuts through the same quartzite belt, and from there, it wanders across almost the full width of the belt of Evington rocks until it reaches the area of Triassic rocks near Howardsville. From there, it continues northeast across Triassic and metamorphic rocks to Scottsville, where it once more turns toward the southeast and crosses the Piedmont. Along the stretch of river between Mount Athos and Scottsville, the larger streams entering the river are on its western side where the drainage basin between the James and the crest of the Blue Ridge is about 25 miles wide, as compared with a drainage basin of only 3 to 10 miles in width on the eastern side of the river.

The gravel deposits resting upon terraces and intermeander spurs along the valleys of the James, Roanoke, and Otter rivers, as described above, are remnants of extensive gravel sheets originally deposited on the river flood plains when they were at higher elevations. Deposits of gravel on the river bluffs just east of Lynchburg are 150 to 220 feet above the bed of the James River, which has an altitude of 480 feet near Mount Athos. Thus, the surfaces of the higher gravel deposits are at altitudes of about 700 feet, or 200 to 300 feet below the level of the upland surface of the divide between the James and Roanoke river drainage basins. Among the most recent physiographic features of alluvial origin are the low, broad terraces on the floodplains of the rivers and larger streams.

PHYSIOGRAPHIC HISTORY

In order to gain a proper perspective and understanding of the development of the physiographic features within this area, the general physiographic features and history of the entire Piedmont province, the neighboring Blue Ridge, Valley and Ridge, and the Coastal Plain provinces, must all be considered. Our knowledge of the physiographic history of these regions is incomplete, however, because few physiographic studies have been made in the Piedmont, and unsolved problems remain in regard to the history of physiographic events in both this and the adjoining provinces. The principal views on the erosional history of the Atlantic slope as reviewed below will aid in understanding the origin of physiographic features of the James River—Roanoke River district.

The basis for modern concepts of the physiographic history of the eastern United States was first outlined by Davis (1890), who concluded that two widespread peneplain surfaces were recognizable throughout much of the region. In the folded Appalachians, he believed the nearly level crests of sandstone ridges to be remnants of a peneplain formed in Cretaceous time at the culmination of a long erosion period during the Mesozoic, and further believed that the broad, rolling valleys on limestone and shale represented a younger peneplain of Tertiary age. He believed the present drainage system to have been entrenched on the Tertiary peneplain following the uplift of the entire region. The rolling surface of the Piedmont to the east of the Blue Ridge was considered to represent the Cretaceous peneplain, because it passed eastward beneath Cretaceous sediments of the Coastal Plain. The elevation of this surface gradually declines eastward from an altitude of at least 1,000 feet, along the base of the outlying spurs of the Blue Ridge west of Lynchburg, to an altitude of about 200 feet at the Fall Line, 80 miles east of Lynchburg, where the crystalline rocks are overlapped by Coastal Plain sediments.

A few years later, Hayes and Campbell (1894) gave a comprehensive account of the geomorphology of the southern Appalachians, in which they agreed with most of Davis' views, and showed by contours on small-scale maps the uplifted and deformed Cretaceous and Tertiary peneplains which they believed had been strongly warped by differential uplift along longitudinal and transverse axes. However, they thought (1894, p. 85–86; pl. 6) that the Piedmont surface represents a Tertiary peneplain instead of an erosion surface developed during the Cretaceous, as Davis had concluded.

Various refinements and modifications of these ideas, consisting mostly of the recognition and correlation of intermediate erosion surfaces, were offered subsequently by other workers. The older of the major peneplains has become known as the Schooley or Kittatinny peneplain, and the younger surface as the Harrisburg, Shenandoah, or Valley peneplain. Outstanding among the new ideas was the theory suggested by Shaw (1918), and later elaborated by Johnson

(1931), that both major peneplains must be Tertiary in age, because the erosion surface beneath Cretaceous sediments of the Coastal Plain projects upward to the west to heights well above the remnants of the older peneplain. The most recent descriptive account of the Blue Ridge-Piedmont provinces has been given by Wright (1931). An important concept of his work is the correlation—with the Harrisburg peneplain—of surfaces that differ considerably in elevation, such as the floor of the Shenandoah Valley, the Piedmont, extensive rolling uplands in the Blue Ridge, and large local basins in the Great Smokies and southern Blue Ridge. He explained the difference in elevations between these various surfaces as being caused chiefly by differences in the base-level of erosion of the several drainage basins, rather than by differential uplift of the peneplain. Wright does not assign any age determinations to the Schooley and Harrisburg peneplains.

The physiographic history of the region is reflected not only by the physiographic features, but also by the record of sedimentation of the Coastal Plain formations of Cretaceous, Tertiary, and Quaternary age. In fact, the sedimentary record is more revealing and shows that the sea level in the Chesapeake Bay region has varied much more than is suggested by the physiographic features of the Piedmont. During the Cretaceous period, sediments of continental origin were deposited extensively on the Coastal Plain. A great transgression of the sea occurred during Eocene time, and glauconitic marine sediments were deposited as far west as the present edge of the Coastal Plain, and perhaps even farther west. Clark and Miller (1912, p. 213) state: "The great amount of glauconite present in these formations indicates that the adjacent landmass must have been low and flat so that the streams carried only small amounts of terrigenous materials."

Sediments of Oligocene and early Miocene age do not occur in the region, thus indicating that these were periods of widespread uplift and erosion. Beginning in middle Miocene time, the region was again downwarped and a series of sediments was deposited that now extends to the western edge of the Coastal Plain. A period of uplift followed in Pliocene time, when the drowned valleys of Chesapeake Bay and its tributary rivers were eroded (Stephenson, Cooke, and Mansfield, 1932, p. 11–14); the region was again submerged at the close of the Pliocene. During Pleistocene time, the sea level fluctuated by several hundred feet; it was lowest during the stages of glaciation and highest in the interglacial stages, when the water from the melted ice had returned to the sea.

The physiographic history of the James River-Roanoke River district may now be examined with these general concepts of the physiographic and sedimentary record in mind. The oldest event that can be recognized with confidence is recorded by the rolling, upland surface, underlain by deeply decayed rock; these features evidently were developed during a long period of peneplanation. Near the end of this period, erosion was at a minimum, and solution and rock decay prevailed. The higher ridges projecting above this surface, such as Candler Mountain, Round Mountain, and Jack Mountain, and others, may be remnants of an earlier peneplain, or may simply have been hills of more resistant rock. No direct evidence on the time of development of the upland surface has been found within the district, but various lines of indirect evidence suggest early Tertiary time as the period of peneplanation. Hewett (1916, p. 43–47) has expressed the view that the manganese deposits probably were formed either during the later stages of peneplanation, or immediately following uplift of the peneplain. He points out further that manganese deposits along the west foot of the Blue Ridge also occur in the residuum of highly decayed rocks at elevations several hundred feet above present drainage levels, and that beds of lignite containing fossil plants of Tertiary age have been found associated with residual iron deposits in Pennsylvania and Vermont. These facts lead him to suggest the possibility that many of the manganese and limonite deposits of residual origin in the east may have been formed during the same general period, probably in early Tertiary time, when the land surface had been reduced to a peneplain over wide areas, and deep rock decay and solution were favored by warm, moist climatic conditions.

Some years ago, Adams (1927) suggested that bauxite deposits in the Coastal Plain, and Valley and Ridge provinces of the southeastern states had been formed during the early Tertiary, and Bridge (1950) has recently presented new facts and interpretations derived from the Geological Survey's wartime studies of these bauxite deposits, which give additional support to Adams' theory. Present knowledge and interpretation of the origin of these bauxite deposits as discussed by Bridge are discussed briefly, as follows: Bauxite deposits are associated with clay lenses of sedimentary origin at the contact between the Midway (Paleocene) and Wilcox (Eocene) groups in the Coastal Plain of Georgia and Alabama. Bauxite deposits are also found in sink holes and in the residuum of early Paleozoic magnesian limestone at a number of places in Alabama, Georgia, Tennessee, and Virginia. At two bauxite deposits of this type in Alabama and Georgia, plant fossils have been found in clay and have been identified as early Tertiary, or possibly Cretaceous, in age (Bridge, 1950). Bridge believes that the bauxite deposits in the limestone sinkholes and residuum, like the ones in the Coastal Plain sediments, were formed from deposits of transported, finely divided aluminous sediments. He concludes that all of the bauxite deposits were formed during the same period (at a time when the region had been reduced to a peneplain, erosion was slight, and rock decay was promoted by warm, moist climatic conditions). Bridge believes that the bauxite deposits in the Appalachian valley region were formed during the Harrisburg time of peneplanation, because they occur slightly below the general surface of the Harrisburg peneplain (probably because of post-Harrisburg erosion), and therefore concludes that the Harrisburg peneplain is early Tertiary in age.

These various items of evidence concerning conditions and time of origin of the bauxite, residual manganese, and limonite deposits in the Valley and Ridge province, seem consistent with one another, and strongly suggest that these deposits originated during the same period of widespread peneplanation (Harrisburg) under favorable climatic conditions. It seems reasonable to assume that these conditions also prevailed in the Piedmont province, and that the deeply weathered upland surface and manganese deposits in the James River–Roanoke River district were likewise formed during the same general period, probably in early Tertiary time.

The time of the peneplain development evidently was ended by a widespread regional uplift (involving the whole Atlantic slope) that rejuvenated the erosion power of the streams and rivers and permitted them to start dissection of the peneplain. In this district, the James, Otter, and Roanoke Rivers have entrenched themselves in valleys 200 to 300 feet below the general level of the upland surface. Entrenchment of streams and rivers to comparable depths below the Harrisburg peneplain has occurred at many places in the Piedmont, Blue Ridge, and Valley and Ridge provinces. At different stages in the dissection of the upland surface in this area, sheets of gravel were deposited in the river floodplains, and are now preserved as deposits of pebbles and cobbles, mantling spurs and terraces as much as 200 feet above the river level. The gravel material is well rounded and composed mostly of quartzite and sandstone resembling the different quartzites and sandstones of early Paleozoic age that comprises the ridges in the Valley and Ridge province to the west. Similar gravels are found much farther east in the Piedmont near the Coastal Plain along the James, Potomac, and other rivers in Virginia and neighboring states, and also to the west, and along the edges of the Shenendoah Valley. Evidently, at some stage or stages during the dissection of the Harrisburg peneplain, a large amount of very coarse material was carried for distances as much as several hundred miles from its source.

The gravel deposits in the eastern Piedmont and the Coastal Plain have been studied by a large group of investigators; the most recent and comprehensive work in Virginia was done by Wentworth (1930). He described the gravel deposits as terraces at six different, general elevations (the gravels in the highest and westernmost terrace being the oldest, and the terraces becoming progressively lower and younger easterly toward the coast). The oldest gravels, known as the Brandy wine, are assigned to the Pliocene age by Wentworth, and the younger gravels are termed Pleistocene. The classification was based on the fact that the younger gravels have large, striated boulders that (according to Wentworth) were ice-rafted in Pleistocene rivers; on the other hand, such boulders are absent in the Brandywine gravels. King (1949a) has recently given an account of gravel deposits in the Shenandoah Valley near Elkton, Va., where the gravels occur on three general surfaces or benches that rise in step-like fashion above the present river level to the foot of the bordering mountains. Beneath the gravel capping (as thick as 140 feet in one place, and 175 feet in another), is the clayey residuum of shales and calcareous rocks containing manganese oxides, which is considered to be the partly eroded and buried mantle of decayed rock on the Harrisburg peneplain. King believes that the gravels were deposited in Pleistocene time, probably during rather arid periods in interglacial stages when the mountains were exposed to erosion because of scant vegetation cover.

It is probable that the terrace gravels in the James River-Roanoke River district were deposited during the same period as gravels in the Shenandoah Valley to the west and the fluviatile gravels in the upper terraces farther east in the Piedmont. The best age classification of the gravels in this district seems to be either Pliocene or Pleistocene.

The period of the establishment of the northeasterly course of the James River cannot be determined, but the remnants of terrace gravel as high as 200 feet above its present channel indicate that the river has followed this general trend during much of the time since uplift of the Harrisburg peneplain; it is quite possible that the ancient James River may also have meandered northeasterly in this area during the development of the Harrisburg peneplain.

The most recent stage in the erosion cycle is marked by alluvial flood plains and flats in the valleys of the rivers and larger streams.

MINERAL DEPOSITS

TYPES AND DISTRIBUTION

The principal mineral deposits of the district are manganese, iron, and barite; nearly all are in or near beds of the Mount Athos formation. The distribution of these deposits is shown in plates 1 and 2. The manganese deposits contain manganese oxide minerals that were formed by ground water action. Limonitic iron deposits also were deposited by circulating ground waters; specular hematite deposits are believed to be sedimentary ferruginous beds that have been metamorphosed. Barite occurs as veins in marble, and as masses in the overlying soil and residuum; its origin is obscure. Copper sulfides and oxidized copper minerals are found in minor amounts in various types of rocks. Quartz veins are widespread and are usually barren, or practically barren, of other minerals; tourmaline is present in some quartz veins nad ilmonite in others.

MANGANESE DEPOSITS

MINERALOGY

The manganese minerals are heavy manganese oxides of the "psilomelane type", and the soft, lightweight manganese oxide, wad. The heavy manganese oxides are generally composed of mixtures or intergrowths of several manganese oxide minerals; species identified from the deposits of this region are cryptomelane, psilomelane, and pyrolusite. Quartz, mica, clay, and chert are the principal gangue minerals.

MANGANESE OXIDES

GENERAL STATEMENT

The manganese oxide minerals of this district exhibit a variety of forms and differ in their physical appearance, color, hardness, and specific gravity, as well as in their chemical composition and crystalline structure. The name, "psilomelane", has generally been applied by previous workers to the hard, heavy varieties, commonly having dense textures and nodular forms. Heavy manganese oxides with visible crystalline structure, usually friable, have been called "pyrolusite"; soft, lightweight mixtures of fine-grained manganese oxides and clay have been named "wad". These terms have been merely convenient field names, however, and have not signified distinct mineral species; similar usage has been followed in classifying manganese oxide minerals of residual manganese deposits elsewhere.

Studies of the complex mineralogy of the manganese oxides by Fleischer and Richmond (1943) of the Geological Survey, by X-ray, chemical analyses, and other means, have provided new data on chemical and physical properties that clarify the identification of these minerals and establish the existence of several new species and varieties. This work has demonstrated that (in many cases) the manganese oxides are difficult or impossible to identify by simple qualitative chemical tests or microscopic examination, either because several minerals are present in fine-grained intergrowths, or because certain species show variations in chemical or physical properties.

Fleischer and Richmond now recognize 21 species of manganese oxide minerals. Four minerals of this group—braunite, cryptomelane, psilomelane, and pyrolusite—are the most common and are known to occur widely throughout the United States. Specimens of manganese oxides from several deposits in this district (submitted to Fleischer and Richmond for study) were found to contain cryptomelane, psilomelane, and pyrolusite; these species are described below.

Fleischer and Richmond (1943, p. 271–272) discuss the problem of naming the manganese oxides, pointing out that the term "psilomelane" has been widely used for any hard, massive, unidentified manganese oxide mineral. They say,

> This usage is doubtless convenient in the field, where it is generally impossible to determine the mineral or minerals present, and some collective term is needed. However, as stated below, the term "psilomelane" should not be used in this sense, but should refer to only one of the several distinct minerals hitherto grouped under this designation.
>
> The following rules of nomenclature are recommended:
>
> (1) Massive, hard, heavy material not specifically identified should be referred to as belonging to the "psilomelane type". This term is to be understood to include several distinct minerals or mixtures of them, and no chemical formula should be given.
>
> (2) Massive, soft material of low apparent specific gravity, not examined in the laboratory, should be referred to as "wad". Such material also may be any one of several distinct minerals, may be a mixture, or may be unidentifiable and no chemical formula should be given.
>
> (3) Definitely identified minerals should be named * * *

According to these recommendations, all the heavy manganese oxides of the deposits in this district should be classed as the "psilomelane type" of minerals, and the soft, lightweight mixture of manganese oxides and clay should be termed "wad". Both types are present in about equal abundance, apparently, but only the heavy psilomelane type minerals have been recovered in mining operations. Characteristics of these minerals are described below.

PSILOMELANE TYPE

The heavy manganese oxides of these deposits show a wide range in their physical appearances. Judging from the results of Fleischer and Richmond's study of a few samples from different localities, it is probable that several mineral species are commonly present as mixtures or intergrowths. Nodular or botryoidal forms are the most common. Some are cellular masses, whereas others are clusters of small rounded particles (ranging from the size of shot to that of grapes), irregular lumpy aggregates, or slabby masses with rounded or discoidal protuberances. Color is typically bluish-black, hardness about 5 or 6, and the texture dense; tiny platy crystals are commonly scattered through the dense matrix. Some specimens consist largely of material with visible crystalline structure. A concentrically layered structure may be evident in the denser varieties in which thin shell-like layers of slightly different color and grain size alternate, thus giving a finely banded appearance. The forms described above are those usually found where the enclosing material ("country rock") is clay, chert, decomposed mica schist or calcareous quartzite. In many instances, these nodular manganese oxides have a flattened shape that evidently is the result of preferred growth along relict foliation planes of the decomposed rock. Scattered quartz grains and mica flakes are nearly always present in the manganese minerals. Dense-textured oxides also occur in hard, relatively fresh rock, as fracture fillings in quartzite, or as the matrix in a breccia of quartzite or vein quartz.

A less abundant form of the heavy manganese oxides has a massive or blocky, layered structure, a somewhat bluer color than the nodular forms, a fine powdery texture, and is friable enough to soil one's hands with a bluish smudge. This variety appears to occur principally as thin seams in wad, but it also forms disseminations in quartzite at a few places; it has generally been called "pyrolusite".

Common impurities of the heavy manganese oxides are quartz, mica, and possibly other silicate minerals derived from the country rock and enclosed in the manganese oxide minerals during their growth. Some iron is usually present also, but it is not known whether it is a component of the manganese minerals or whether it is in an admixed iron mineral. Limonite is rarely recognized in the manganese deposits, although it is a widespread mineral in the district and occurs at a number of localities in deposits of appreciable size within a few hundred feet of manganese deposits. Barium has been found to be a constituent of the manganese oxide minerals from several deposits; it is an essential component of the mineral psilomelane, as discussed below.

WAD

Soft, brown to black manganese oxides, of apparently low specific gravity and rather high moisture content, occur at numerous localities, as mixtures with clay, sand, or mica, or as seams interlayered with seams of clay and decomposed mica schist. The mineralogy of these manganese oxides has not been studied.

DISTINCT MINERAL SPECIES

The three mineral species identified in the heavy manganese ores of the district by Fleischer and Richmond are described below:

Cryptomelane.—The chemical formula provisionally assigned to cryptomelane is KR_8O_{16}(?), in which R is chiefly Mn (tetravalent), and may also be Mn (divalent), Zn, and Co. Two to four percent of nonessential water may be present. Cryptomelane was identified in samples of nodular ore from the Bell, Mortimer, and Piedmont mines in Campbell County. In the Bell mine specimen, the hard portion of the ore was found to be cryptomelane; the rest of the material was undeterminable. The sample from the Mortimer mine was almost entirely cryptomelane; the specimen from the Piedmont mine was found to consist of breccia fragments of cryptomelane in a matrix of pyrolusite.

Psilomelane.—The formula, $BaR_9O_{18}.2H_2O$(?), is given as the provisional composition of psilomelane; R is chiefly Mn (tetravalent), and also Mn (divalent) and Co. Psilomelane was identified in ore specimens from the Hancock-Ferguson mine and the Pribble mine. The psilomelane in both specimens forms feathery aggregates of small prismatic crystals with a bluish-gray steely luster resembling a common variety of pyrolusite; apparently, this is a rather rare form of psilomelane. Partial analysis of the specimen from the Pribble mine showed 49.1 percent Mn, 14.03 percent BaO, and 0.63 percent SiO_2 (M. Fleischer, analyst). Psilomelane probably is an important constituent of the ores of the Stonewall mine also, because a carload of ore from there is reported to have analyzed 8.76 percent BaO. It is not known whether this ore showed a crystalline structure similar to the Hancock-Ferguson and Pribble specimens.

Pyrolusite.—The formula is MnO_2, usually with a little nonessential water. Pyrolusite was found in nodular ore from the Piedmont mine as the matrix to cryptomelane fragments, and in nodular ore from the Stonewall mine.

GANGUE MINERALS

Quartz, chert, mica, and clay are the principal gangue minerals associated with the manganese oxides; they were derived through weathering of the country rocks, either as resistant, relict minerals (quartz from quartzite and quartz veins, mica from schist, quartzite, and marble), or as secondary minerals (chert and clay). Quartz and mica are disseminated through the manganese oxides at nearly every deposit in the district. The manganese minerals evidently have grown in decomposed quartzite or micaceous rock, the disseminated quartz and mica representing unreplaced portions of the rock or rock residuum. Manganese oxides also occur as disseminations in decomposed quartzite, perhaps representing initial stages of replacement. Angular breccia fragments of hard quartzite or vein quartz are found with the manganese oxides of some deposits; the manganese minerals appear to have filled open spaces as a cementing matrix.

Yellow to brown micaceous clay is the typical material enclosing the nodular oxides of these deposits. The clay generally occurs in seams conformable to the foliation of the country rocks and may have a banding parallel to the foliation, owing to variations in color or quartz-mica content. The clay is believed to have been derived from decomposition of marble, calcareous schist, or quartzite.

Nodular manganese oxides are found in a matrix of yellow to brown chert or jasperoid at numerous deposits. This association, which has not previously been reported from this district to the writer's knowledge, is so common that experienced prospectors consider chert (with or without manganese minerals) as a favorable guide to ore. The chert usually forms masses or seams as much as several feet thick within yellow to brown clay. Small cavities lined with tiny white quartz crystals may be present in the chert. Age relations of the manganese oxide nodules and the chert have not been determined, so it is not known whether the nodules grew within chert, or possibly gelatinous silica, or whether they grew in marble or clay that was later replaced by chert.

Carbonate minerals in the form of white marble have been found in more than half a dozen deposits as undissolved relicts of the calcareous beds interbedded with the quartzite and mica schist members of the Mount Athos formation throughout the district. White marble at the Piedmont and Pribble mines is streaked with brown carbonates, and the marble at the Lucas mine has irregular streaks of pink carbonate. The white marble is always manganiferous, as are the brown and pink carbonates; partial analyses of white marble from different localities range from 0.11 to 0.85 percent MnO. These manganiferous carbonates are believed to have been the source of the manganese released through weathering to form the manganese oxides.

DISTRIBUTION

Every manganese deposit in the district is associated with the Mount Athos formation. As already mentioned, calcareous beds in the Mount Athos formation have a small, but persistent, manganese content, and it is thought that the deep weathering of these beds has resulted in the formation of the manganese oxide deposits; this subject is discussed in more detail in the section on the origin of the deposits. Distribution of manganese deposits and quartzite and white marble are shown in plate 2. It will be seen that manganese deposits are not found uniformly throughout the district where quartzite and white marble occur. In the northern third of the district, manganese deposits are scarce and largely restricted to a narrow belt about 5 miles long near Warminster, although the Mount Athos beds seem to be almost as extensively distributed here as elsewhere in the region. Most of the deposits are in Campbell and Appomattox Counties between the mouth of Wreck Island Creek and the Roanoke River, a distance of about 40 miles. In this part of the area, manganese deposits seem to occur principally where the Mount Athos beds are calcareous and are absent from some larger areas of quartzite that are apparently non-calcareous. White marble of the Mount Athos formation is known to occur southwest of the Roanoke River in Pittsylvania County where several manganese deposits have been found, but very little mining has been done.

STRUCTURAL FEATURES

The four principal modes of occurrences of manganese oxides are:

1. Nodules and masses of psilomelane-type oxides in seams of clay,

chert, or decomposed rocks, conformable to the dip of bedding or cleavage which is usually steep.

2. Psilomelane-type oxides forming coatings or fillings in cavities in fractured rock, as in open fractures and as the matrix in a breccia of quartz and quartzite fragments.

3. Wad mixed with clay and in seams interlayered with clay or decomposed rock conformable to the bedding or cleavage.

4. Residual concentrations of psilomelane-type minerals in the red clay soil overlying eroded manganese deposits.

The deposits that have been most productive are those with nodular or lumpy oxides of the psilomelane-type in seams of clay, chert, or decomposed rock, generally along a contact of quartzite with mica schist or marble, dipping steeply and conformable with the enclosing rocks. Such manganiferous zones are locally known as "leads." The clay seams are the product resulting from the decomposition of calcareous beds or mica schist by ground water; the bedding or foliation of the parent rock is preserved in the clay as color banding or mica-rich layers. In some deposits, the nodules or masses of the psilomelane-type mineral are distributed along certain planes of this relict bedding or foliation and may have a flattened form parallel to the layering, which evidently is due to preferential growth along these planes. The lumps of ore range from the size of peas to masses weighing several hundred pounds. The amount of manganese oxides is small in proportion to the clay in most deposits, but parts of the ore bodies of the Piedmont and Saunders mines are said to have been practically massive manganese oxides with only minor amounts of clay.

One wall of the manganiferous zone, usually the hanging wall, is generally composed of quartzite; the other wall may be mica schist or marble. The quartzite is commonly porous and leached due to solution of interstitial calcite by ground waters. Mica schist may be decomposed to a soft aggregate retaining its physical appearance as a schist, or it may be completely weathered to micaceous clay. Marble weathers to clay also, but where it is protected from ground water solution, it is preserved as fresh solid rock, as in the footwall of the Piedmont deposit (pl. 6). Blocks of decomposed quartzite or schist may be intermingled in the clay as a breccia that has probably been formed by the spalling off of rock fragments into solution cavities with formation of a rubble whose interstices are later filled with clay and sand.

The manganiferous lenses have trends conformable in strike and dip to contacts and bedding. At least one deposit, the Stonewall, plunges in the same direction as the lineations in the country rock. It seems probable that there was an original structural feature at this point, perhaps a plunging fold, along which the deposition of manganese oxides was favored. The Piedmont deposit (pl. 6) also appears to plunge steeply, with elongation of the ore body in the direction of plunge. This apparent relationship between the plunge of ore shoots and the plunge of linear structures in the country rock may be found to be a rather common characteristic of the deposits; knowledge of these relationships should be a helpful guide in exploration and mining.

The ore-bearing clay seams are seldom over 6 feet thick, nor more than several hundred feet long. The thickest ore body found is the Piedmont (pl. 6), which had a maximum thickness of about 30 feet; the longest ore body known is the Saunders deposit which is said to have been about 900 feet long with a barren interval of about 100 feet. Maximum depth of the deposits is determined by the depths to which ground waters were able to circulate; these depths seem to be from 300 to 400 feet for some deposits, but they may be shallower for others. The Leets deposit was followed to a depth of 312 feet below its outcrop, and the Piedmont or Myers ore body was worked to a depth of about 240 feet without reaching the lower limits of manganese oxide mineralization. At the Piedmont mine, a deep drill hole beneath the lowest workings found perfectly fresh quartzite and marble with no manganese oxides at a depth of 367 feet below the surface; presumably, the bottom of the ore body lies somewhere between the lowest mine workings and this intersection of the quartzite-marble contact, that is, between 240 and 367 feet beneath the surface.

At some localities, psilomelane-type minerals occur as the coatings or fillings of cavities in fresh or fairly hard rock, but such occurrences seem to be small and of no commercial importance. Principal examples of this type are breccias composed of angular fragments of quartzite or vein quartz in a matrix of manganese oxides. Fractures in quartzite that are coated or filled with manganese oxides are common. Porous quartzite may be impregnated rather uniformly with manganese oxides, as at Chestnut Mountain, the Theresa, and Dews deposits.

Wad deposits are composed of seams of soft, greasy, brown to black wad, usually containing disseminated sand or clay, interlayered with yellow, white, or red clay or decomposed quartzite. The original foliation or bedding of the country rock (which was probably highly calcareous in most instances) may be preserved as alternating seams of wad and clay having uniform steep dips. In some deposits the wad and clay seams are highly contorted because of slumping and compaction of the rock residuum; the Dews mine (fig. 14) is an example of this type. Friable, granular, manganese oxides of the type previously termed "pyrolusite" occur as stringers or seams in many wad deposits; on the other hand, the nodular type of oxides, which is so common in yellow clay seams, is very scarce in wad.

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Erosion and weathering of the manganese deposits have resulted in some residual concentration of the hard psilomelane-type minerals in the red clay surface mantle overlying the deposits. The heavy manganese minerals have gradually accumulated in the soil cover as erosion progressed. The amount of ore concentrated in this fashion is usually negligible compared to the size of the underlying ore body, and the layer in which there has been residual concentration of manganese oxides may be only one or two feet thick. However, exceptionally rich concentrations of ore were found in the soil and residual clay mantles over the Cabell and Bugley deposits.

GRADE OF ORE

Grade of ore, as used here, refers to manganese oxide-bearing materials, whether they are of commercial value or not. The only type of ore that has been of commercial importance in the past is the hard nodular or lumpy oxides type that occurs in yellow or brown clays. Manganese oxides intimately associated with abundant siliceous material (quartzite, quartz, or chert), and the soft, fine-grained wad type of ore have not been of value because beneficiation of such ores is difficult or costly.

The grade of the nodular oxide-clay ore must be considered from two viewpoints, namely, the manganese content of the mixture of nodular oxides and clay as it occurs in the ground, and the chemical composition of the nodular oxide concentrate after the clay has been washed away. There is not much information in regard to the grade of ore in the ground, but an indication of the range of grade is given by the concentration ratios of ores from two deposits in the district, the Piedmont (Campbell Co.), and the Stonewall. According to Hewett (1916, p. 52), the yield of lump oxides or washed ore from the Piedmont mine ranged from 1/3 to 2/3 the weight of the mine dirt; therefore, the corresponding manganese content would range from about 15 to 30 percent. At the Stonewall mine, the average recovery of washed ore was found to be about 1/15 the volume of the mine dirt, or probably about 1/12 the weight; manganese content of the mine dirt would be about 3.5 percent. The nodular oxide content of the Piedmont ore is certainly exceptionally high for the district; the content of the Stonewall ore seems to be fairly typical of most of the deposits.

Information on chemical composition of concentrates or washed ore is available for shipments from 6 mines, and is tabulated below:

	Average (percent)	*Range (percent)*	*Washed ore (long tons)*
Manganese	43. 3	40. 4 to 50. 2	1, 021
Iron	5. 1	1.9 to 5. 5	863
Silica	12. 3	7. 0 to 20. 6	863

Phosphorus content of the nodular ores is variable. The average content of 101 tons shipped from the Stonewall mine was 0.159 percent P. Analyses of picked samples of hard ores from several other deposits range from 0.087 to 0.254 percent P.

Information on the grade of other types of manganiferous materials, or "ores," is given below. Selected samples of siliceous ore (manganese oxides disseminated in quartzite) from Chestnut Mountain contained about 21 percent Mn, 4 percent Fe, and over 40 percent SiO_2 (Furcron, 1935, p. 107). Manganiferous limonite from the McGehee mine contained 12.4 percent Mn, 41.5 percent Fe, and 8.5 percent SiO_2 Wad ore from Chestnut Mountain contained 11.63 percent Mn, 29.13 percent Fe, 29.04 percent SiO_2, and 0.214 percent P (Furcron, 1935, p. 107). A 100-pound sample of wad ore taken by the Bureau of Mines from the Columbia manganese deposit (old Mortimer mine) analyzed 8.8 percent Mn, 3.4 percent Fe, 41.9 percent SiO_2, and 0.42 percent P (Montgomery, 1949, p. 6). In 1952, the Defense Materials Procurement Agency contracted with a private firm to sample and make beneficiation tests of the wad ores of this district. Large channel samples were taken of wad ores by means of hand-dug trenches and bulldozer trenches at the following places: Mays (loc. 35, pl. 2), Wright (loc. 41, pl. 2), Piedmont (Campbell County), Lindsay, Pribble, and Dews. Partial analyses of these samples are given below.

Partial analyses of typical wad ores

[in percent]

Sample	Mn	Fe	SiO_2	Al_2O_3	P	CaO	MgO	Pb
A	5.37	15.52	47.61	3.00	0.54	0.06	0.26	0.76
B	5.95	11.10	47.84	8.48	.35	.09	.64	.07
C	6.52	8.84	69.55	3.49	.38	.06	.03	.10
D	6.72	20.06	37.01	8.42	.39	.07	.01	.24
E	6.91	20.42	40.72	8.72	.32	.11	.04	.48
F	7.29	18.51	40.21	3.57	.59	.08	.23	.59
G	9.48	27.56	17.54	7.72	.46	.25	.18	.03
H	11.30	23.24	29.50	4.93	.34	.21	.07	.04

ORIGIN

GENERAL STATEMENT

Most of the features relating to the origin of the manganese deposits have already been mentioned, but they are summarized here as a preface to a more complete discussion of the genesis of the deposits:

1. The concentrations of manganese oxides occur only in decomposed rock material and evidently were formed during, or following, the period of weathering that caused rock decay. Manganese was dissolved from the country rock by circulating ground waters, and was transported and deposited in rock residuum as manganese oxides.

2. The manganese deposits are normally restricted to the residuum of one formation, the Mount Athos; only minor amounts of manganese oxides occur with other formations. Calcareous beds of the

Mount Athos formation usually have a small content of manganese, apparently present as manganese carbonate of sedimentary origin; these beds are believed to have been the chief source of manganese dissolved by ground waters.

3. Ground water circulation seems to have been most active in the calcareous quartzite beds of the Mount Athos formation because of the increased permeability resulting from solution of interstitial carbonates. Ground water movement, attended by deposition of manganese oxides, has reached depths of several hundred feet below the ground water table by circulation along restricted channelways in steeply-dipping beds.

4. The outcrops of most deposits are on the upland, above the present drainage system, and it appears that the manganese deposits were formed during an earlier erosion cycle, probably in Tertiary time.

OCCURRENCE OF MANGANESE OXIDE MINERALS IN ROCK RESIDUUM

The intimate association in this region of manganese oxide minerals with decomposed rock material was recognized years ago; this association has generally been accepted as signifying that the deposits were formed by circulating ground waters and that the manganese was dissolved from the country rock, transported, and deposited as manganese oxides in the rock residuum. (Watson, 1907, p. 238; Harder, 1910, p. 46–47; Hewett, 1916, p. 43–60). The numerous manganese oxide and limonite deposits elsewhere in the Appalachian region, particularly along the west foot of the Blue Ridge, also have been thought to be of similar origin.

The additional information on the nature of the deposits, which was gathered during the present study, is in harmony with the theory of origin by circulating ground waters. Present evidence pointing to this origin is briefly as follows:

1. The manganese oxide minerals are most abundantly associated with decomposed rock material, generally micaceous or sandy clay.

2. The manganese minerals commonly show evidence of having grown by replacement of the enclosing clay. Psilomelane-type minerals commonly contain quartz or mica particles, and occur as flattened masses along layers parallel to the relict bedding or foliation of the country rock; seams of wad are also interlayered with clay seams parallel to this relict structure.

3. Manganese oxides have coated and replaced quartzite and quartz in the zone of weathering, and occur as coatings and fillings in fractures, as the matrix of breccias, as disseminations in porous quartzite (whose porosity is evidently due to ground water leaching), and as a thin rind on quartz fragments in the soil cover.

4. Massive manganese oxide minerals have not been found in fresh quartzite or marble unaffected by ground waters (as could be expected

if the manganese oxides had originally been deposited in the parent sediments or had been formed during regional metamorphism or by hydrothermal solutions). An item of especial interest here is given by the data of a deep drill hole at the Piedmont mine (No. 1, pl. 6), which encountered perfectly fresh quartzite and white marble with no manganese oxides at a depth of about 130 feet beneath the lowest mine working; manganese oxides had been found in abundance with decomposed rocks from the surface to the bottom of the mine. Manganese oxide nodules occur in porous or crumbly quartzite at several localities, but at these places the quartzite has obviously been thoroughly decomposed by ground waters. Nodules are present in massive brown chert or jasperoid at numerous places, and it might be argued that both the chert and the manganese minerals were deposited in the original sediments. However, this type of chert, both manganiferous and non-manganiferous, is associated with clay, and has never been observed to occur in fresh, unweathered rock; this is regarded as evidence that the chert also was deposited by circulating ground waters. It is interesting that jasperoid of apparently very similar character is associated with the manganese deposits in the residuum of the Shady dolomite in northeastern Tennessee, and is thought by King, Ferguson, Craig, and Rodgers (1944, p. 22–24), to be supergene replacement of the dolomite.

The process of solution of manganese from the country rock during weathering, its transportation in ground water, and deposition as manganese oxides is a common phenomenon, and has been the subject of considerable investigation. Detailed discussions of the problem are given by Stose, Miser, Katz, and Hewett (1919, p. 54–56), Zappfe (1931), Hewett (1932), and Savage (1936). There appears to be general agreement that the following three processes have taken place in the formation of such manganese oxide deposits.

(1) Solution: Percolating ground water containing free carbonic acid is probably the most common agent capable of dissolving manganese from the country rock.

(2) Transportation: Manganese is possibly carried in solution in the carbonated ground waters as manganese bicarbonate. However, Hewett (1932, p. 579) suggests that manganese in waters carrying organic matter exists as a hydrosol that is stabilized by organic colloids.

(3) Precipitation: Precipitation of manganese oxides may be caused by several agents, such as thread bacteria, free oxygen, limestone, and by the catalytic effect of previously formed MnO_2 (one of the best agents according to Zappfe). The acidic ground waters must become neutral or slightly alkaline in order to permit precipitation of manganese oxides.

In this district, the manganese oxides commonly replace clay, quartzite, and brown chert, and either replace or coat vein quartz. They have not been found in similar association with marble, as might be expected if marble had acted as an important precipitating agent. This association of manganese oxides with quartz and clay minerals is a common one in the southeastern deposits and is found in many of the manganese deposits along the west foot of the Blue Ridge. There seems to be a particular affinity of the manganese oxides for silica and clay minerals, and the question may be raised as to whether these minerals play a part in the precipitation of manganese oxides. The subject seems to deserve some experimental research.

ASSOCIATION OF MANGANESE DEPOSITS WITH THE MOUNT ATHOS FORMATION

The present study has ascertained that every known manganese deposit in the area is associated with the Mount Athos formation, and that only minor amounts of manganese oxides are found with other formations. This association naturally indicates genetic significance in the weathering theory of origin, and it may be assumed that the Mount Athos formation either originally contained the manganese that was provided to the ground water, or that it has characteristics especially favorable for the circulation of ground water. It now appears that the Mount Athos formation possesses both these features. The calcareous members of the formation have been found to contain manganese in amounts that are small but appear to be significantly greater than the quantities of manganese found in other formations; furthermore, the manganese is probably present as a carbonate mineral which would be readily soluble in ground waters. The calcareous beds of the Mount Athos formation appear to have aided ground water circulation by virtue of their relative solubility. This seems to be particularly true of the calcareous quartzite beds, which become highly porous after leaching of the interstitial calcite by ground water.

In order to discover the original source of the manganese, qualitative blowpipe tests for manganese were made of fresh, unweathered specimens of the different rock types of the region during the course of the field studies. Manganese was found to be present in practically every specimen of white marble or calcareous quartzite from the Mount Athos formation. It should be mentioned here that according to Harder (1910, p. 38), a suggestion was made by Watson years ago that the black manganiferous earth, or "umber", associated with the manganese deposits in this area, was residual from crystalline limestone. Specimens from the other important calcareous beds of the area, the blue marble member of the Archer Creek formation, were found to give only a few, weak reactions for manganese. A little manganese had previously been found in the graphitic schist member of the Archer Creek formation by W. R. Brown (oral communication) during his field investigations in the Lynchburg quadrangle. Blowpipe tests by the writer proved this association to be fairly widespread; the garnets that are occasionally present in the graphitic schist were found to be manganiferous.

Specimens of the two predominant types of manganese-bearing rocks, calcareous beds of the Mount Athos formation and graphitic schists of the Archer Creek formation, were analyzed for manganese in the chemical laboratory of the Geological Survey, with the results given in table 2. The total MnO content of white marble from the Mount Athos formation was found to range from 0.11 to 0.85 percent in the specimens analyzed. Most of the manganese contained in the white marble is in a form that is soluble in 10 percent HNO_3, presumably as a manganiferous carbonate. The three samples of graphitic schist from the Archer Creek formation were found to contain from 0.036 to 0.161 percent total MnO; the greater portion of this is in a form not soluble in 10 percent HNO_3, probably as a manganiferous silicate.

TABLE 2.—*Manganese content of calcareous beds of Mount Athos formation and graphitic schist member of Archer Creek formation*

[Samples 1–5, 16–18 analyzed by Joseph M. Axelrod; samples 6–15 analyzed by Charlotte M. Warshaw]

Description of sample	Percent of MnO as soluble manganese [1]	Percent of MnO as insoluble manganese
Mount Athos formation		
1. White marble, Pribble mine	0.85	0.004
2. Brown carbonate veins in above marble sample, Pribble mine	.46	.14
3. Pinkish carbonate, Lucas mine	.35	.070
4. White marble along C. & O. R. R. near Gladstone	.10	.013
5. White and tan marble, Piedmont mine, Campbell County	.29	.016
6. White marble from stream near Bishop mine [2]	.31	<.001
7–15. White marble from drill hole 1, Piedmont mine, Campbell County [3]		
7. From 359 to 359½ feet	.41	.007
8. From 362 to 363 feet	.54	.002
9. From 370½ to 371 feet	.51	.015
10. From 372½ to 373½ feet	.58	.005
11. From 376 to 377 feet	.54	.001
12. From 381 to 382 feet	.70	.003
13. From 386 to 387 feet	.57	<.001
14. From 390½ to 391½ feet	.65	.001
15. From 485 to 486½ feet	.60	.003
Archer Creek formation		
16. Graphitic schist, tributary to Stonewall Creek, just SW. of Stonewall mine	.031	.13
17. Graphitic schist, Tardy Creek near Scott Mountain	.016	.047
18. Graphitic schist, Archer Creek near Leets mine	.018	.018

[1] Soluble manganese is that soluble in 10 percent HNO_3.
[2] Sample 6 contains 0.01 percent BaO.
[3] Samples 7 to 15 all contain less than 0.01 percent BaO.

Sampling of the white marble beds has been insufficient to show a pattern in the local or regional distribution of manganese in these beds. However, the nine samples of white marble from drill hole 1 at the Piedmont mine, Campbell County, are interesting because they give an example of the manganese content of the marble associated with the largest known manganese deposit in the district; total MnO content of the samples ranges from 0.42 to 0.70 percent. This drill hole first cut white marble at a depth of approximately 130 feet beneath the lowest mine working and remained in marble to the bottom of the hole, 253 feet vertically beneath the mine bottom (pl. 6); no manganese oxides were found and the marble showed no signs whatever of having undergone decomposition. The low manganese content (0.11 percent MnO) of the white marble specimen from near Gladstone (table 2, sample 4), may be of significance in explaining the scarcity of manganese deposits in this part of the district. Systematic sampling would be necessary to determine whether the white marble has a generally lower manganese content in the part of the region around Gladstone than it does farther south, where there are more manganese deposits.

The presence of manganese in the Mount Athos calcareous beds and its scarcity in other formations, particularly in the calcareous beds of the Archer Creek formation, is a good indication that the manganese was deposited as an original sedimentary constituent of the Mount Athos calcareous rocks. Veinlike occurrences of brown carbonate in white marble at the Piedmont and Pribble mines, and pink carbonate in white marble at the Lucas mine might be suspected to be of hydrothermal origin; however, they could also represent original sedimentary segregations that became highly deformed during flowage of the marble under conditions of regional metamorphism. These colored carbonates apparently veining white marble are not known to occur at other deposits in the district, and if they have a hydrothermal origin, it is believed that hydrothermal activity played only a very minor role in the formation of manganese carbonates. Furthermore, analyses in table 2 show that the white carbonates of probable sedimentary origin commonly contain more manganese than the colored carbonates of possible hydrothermal origin.

The occurrence in this district of manganese deposits in clay residual from calcareous rocks that contained manganese carbonate of probable sedimentary origin is paralleled by the occurrence of manganese oxide minerals in residual clays of manganiferous Paleozoic limestones in the two other Virginia districts, one along the west foot of the Blue Ridge and the other near the western border of the state (fig. 1). The deposits at the foot of the Blue Ridge are in residual clays of the lower Tomstown (Shady) dolomite, and commonly rest on Antietam (Erwin) quartzite (both formations are Early Cambrian in age); similar manganese and limonite deposits are found at this stratigraphic horizon at many places from Alabama to Vermont. It was suggested some years ago by Stose and his associates (1919, p. 54–56) that the manganese was derived from the weathering of beds in the Shady dolomite containing manganese minerals of sedimentary origin, and this widespread occurrence of sedimentary manganese minerals, probably as a manganiferous carbonate, now seems to be satisfactorily demonstrated (Stose, 1942; King, Ferguson, Craig, and Rodgers, 1944, p. 57–59; Rodgers, 1945). The analyses presented by Rodgers of drill core from the lower part of the Shady dolomite in Bumpass Cove, Tenn. are of particular interest; the maximum concentration of manganese in the dolomite was found to average 0.6 percent MnO for a thickness of 43 feet. This content is practically identical with the manganese content of white marble at the Piedmont mine, Campbell County, as indicated by the nine analyses of drill core samples (table 2). King reports manganese content as high as 1.24 percent Mn in a sample of the Shady dolomite from Shady Valley, Tenn. Along the border of Virginia and West Virginia, manganese deposits commonly occur in residuum of upper Silurian and Lower Devonian limestones and sandstones (Stose and Miser, 1922; Ladd and Stead, 1944, p. 235); two samples of Tonoloway limestone (Silurian) are reported by Ladd to carry 0.36 and 0.23 percent Mn respectively.

Thus, it appears that the source beds in each of the three Virginia manganese districts are calcareous rocks containing sedimentary manganiferous carbonates in small but essentially equivalent amounts; sandy beds are closely associated with the calcareous beds in each district. It is not known whether the manganiferous limy beds of the James River-Roanoke River district are equivalent in age to manganiferous sediments in either one of the other districts. The erosion history of each region has been very similar, and probably all of the manganese oxide concentrations were formed under similar conditions and during, or just following, the same period of prolonged weathering.

CONDITIONS OF GROUND-WATER CIRCULATION

Attention is now turned from the manganese content of the calcareous beds of the Mount Athos formation to the other characteristic of the formation that is of importance in the genesis of the manganese deposits, namely, the ready solubility of the carbonate minerals in ground waters. As the calcite is dissolved from the rock, particularly where minerals of differing solubilities are closely associated, an insoluble residue of quartz, mica, or clay is left, and this aggregate appears to be more permeable to ground waters than the parent rock. During the course of time, channelways of ground-water circulation may be extended laterally and to greater depths because of leaching of carbonates.

The Mount Athos formation contains beds of fairly pure quartzite, of nearly pure marble, of muscovite schist, and beds with compositions intermediate between these three types. There is considerable difference in the relative solubilities of the various rock types, and in the permeabilities of the weathered rocks. The type most easily decomposed by weathering seems to be calcareous quartzite, which is present in the formation at many places in the region, as shown by exposures of the fresh rock in some of the stream valleys, and by the porous, leached quartzite, stained with manganese or iron oxides, that is found on the surface or underground at most of the manganese deposits. The rock contains several times as much quartz as calcite; a few thin sections of fresh calcareous quartzite were found to contain 20 to 30 percent carbonate by weight. When the interstitial calcite is dissolved, a residual mass of quartz grains is left that may retain much of its coherence or may break down to loose sand; in either case, permeability is increasing by leaching.

None of the other rocks of the Mount Athos formation react in quite the same way. In the case of thick beds of fairly pure marble not closely associated with calcareous quartzite, the argillaceous material in the marble is decomposed to clay at the surface, and a thick mantle of clay is gradually developed on the marble that apparently inhibits ground water movement. Permeability of thick quartzite or mica schist beds is not much increased through weathering. Thus, there seems to be a tendency for channelways of ground water circulation to be more extensively developed in calcareous quartzite than in any of the other rock types. Once such a channelway is started, the attitude of the beds (usually more than 50 degrees) favors its extension to depths of several hundred feet; the seams of manganese oxide-bearing clays that are now found in thick beds of leached quartzite at such depths probably were thin beds of marble or layers of schist at one time.

Some ore bodies plunge at an angle to the direction of dip with a trend nearly parallel to the plunge of linear structures in the country rock; examples are the Stonewall deposit (pl. 4), and possibly the Piedmont deposit (pl. 6). Such plunging ore bodies may lie in or alongside steeply plunging tight folds and may have been deposited from ground waters that followed beds of calcareous quartzite within the fold.

Not only is there a difference between ground water circulation in marble and in calcareous quartzite, but there is also a difference between the character of manganese oxide minerals in weathered marble and those in calcareous quartzite. Wad and clay appear to be developed most extensively in the decomposition of nearly pure marble, as at the Bishop and Pribble mines. Yellow clay seams containing psilomelane-type minerals are nearly everywhere associated with calcareous quartzite or occur at the contact of quartzite with marble or schist and apparently extend to greater depths than the wad deposits. Both types of oxides are present at the Piedmont mine, Campbell Co.; the psilomelane-type mineral is most abundant at the contact of quartzite and marble, whereas wad seems to be the dominant manganese oxide mineral overlying the main mass of marble. The nodular oxides along the contact between quartzite and marble extend to depths of over 240 feet; the wad probably extends to much shallower depths, because fresh marble is exposed in Little Beaver Creek at an elevation about 130 feet below the collar of the shaft. These relationships seem to indicate that the deep lying deposits of psilomelane-type oxides are formed in calcareous quartzite because of active ground water circulation and that shallow deposits of wad are formed from marble where ground water movement has been less active.

In deposits where underground conditions could be examined during the present study (at the Stonewall, Grasty, and Dews mines, and in the exploratory tunnel at the Cabell mine), angular fragments and blocks of decomposed mica schist and quartzite in clay or sand were found in some abundance either in the manganiferous zone or in its hanging wall. It seems most likely that these breccias were formed by collapse of the rock in places where support was weakened by solution, and the resulting cavities were then filled with a rubble of rock fragments. Gradually the interstices between breccia blocks were filled with clay and sand, and the mass became compacted and thoroughly decomposed.

The two deepest mines in the district, the Piedmont (Campbell County), and the Leets mines, were examined by Hewett who was able to observe the nature of the manganese oxides and rock decomposition on the lowest levels. He has drawn attention to the fact that ground waters have evidently circulated to considerable depths below the present ground water table in nearby streams (1916, p. 47–48)—over 200 feet in the case of the Leets mine (1935). He suggests in his latter paper that precipitation of manganese oxides at these depths may have been accomplished by free oxygen carried from the surface in the ground waters. As pointed out above, it is believed that such deep circulation may readily be explained as taking place along permeable channels leached in steeply dipping beds of calcareous quartzite.

RELATIONS OF THE OUTCROPS OF THE MANGANESE DEPOSITS TO THE UPLAND SURFACE AND PERSISTENCE OF THE DEPOSITS IN DEPTH

The majority of the manganese deposits in the district crop out either on the upland, or on lower hills or ridges, at elevations 100 to 400 feet above the nearby streams. The range in elevation is considerable, with such extremes as at the Bell mine, which is over 300 feet above Flat Creek half a mile away, and the Chestnut Mountain deposits at an elevation about 500 feet higher than the James River only 0.7 miles distant. The rocks on the upland surfaces are very thoroughly decomposed; exposures of hard rock are scarce and consist mainly of siliceous quartzite. On the other hand, fresh exposures of all rock types, including marble, are found along the stream valleys. A number of deposits, including such important ones as the Piedmont (Campbell County), Saunders, and Leets, are located on bluffs or knolls adjacent to streams, and it is evident that the manganese deposits and associated decomposed country rock have been partly eroded by the streams. Furthermore, as Hewett originally pointed out (1916, p. 44), these deposits are on isolated hills or ridges whose surface areas are hardly large enough to provide sufficient ground water at the present time for contemporaneous deposition of manganese oxides on a large scale. All these features point to the formation of the manganese deposits during the earlier erosion cycle which developed the upland surface and which provided the necessary conditions of deep weathering and ground water action. The manganese deposits and the deeply decayed rock of this old surface have gradually been eroded over a long period of time, thus removing the upper parts of many deposits so that their present outcrops are appreciably lower than their original elevations.

The statistical distribution of the average surface elevations of the manganese deposits, and the percentages of total manganese production from mines in different 100-foot elevation intervals are shown in figure 2. The outcrops of the majority of the deposits (65.4 percent) have surface elevations between 600 and 800 feet above sea level, and the greater portion of total manganese production from the district (82.0 percent) has come from mines that crop out in this same elevation interval. Manganese deposition seems to have been of less consequence on that part of the old surface that now lies above 800 feet; the outcrops of 20 percent of the deposits have average surface elevations above 800 feet, but only 2.3 percent of the total district production has come from these deposits.

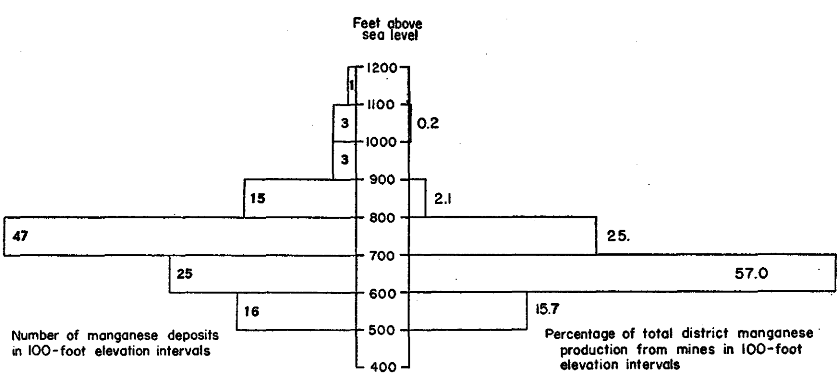

FIGURE 2.—Distribution of manganese deposits and manganese production according to outcrop elevation of the deposit.

Hewett (1916, pp. 43–47) was the first to suggest that the manganese deposits of this region were formed in an earlier erosion cycle; he pointed out that manganese deposits along the west foot of the Blue Ridge are also situated on upland surfaces underlain by decayed rock, and that these deposits were formed during an old erosion cycle, probably during early Tertiary time. He believed that conditions for deposition of manganese oxides were most favorable either in the late stages of peneplanation when rock decay and solution predominated over erosion, or immediately following uplift of the peneplain when deeper ground water circulation was facilitated. He says:

During the period when peneplanation was being perfected locally there was probably little rock disintegration and removal, but solution and decay were going on in the zone accessible to migrating waters that contained oxygen. At this time the best conditions for the solution of large amounts of manganese probably existed, but as the relief of the surface was low the opportunity for circulation in localized channels was poor. During the next stage in the erosional history of the region, that represented by the uplift of the early Tertiary peneplain, the gradients of the streams and consequently their capacity for transporting sediment were again augmented, but also with the increase in surface relief the opportunity was afforded for more active circulation of water to deeper levels.

In considering the effectiveness of the processes that went on during the last two periods in aiding the accumulation of manganese oxide it is necessary to balance the duration of the first period against the better facility for circulation during the second period. There is no doubt that the depth below the peneplain to which the ores are known to occur is a good reason for placing a considerable part of the accumulation in the last period, but it is also known that surface water may descend much deeper below the surface than the difference in elevation between the points of entrance and outlet, a difference which on the early Tertiary peneplain was probably in some place as much as 100 feet. The data are not available at present to evaluate properly the relative importance of these two periods in the formation of the masses of manganese ore.

It would be unwise without further study to assert that all the manganese deposits of Virginia or the region from Alabama to eastern Pennsylvania were formed during the early Tertiary period of erosion, but it is interesting to note that this suggestion was once made for the Appalachian deposits of iron ore, which have a similar areal distribution, as a result of the discovery of small basins of lignite of Tertiary age near Brandon, Vt. (Hitchcock, 1861), and Pond Bank, Pa. (Lesley, 1864), near deposits of iron ore. It was then thought, however, that the residual iron ores within this entire region were the weathered residue of an essentially continuous horizontal iron-bearing bed. This assumption is not necessary, but it is reasonable to suppose that conditions during early Tertiary time may have favored, more than those of later periods, the solution and transportation of iron and manganese salts to favorable sites for deposition. The existence of many extensive deposits of residual iron ore and related laterite in regions having warm and moist if not tropical climates has long been recognized. In this connection it may be noted that Berry, as a result of the study of the floras of the Upper Cretaceous and Eocene formations of the Coastal Plain of South Carolina and Georgia, concludes that the prevailing

climate of that region at the time these beds were laid down was mild and humid, with possibly a brief period during Eocene time that was less mild.

Geologic investigations by other authorities of manganese deposits west of the Blue Ridge since the appearance of Hewett's paper have confirmed his view that most of the deposits crop out above present drainage systems, commonly on terraces, spurs or ridges that are the much weathered remnants of old soil erosion surfaces. King (1949a) has recently discussed the nature, origin, and age of the physiographic features in the Elkton region where he and Rodgers investigated the manganese deposits in the residuum of the Tomstown dolomite. The residuum in which these deposits occur lies mostly at the eastern border of the Shenandoah Valley along the base of the Blue Ridge; sheets of gravel composed of pebbles and boulders of fresh quartzite overlie the residuum. King considers the physiographic history to have been more complex than previously believed; he concludes that the residuum and its manganese deposits were formed in Tertiary time, probably in a warm moist climate, and that the gravel sheets were laid down in the Pleistocene.

Although our knowledge of the physiographic history of this part of the Piedmont province is rather meager, there seems to be good reason to believe that manganese deposition in this district, as well as in areas west of the Blue Ridge, occurred in the deeply decayed material of an old peneplain. As has already been pointed out in the discussion of the physiographic history, the formation of manganese deposits probably took place at about the same time that bauxite and residual limonite deposits were being formed (that is, during a period in early Tertiary time when favorable climatic and physiographic conditions permitted extreme rock decay and solution).

Some solution, transportation, and deposition of manganese has doubtless continued to the present time, but the amount of manganese oxides formed since the early Tertiary period is believed to be relatively small. Little pieces of quartz and quartzite with a thin rind of manganese oxide are found at many places in the soil cover; the manganese oxide coatings may have been formed during the early Tertiary or at any time since then. An example of formation of manganese oxides at the present time has been described by Hamaker (1933). During an investigation by one of his students (L. B. Henderson) of the plant ecology of a small bog on the headwaters of a branch of Burton Creek, about 2 miles south of Lynchburg, small rounded manganiferous pellets as large as marbles were found on the surface of the lower part of the bog. The pellets were distributed along mud cracks on barren patches of the surface in a manner suggesting that they had been deposited from solutions rising through the soil. No pellets were found beneath the surface, in vegetated areas, or in the upper part of the bog that had never been cultivated. According to Hamaker, he was informed by Hewett that samples of the pellets, which were analyzed in the Geological Survey laboratory, contained about 5 percent Mn and 25 percent Fe. Hamaker found considerable lime in the water of the small fork draining into this part of the bog from Candler Mountain, and suggested that passage of this lime-bearing water through soil of the upper bog, which was saturated in CO_2 and organic acids, and emergence of these ground waters in barren patches of the lower bog, may have caused formation of the pellets in some manner. The rocks within the drainage basin, phyllite of the Candler formation, Lynchburg gneiss, and greenstone, are not known to be particularly manganiferous.

If only minor amounts of manganese oxides have been formed since the early Tertiary, then the depth to which a deposit extends beneath the present surface depends on the original depth of the deposit beneath the peneplain and the amount that has been eroded from the upper part of the deposit since uplift of the peneplain. The best information on persistence of the deposits in depth pertains to the Leets and Piedmont (Campbell County) deposits. The Leets deposit crops out at an altitude of about 670 feet, and manganese oxides were present in the lowest mine workings at an altitude of about 360 feet. The surface of the Piedmont deposit is at an altitude of about 615 feet. Manganese oxides persisted to the lowest mine workings, and were found in a drill hole a short distance below the workings at an altitude of about 375 feet; in the deeper drill hole that seems to have cut beneath the ore body, fresh rock with no manganese oxides were found at the intersection of the quartzite-marble contact at an altitude of about 265 feet.

The upland surface in the vicinity of these two deposits, which are a little more than a mile apart and within 2 miles of the James River, has undergone considerable erosion since its uplift. The highest altitudes within a few miles of the deposits are a little over 800 feet, which may represent the average elevation of the upland surface here. Thus, the amount that has been eroded from the upper parts of the two deposits seems to be between 100 to 200 feet; their bottoms may have originally been 400 to 500 feet beneath the upland surface. In discussing the persistence in depth of manganese ores of residual origin in Virginia and Maryland, Hewett (1916, p. 48) reached a similar conclusion: "From analogy with similar deposits it is very doubtful whether manganese ores in any of these deposits will persist 500 feet below the surface, and a more probable limit is 400 feet."

RÉSUMÉ OF FACTORS INVOLVED IN ORIGIN OF DEPOSITS

In addition to the optimum climatic conditions for development of such manganese oxide deposits—a warm, moist climate—the four principal factors that have governed the formation of the deposits to their present-day character are: (1) Amount of manganese originally available in calcareous beds for solution by ground waters, (2) effect of local stratigraphic and structural conditions upon development of channels for ground water circulation, (3) effect of local topographic and drainage conditions upon ground water circulation; these conditions are chiefly those prevailing in Tertiary time, and may have been quite different from present conditions, and (4) amount of erosion a deposit has undergone since its formation.

The formation of one deposit may have been favored by unusually large quantities of manganese available to the ground waters. At another site excellent channels for ground water circulation, such as thick beds of calcareous quartzite, perhaps in steeply plunging folds, may have been present. Or local topographic and drainage conditions may have been more important in influencing composition and circulation of ground waters at other places. Some deposits may owe their existence to the fortunate conjunction of two or more of these factors.

If it were possible to determine the relative importance of the role played by each of these factors in the formation of any one deposit or group of deposits, that information would be very helpful in guiding exploration. Unfortunately, rock exposures are far too poor to enable the detailed determination of such local geologic conditions as average manganese content of calcareous beds, thickness of calcareous quartzite, and various structural features. Furthermore, it seems impossible to analyze the physiographic history in sufficient detail to deduce what may have been the local topographic and drainage conditions in Tertiary time which would have influenced ground water circulation. The only factor that can be used is the extent of erosion undergone by a deposit since its origin. The manganese deposits in a belt of Mount Athos formation outcropping on the old upland surface should be eroded only slightly, whereas the deposits in Mount Athos beds, which now outcrop in the bottoms of major valleys, may have been reduced by erosion to only a fraction of their original size.

IRON DEPOSITS

The iron deposits in the district are of two distinct types: the limonite or brown ore deposits, and the specular hematite deposits. These two types of deposits are very different in their mineralogical and geologic characteristics and in their modes of origin.

The limonite deposits are composed primarily of impure mixtures of limonitic minerals, quartz, and mica, and have been formed as near surface accumulations by ground waters carrying a solution of iron that had been leached from the country rock. The ores are variable in chemical composition; in eight analyses of limonite ore from near Mount Athos, quoted from Britton by Furcron (1935, p. 101), the following ranges in composition were determined:

Iron	from 34.63 percent to 55.95 percent
Phosphorus	from 0.43 percent to 1.048 percent
Silica	from 7.08 percent to 31.31 percent
Manganese oxide	from trace to 2.97 percent

These limonitic accumulations range in size from a few tons to deposits that probably contain several thousand tons of recoverable limonite, and they have been found to occur with nearly every formation in the region, except the Triassic sedimentary rocks and diabase. They occur most abundantly, however, in mica schists, graphitic mica schists, in quartzite, or along the contacts between quartzite and schist. Some of the larger limonite deposits are in the graphitic mica schist member of the Archer Creek formation, such as deposits of the old Oxford or Ross mine and those along and near Stonewall Creek. It is assumed that the pyrite disseminated through the graphitic mica schists provided a nearby source of iron for the ground water solutions that formed the limonite deposits. In some of the deposits, the iron may have been derived from the weathering of other iron minerals, such as the iron-bearing silicates or carbonates. Possibly, in some deposits the iron was not derived from the adjacent country rock but was transported for some distance from a source in other formations and accumulated in its present site because of favorable topographic, structural, or permeability conditions. The limonite deposits are believed to have been formed under similar geologic conditions, and during the same general period, as the manganese deposits of the region.

Little information is available now in regard to the size, shape, and extent of the limonite deposits, because no records were kept of the conditions encountered in mining a century or more ago, and present exposures of the deposits are inadequate. Much of the limonite contains relict layers of mica schist; this fact suggests that the ore was formed by partial replacement of schist. Because the schist is less permeable and less soluble than the calcareous quartzite and marble associated with the manganese deposits, it is probable that the limonite deposits do not extend to the depths of some manganese deposits. However, some of the limonite deposits seem to have had a lateral extent of several hundred yards, judging from the clusters of large pits at a few places. Many of the limonite deposits occur within a few hundred feet of manganese deposits, but the deposits are not intimately associated.

The specular hematite deposits consist of iron-rich lenses or seams in schistose and quartzitic beds of the Mount Athos formation. Deposits of this type have been found throughout the area, but the majority of mines and deposits are located along the west side of the James River in Amherst and Nelson Counties (pl. 2). Specular hematite is the dominant iron mineral and is accompanied by minor amounts of magnetite and martite. Quartz is always present and ranges from a minor constituent in schistose specular hematite to the principal mineral in hematitic quartzite. The ore is commonly conglomeratic. Barite and marble were found in one of the mines near Riverville. The iron-rich, schistose seams are commonly no more than 1 to 2 feet thick, and several such layers separated by leaner, siliceous beds may occur close together. According to Furcron (1935, p. 84), the lenses that were mined probably averaged only 1 to 3 feet thick, including the lean layers. The No. 16 ore body near Greenway is described by Frazer (1883, p. 209) as being exceptionally thick for the area; several iron-rich layers having a total thickness of 7 feet are present within a 10-foot thickness of vein.

Much of the ore shipped from the district had a high silica content. Frazer (1883, p. 211–214) gives numerous analyses of the ore, which are summarized below.

Average analyses of specular hematite ores

	Percent	*Number of analyses*
Iron	48.69	82
Phosphorus	.07	77
Silica	23.98	22

Very good, contemporary accounts of the iron deposits and mining operations have been given by Frazer (1883), Campbell (1882), and several other authors from whom Furcron (1935, p. 81–104) has abstracted information. Both Frazer and Campbell point out that the ore bodies are lenticular and that they pinch out laterally and vertically. Frazer also notes that some ore bodies were terminated by bodies of quartz, that were found in every case to plunge toward the southwest at angles of 25 to 50 degrees. The nature of these quartz bodies cannot be determined now, but they are probably plunging, podlike bodies that belong structurally to the lineation pattern of the region.

Several of the early geologists considered these specular hematite ores to be of sedimentary origin; Frazer (1883, p. 210–211) and Furcron (1935, p. 98–100) concluded that they probably were hydrothermal in origin. The constant occurrence of the deposits in the restricted stratigraphic interval of the Mount Athos formation, whose calcareous beds contain manganese minerals of sedimentary origin, leads the writer to believe that originally they were formed as thin accumulations of iron-rich sediments, and later they were altered to their present state by metamorphic processes. Ferruginous schist, in layers as much as several hundred feet thick, is present between the quartzite member of the Mount Athos formation and greenstone near Evington, Mount Athos, and other places.

BARITE DEPOSITS

Barite deposits have been found in Campbell County at about a dozen localities in the southwestern part of the district (pls. 1 and 2), and also to the south of Roanoke River in Pittsylvania County. All of the barite deposits in Campbell County are within the white marble member of the Mount Athos formation; the deposits in Pittsylvania County are also associated with marble and quartzites that are presumably the continuation of the Mount Athos formation. Barite occurs as fragments and masses in the black, manganiferous residual clay, or "umber", that overlies the marble, and as stringers and veins within marble; pyrite and chalcopyrite are commonly disseminated in the deposits. The barite in the residual mantle has been derived from barite veins in marble and has accumulated in the clay during weathering of the marble; the general relationships are shown diagrammatically in figure 3. At several of the barite deposits, hard manganese oxides are present or occur nearby; deposits on the Burton, Grasty, and Merritt tracts of the Otter River Mining Co. near Altavista, are examples of this situation.

The barite deposits and mining operations were first described in detail by Watson (1907a) in a paper on Virginia barite deposits, and have been discussed by Edmundson (1938) in a more recent study of the barite deposits of the state. These writers both point out that barite in this region is practically limited in its occurence to white marble and to the overlying residual and surficial clays, and they give information on geologic details, as well as history and data about the mining operations. Little additional information on the nature of the barite deposits was gathered during the present study because of poor exposures.

Watson and Edmundson arrived at opposing conclusions in regard to the origin of the barite deposits of Pittsylvania and Campbell Counties, and the other deposits of the state; Watson concluded that the barite deposits were formed by weathering processes, whereas Edmundson believed that they were of hydrothermal origin. Watson

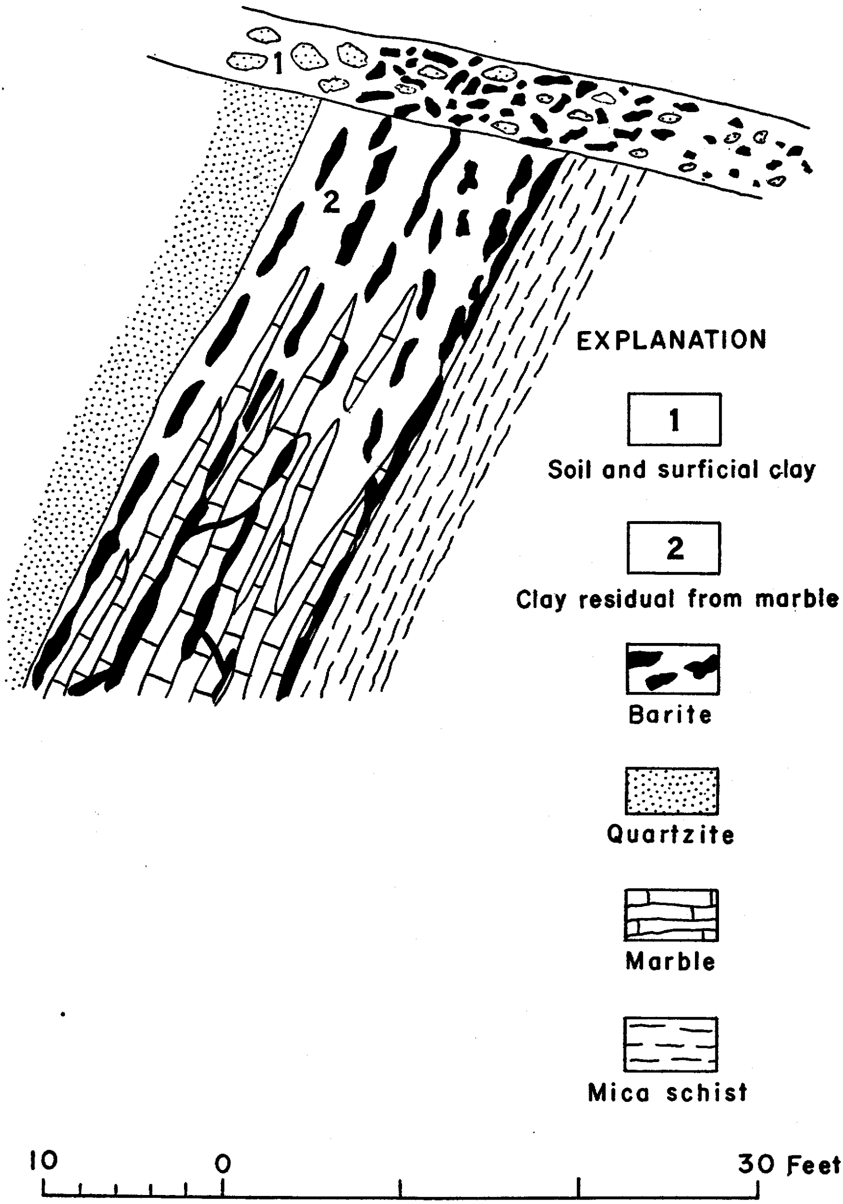

FIGURE 3.—Diagrammatic cross section showing typical deposit of barite in marble, residual clay, and surficial clay.

(1907, p. 720–721) gives three analyses of marble that have a range in barium sulfate content from 0.62 to 1.62 percent; black clay from one deposit contained only a trace of barium oxide. He does not state, however, whether he regards the barite content of the marble to be of primary origin or of secondary origin due to weathering action. On the other hand, Edmundson (1938, p. 20–24) lists analyses of marble and other rock types in the vicinity of barite deposits that show a lower barium content, as follows:

Content of barium oxide in rocks associated with Barite deposits

Rock type	*BaO (percent)*
Marble from Hewitt mine, Campbell County	0.078
Marble not associated with any known barite deposits	.02
Pegmatite dike in vicinity of Thompson mine, Pittsylvania County (barite was observed microscopically in sample)	.12
Diabase dike in vicinity of Phillips mine, Campbell County	.044
Mica schist from barite workings in Campbell and Pittsylvania Counties	.12

Ten samples of white marble were analyzed for BaO in the present study (table 2), and only one sample (from near the Bishop manganese mine) was found to contain as much as 0.01 percent BaO.

Edmundson thinks it doubtful that the barite deposits of the region could have been concentrated by the weathering of rocks that originally contained barium in such small amounts. He found tourmaline, hornblende, biotite, epidote, and chlorite to occur in the barite deposits of the region, and he considered these minerals, as well as the presence of barite in a few pegmatites, to indicate a hydrothermal origin of the barite. As supporting evidence, he states that the wall rocks of many veins are hydrothermally altered to quartz, epidote, and chlorite, that leaching is absent in the wall rocks, and that magmatic solutions are probably better agents of transportation and deposition than meteoric solutions.

The writer believes that the case for hydrothermal origin of these barite deposits in marble has not been conclusively established. The strongest evidence to support that theory is the occurrence of tourmaline in several barite deposits, and the presence of barite in minor amounts in a few pegmatites. Such accessory minerals as hornblende, biotite, epidote, chlorite, quartz, and pyrite are common and characteristic minerals of the different metamorphic rocks of the area and have been formed or modified by the processes of regional metamorphism, rather than by localized hydrothermal action. Some leaching of the barite deposits and their wall rocks by meteoric waters has obviously taken place, because every deposit shows such features as residual clays, wad, and porous quartzite fragments that were orginally calcareous.

The writer has no further evidence to offer in regard to the origin of the barite deposits, but he feels that several additional points should be given consideration. The first point to be emphasized is that the restriction of all the barite deposits in Campbell County to a limited stratigraphic interval—the white marble member of the Mount Athos formation—and their absence from the blue marble member of the Archer Creek formation suggests that sedimentary deposition of barium minerals might have taken place locally in the calcareous beds. Another point is that there sems to be very little information about the behavior of barite or other barium minerals in the regional metamorphism of rocks that contained barium minerals prior to metamorphism. Are barium minerals relatively stable and unaffected by metamorphism, or are they mobilized and transported under certain conditions? Is it possible that barium may have been present (possibly as a mineral of sedimentary origin) in the limestone before its metamorphism, and could it have been transported during metamorphism to form the present vein deposits in marble? In this connection, it may be pointed out that the barite deposits in Campbell County all lie a short distance west of the garnet-staurolite zone of most intense deformation and metamorphism. The regional metamorphic features of the area of barite deposits in Pittsylvania County are unknown to the writer. The final point is that barium is known to occur in significant quantities in some manganese ore of the district; analysis of a shipment of 51 tons of manganese ore from the Stonewall mine showed a content of 8.76 percent BaO. It is evident that barium was mobile to a certain extent, and underwent solution, transportation, and deposition during the weathering process that formed the manganese deposits from the marble and calcareous quartzites of the Mount Athos formation.

To sum up, the writer feels that the genesis of these barite deposits is obscure and that a possibility exists that several geologic processes may have played a part in the origin of the deposits. The barite may be hydrothermal in origin, or it, or some other barium mineral, may have been an original sedimentary constituent of the limestone and occurred locally in greater amounts in the southwestern part of the belt. These barium minerals may have been transported and deposited as barite veins in marble under favorable metamorphic conditions, and locally mixed with minor hydrothermal solutions to form the association with tournaline or pegmatitic solutions to form the few occurrences of barite in pegmatite. As a final step, some transportation and deposition of barium by ground waters in the residual clay may have taken place during the long weathering process that has affected the region.

COPPER DEPOSITS

Minor amounts of copper minerals have been found at several places in the region, principally in the Glades west of Buffalo Ridge, along Wreck Island Creek, at the Bishop manganese mine, and in the area of Triassic sedimentary rocks southwest of Rockfish River. These deposits occur in three different types of rocks and are probably different in nature and mode of origin; however, poor exposures prevent adequate study of their characteristics. Stringers and disseminations of copper sulfides appear to be present at all of the localities. Near the surface, the sulfides have been oxidized to malachite, and in one case, to turquoise.

Copper deposits in the Glades are in altered peridotite, or soapstone; stringers and small lenses of bornite and chalcopyrite are associated with tremolite. At the copper prospect on Wreck Island Creek, stringers and disseminations of pyrite, hematite, and chalcopyrite are found in marble; bornite and chrysocolla are also present according to Furcron (1935, p. 110)—(no copper minerals were visible at the time of the writer's visit). Crystalline turquoise has been found on the dump of the old Bishop mine, which is the only locality in the world where turquoise with crystalline structure is known (Schaller, 1912; Robinson, 1942). Chalcopyrite disseminated in white marble has been observed at several localities, and the copper deposit at the Bishop mine may be of this type. In the largest area of Triassic rocks near Warminster, grains of bornite and malachite with small lenses of quartz and calcite are found in irregular fractures in shale; the fractures and mineralization may be related to the fault bordering the Triassic rocks on the west.

QUARTZ VEINS

Quartz veins are common in all of the metamorphic rocks in the region; they range in size from short, thin lenses, less than an inch thick, to veins several hundred feet long and as much as 30 feet wide. Veins in schistose rocks are very numerous, small, and usually conformable to cleavage, even where the cleavage is folded. Veins in quartzite and other massive rocks are less numerous, but they are larger and may cut across the cleavage, apparently occupying tension fractures. The quartz is commonly fractured or crushed, and the veins have the same systems of joints and linear structures as the enclosing rocks.

Ilmenite occurs in some of the quartz veins and is particularly abundant in veins cutting greenstone. Carbonates and pyrite are common in some veins; a few veins carry small amounts of feldspar and muscovite. An unusually persistent tourmaline-quartz vein, in which black tourmaline exceeds quartz, occurs at Riverville, about a quarter of a mile east of St. James Church (fig. 4). This vein attains a width of 30 feet in places, and can be traced for a third of a mile in a northerly direction. Limonitic alteration of the abundant tourmaline attracted attention in the days of iron mining around Riverville, and the vein was explored by an open-cut at one place. Float of tourmaline-bearing quartz has also been found near the southwest end

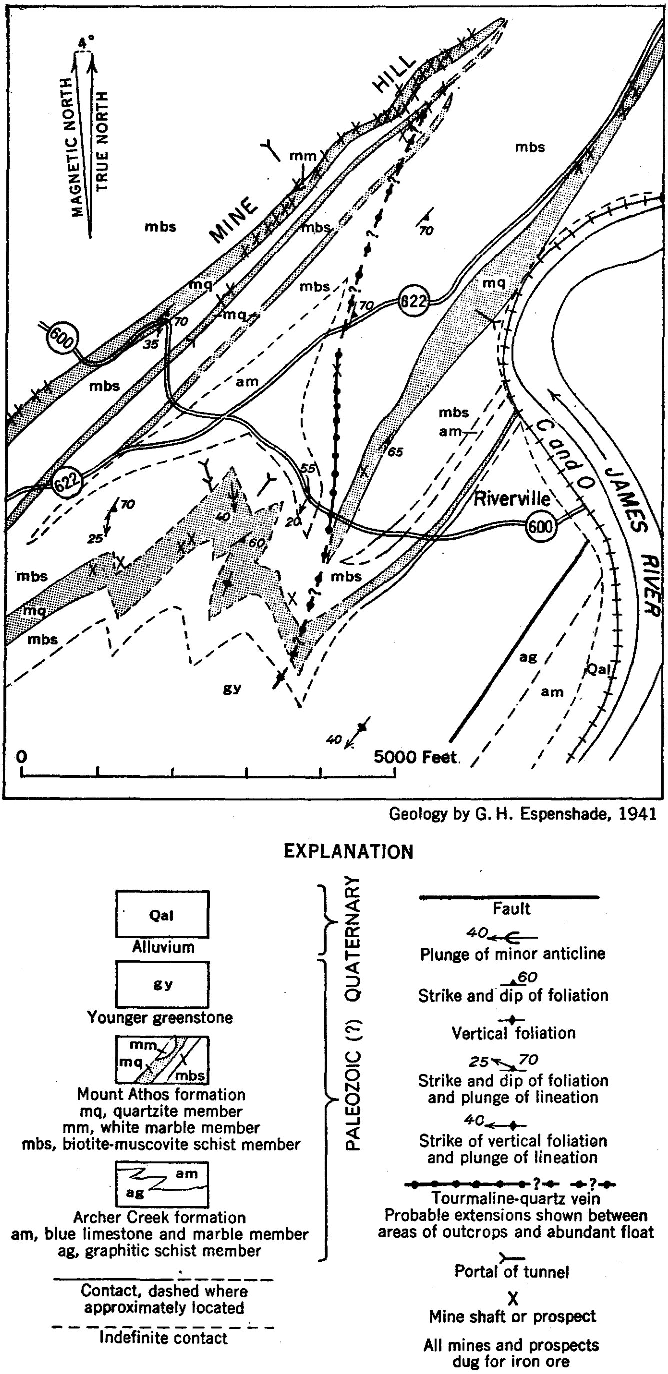

FIGURE. 4.—Geologic map of Riverville area, Amherst County, Va.

of Chestnut Mountain and in the valley of Flat Creek northeast of Evington.

MANGANESE MINES AND PROSPECTS

HISTORY AND PRODUCTION

Manganese mining in the district was initiated in 1868 and 1869 when the Cabell and Bugley mines in Nelson County were operated by James E. Mills (1871) who had undertaken a search for manganese oxide ores to supply a firm in Newcastle, England, for the manufacture of chlorine gas in the making of bleaching powder. About 7,000 tons of ore was shipped to England for this purpose from these two mines. There is no record of manganese production during the seventies, but ore was produced in the eighties (according to official records) from the Simpson and Davis mines in Nelson County,[3] and from the Leets (or Mount Athos), Bishop, and Lucas mines in Campbell County. Some, or all of this ore was shipped to England for the manufacture of chemicals. The Saunders, Phillips, and Mortimer mines near Evington may also have been operated in the eighties (Watson, 1907b, p. 241–242); according to local residents the Piedmont mine in Nelson County and the Perrow mine south of Leesville were operated about the same time. Mining at the Saunders and Lucas mines was carried on by a Robert Wood, who is credited with other manganese mining operations in the region during the eighties and nineties.

The record of mining operations and production for the period 1889–1894 is very poor, but it is known that the Bishop and Leets mines were worked during some of these years. The production records from 1895 to 1905 have been preserved[4] and show that ore was produced from the Saunders mine, Piedmont or Lerner mine, W. R. Wood mine near Evington,[5] and the Pittsville Mining Co., near Pittsville, Pittsylvania County. Apparently, the Leets mine was not operated during these years.

From 1903 or 1904 until 1907 the Saunders mine was operated by the National Paint and Manganese Co., and the ore was ground at the company's plant in Lynchburg for use as a pigment in paint and brick and as a decolorizing agent in glass. This company is still active and purchases most of the local ores; the company has not operated any mines for many years. No record is available for the production from 1906 to 1910, but it is known that the Piedmont (Campbell County) and Saunders mines were active during much of this period. The Theresa mine was worked in 1908.

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[3] The Davis mine is thought to be the same as the Simpson mine.
[4] U. S. Bureau of Mines, unpublished records.
[5] This is probably the Mortimer mine, which has been called the Wood mine in the past.

The period from 1911 to 1918 was one of the most active and productive in the history of mining in the district; ore was produced from at least 15 mines, most of which were in Campbell County, two were in Nelson County, and one was in Pittsylvania County. The principal producer during these years was the Piedmont or Lerner mine, which was worked by several different operators between 1911 and 1918. Other producing mines of importance were the Mortimer and Pribble mines, worked by the Virginia Ores Corporation; the Theresa mine, operated by John B. Guernsey and Co., Inc.; and the Saunders mine. Production from the rest of the mines in the district was small and averaged considerably less than 100 tons per mine.

Manganese mining evidently ceased altogether following the drop in the price of ore at the close of World War I; no production is recorded from the district for the year 1920. From 1921 to 1926 a small amount of ore was produced, mainly from the adjoining Saunders and Wood properties near Evington, by small hand operations conducted by local lessees who sold the washed ore to the National Paint and Manganese Co. in Lynchburg. There seems to have been no production from 1927 to 1929. Small scale production at the Saunders mine was resumed in 1930, and has been intermittent since then. In 1933, the Leets or Mount Athos mine was reopened by the Southern Mines and Metals Co., Inc., after about 40 years of inactivity and was worked until 1935 when the shaft was destroyed by fire.

Interest in the manganese deposits of the region was revived in the late thirties, as in manganese districts in other parts of the country, and more than 25 different deposits were worked or prospected until the close of World War II in 1945. Production, however, during the period 1937 to 1945 amounted to only 993 tons from about 20 deposits, compared to the 1930–35 production of 1,035 tons, or the 1911–1918 production of 7,607 tons. The more ambitious operations were those conducted by the Otter River Mining Co. on a group of properties near Altavista from 1937 to 1943, and work done at the Stonewall mine, Appomattox County, by several different operators from 1937 until late 1941. The combined production from the Bell and Saunders mines probably amounted to nearly as much as the combined production of the Stonewall mine and the Otter River Mining Co., although operations at the Bell and Saunders mines were crude and the ore was washed by hand. Production from other mines was very small; work was done on a small scale with shallow workings and inexperienced labor and supervision. Part of the ore mined in the district during this period was sold to the National Paint and Manganese Co. at Lynchburg, and the remainder was sold to E. J. Lavino Co., Reusens (near Lynchburg), manufacturers of ferromanganese.

The production records for manganese ore from this district are incomplete, and the total amount produced is not accurately known.

The official recorded production is 26,107 long tons, but it is probable that the total quantity of washed ore produced is twice as large as this figure. Recorded production of washed ore from the district since 1868 is summarized in table 3; this information has been compiled from official records of the U. S. Geological Survey, the U. S. Bureau of Mines, the Virginia Geological Survey, and purchase records of the National Paint and Manganese Co. The record from 1911 through 1945 appears to be complete, but records are not available for 20 of the 43 years from 1868 through 1910. According to statements in the literature, production from the Piedmont and Saunders mines was larger than the amounts listed in available official records. Hewett (1916, p. 50) states that the total yield of the Piedmont mine is reported to be about 30,000 tons of washed ore; since the recorded production from the mine amounts to 9,350 long tons, it is possible that the unrecorded production is about 20,000 tons. Watson (1907b, p. 241) said that the total output of the Saunders mine up to 1907 was between 6,000 and 7,000 tons of ore; the recorded production through 1905 was 2,453 tons, so the unrecorded production may be about 4,000 tons. The production of other mines brings the production for the district to an estimated total of 52,779 long tons of washed ore (including recorded and unrecorded production). Over 90 percent of the manganese ore produced in the district has come from six mines; arranged in order of production, they are as follows: Piedmont or Myers (the largest producer), Saunders, Cabell, Leets, Bugley, and Simpson mines.

TABLE 3.—*Recorded production of manganese ore* [1] *from the James River-Roanoke River district*

Period	Washed ore (long tons)	Principal producing mines
1868–69	7,000	Cabell, Bugley.
1870	(2)	
1880–88	2,459	Leets, Simpson.
1889–92	(2)	Small production from Leets mine in 1889–90.
1893	700	Record for Bishop mine only.
1894	(2)	
1895–1905	[3] 5,953	Piedmont, Saunders, Wood.
1906–10	(2)	The Piedmont, Theresa, and Saunders mines were operated during part or all of this period.
1911–14	4,185	Piedmont.
1915–19	[4] 3,463	Piedmont, Saunders.
1920	(5)	
1921–26	319	Saunders, Wood.
1927–29	(5)	
1930–35	1,035	Leets, Saunders.
1936	(5)	
1937–39	484	Stonewall, Otter River Mining Co., Saunders.
1940–45	509	Stonewall, Saunders, Bell.
Total 1868–1945	26,107	

[1] Manganese ore was defined prior to 1917 as containing more than 40 percent Mn, and since then as containing more than 35 percent Mn.
[2] No record.
[3] Includes 177 long tons from Pittsylvania County.
[4] Includes 11 long tons from Pittsylvania County.
[5] No production ?.

Production of manganiferous iron ore in the district is known only for Campbell County for the years 1916 through 1918 and is given in table 4. The unrecorded production of manganiferous iron ore from manganese mining operations is probably quite small; there is no way of estimating the amount of this ore produced or its grade.

TABLE 4.—*Recorded production of manganiferous iron ore from Campbell County, Va.*

Year	Washed ore (long tons)	Manganese (percent)
1916	30	15-40
1917	561	10-35
1918	150	10-35

PROSPECTING, MINING, AND MILLING METHODS

Practically all of the manganese ore mined in the district has been of the nodular or lump type which consists of coherent nodules or rounded lumps of relatively hard manganese oxides embedded in a matrix of clay or soft clayey rock residuum. This ore has been mined in preference to the other kinds of manganiferous material because the manganese oxide lumps can readily be recovered from the mine dirt by simply washing away the clay, and the resulting "washed ore" or "concentrate" is generally a merchantable product containing at least 40 percent manganese. However, the other types of manganiferous material are not amenable to treatment by the washing methods. The friable manganese oxides and the soft, fine-grained material in the wad ores are washed away with the clay in the washing processes; in material containing abundant silica interspersed with manganese oxides (as manganiferous chert, quartzite with disseminated manganese oxides, and brecciated quartzite or vein quartz cemented by manganese oxides), the washing process will not remove the interlocked silica, and the resulting product may contain no more than 20 or 30 percent manganese.

Naturally, prospecting and mining methods have been influenced by the characteristics of the deposits of nodular ores. These are usually steeply dipping lenses of clay containing manganese oxide lumps; the wall rocks too are commonly decomposed and soft. The soft nature of the ore and wall rock permits prospecting and small-scale mining to be carried on at moderate depths with simple tools and procedures (using pick and shovel, hand windlass, etc.). The lump ore can easily be separated from the mine dirt by washing away the clay with a stream of water. A nearby market for local manganese ores within 40 miles has existed for many years at the National Paint and Manganese Co., Lynchburg, and the E. J. Lavino furnace (makers of ferromanganese) at Reusens, a few miles up river from

Lynchburg. As a result, it has been possible to mine, wash the ore, and sell on a small scale, without the necessity of a large capital investment to start and maintain the operation. Many of the manganese mines and prospects in the region have been small enterprises worked by a few individuals with modest equipment; however, total production from these small and crude operations has been small (less than 10 percent of the district total).

The practices followed in prospecting, mining, and milling the ore are described below. Prospecting has been done mainly by sinking pits or driving tunnels at places where float of manganese oxides appeared on the surface. The manganiferous zones are usually prospected along the strike by a series of pits, which may be enlarged into mine workings where ore is discovered and followed downward or laterally. Trenches dug normal to the strike at intervals of 100 feet or more along the manganiferous zone were used extensively as a means of prospecting by the Otter River Mining Co.; some thousands of feet of trenches were dug by a ditch digging machine, and by hand. A bulldozer was used for trenching by the Bureau of Mines in some of its exploration in the district. Trenches that are 5 to 6 feet deep are generally deep enough to give good exposures of the saprolite in place except on some of the steeper slopes where the cover of transported red clay and soil extends to greater depths. The only type of prospect drilling known to have been tried in the area has been diamond drilling; most of the drilling was done by the Bureau of Mines. Core recovery in the manganiferous clay and other rock residuum has been very poor, and this method of drilling has not proved to be satisfactory.

Because the ore-bearing clay lenses dip steeply, nearly all of the mining has been done underground. Open-pit work has been done at only a few places, at the Cabell and Bugley mines where considerable ore was mined from shallow cuts, and at the Pribble mine where the manganiferous zone was exposed in long open-cuts. Most of the shafts and underground workings in the region have been less than 100 feet deep because power hoists are needed for deep operations, and pumps are required where workings extend below the ground water table. The deepest mines in the area are the Leets, 312 feet deep, and the Piedmont or Myers mine, about 240 feet deep. The mine workings are usually in soft, decomposed rock, and strong timbering is generally necessary to support the roof. Proper timbering has seldom been done, however, and because of the poor support the workings have quickly caved. The Oxford shaft in the marble footwall of the Piedmont deposit is one of the few shafts that have been put down in solid rock.

The simplest method used to wash away the soft clay from the lump oxides has been to spread the mine dirt out on a wooden platform and rake it back and forth while washing it with a stream of water; any large pieces of quartz or rock are picked out by hand. It is reported that a small concrete mixer was used successfully by the Virginia-Wisconsin Manganese Co. to wash the ore at the Stonewall mine. The most elaborate treatment plant in recent years was installed at the Stonewall mine by the Stonewall Mining Co.; it consisted of log washers (to remove clay), screens (to size the washed material), and jigs (to separate pieces of quartz and rock from the manganese oxides).

Methods of treating the other types of manganiferous material by processes other than washing have not received much attention until recently. It is understood that experiments have been made since 1945 by the Myers Chemical Co. of Lynchburg to extract manganese from the wad ores of the Piedmont or Myers mine by sulfuric acid leaching, followed by evaporation of the leach liquor to precipitate manganese sulfate. Beneficiation tests of the samples of wad ore taken in 1952 for the Defense Materials Procurement Agency are still in progress (March 1954).

DESCRIPTIONS OF MINES AND PROSPECTS

NELSON COUNTY

The principal deposits of manganese in Nelson County are near Warminster, about midway between the Rockfish River and the Buffalo River. The manganese deposits are associated with the quartzite member of the Mount Athos formation which is enclosed in fissile chlorite-muscovite schists. The quartzite is rather conglomeratic and highly sheared; it is commonly weathered to fine micaceous sand. Marble interbedded with the quartzite is exposed at the northern end of the belt near Rockfish River and was found in the northernmost mine opening; marble has not been found in the quartzite at the various Nelson County mines and prospects farther south, but possibly it exists below the limits of weathering. Mining and prospecting have been done at different places for a distance of about four miles along the strike of the quartzite bed. The principal mines from northeast to southwest are the Piedmont, Cabell, Bugley, and Simpson mines; they are discussed in detail below. These mines were active between 1868 and 1887, when eight or nine thousand tons of washed ore is reported to have been shipped. A little prospecting and mining were done in the county during World Wars I and II. The Cabell and Bugley properties were explored by the Bureau of Mines in 1942.

PIEDMONT

The Piedmont, or Laynesville, mine is located about 1½ miles north of Warminster on property owned by C. D. Larus, Jr. of Richmond, Va. According to A. C. Horsley (oral communication), of Manteo, the first work on this property was done about 1887 by a Mr. Miller.

At a point about half a mile northeast of the Cabell mine, a tunnel was driven, and a shaft was sunk to a depth of about 150 feet (loc. 3, pl. 2). Considerable water was encountered which could not be pumped out satisfactorily, although a 12-inch pump was installed. The mine was closed down after a serious accident killed two of the miners. No ore is reported to have been shipped from the mine at this time. In 1917 a shaft was sunk near the old shaft to a depth of 100 feet by Messrs. Hancock and Bondron, and a drift was run to the old workings. No high-grade ore was found, although 21 tons of low-grade ore was shipped which analyzed 33 percent Mn, 3.6 percent Fe, and 31.8 percent SiO_2. Presumably this was cherty ore of the type occurring on the dump; quartzite and wad are also present on the dump. Two old pits about 10 feet deep (loc. 2, pl. 2) are located a fifth of a mile to the northeast. Rotten quartzite is exposed in the pits, and some chert with nodular manganese oxides is scattered on the dumps. An old water-filled shaft (loc. 1, pl. 2) is located two-fifths of a mile farther northeast; the dump is composed of white to gray dolomitic marble, but no manganese ore is visible.

CABELL

The Cabell mine (loc. 4, pl. 2) lies southwest of the Piedmont mine, about 1½ miles northwest of Warminster, on property owned by A. R. Holladay. It appears to have been the first manganese mine operated in the James River district. During the years 1868–1869, about 5,000 long tons of washed ore is reported to have been shipped from the Cabell mine to England; the mine was closed in 1871 (Weeks, 1886, p. 312). All of this ore presumably came from a large open-cut, about 250 feet long, 130 feet wide, and 30 feet deep (pl. 3). A. C. Horsley, of Manteo, states (oral communication) that in 1917 he shipped four carloads of screenings from the old dumps to the Bethlehem Steel Co. In 1942 the Cabell deposit was explored by the Bureau of Mines by means of trenches, test pits, and a short adit or tunnel.

Much of the manganese ore at the Cabell mine seems to have been contained in a surficial layer of red clay. It is one of the few deposits of this type in the district in which the surficial concentration of manganese oxides was large enough to be mineable. The country rock is quartzite, now thoroughly weathered to loose micaeous sand, that encloses several lenses of chert and clay containing manganese oxide nodules. Two manganiferous chert seams, 3 to 6 feet thick, dip 30 to 40 degrees southeast, and are separated by about 35 feet of quartzite (pl. 3 and fig. 5). Some manganese oxides occur in quartzite in a thin layer just beneath the western chert seam. A short distance east of the open-cut is a caved shaft with considerable manganiferous chert on its dump; the shaft evidently cut one of the cherty seams in depth. On

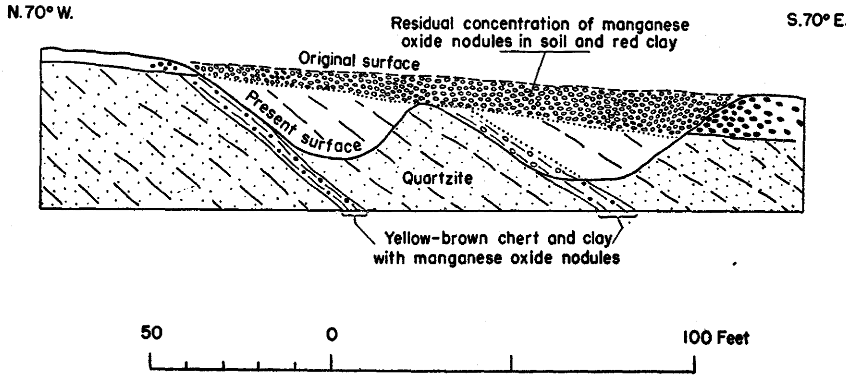

FIGURE 5.—Cross section through open-cut of the Cabell mine (about at right angles to the strike).

the northeast side of the pit, a manganiferous clay seam was followed in the Bureau of Mines adit for a distance of 90 feet. This clay seam, containing scattered nodules of manganese oxides, is 3 to 6 feet thick and has an irregular northeasterly strike with a dip of 35 to 55 degrees southeast. The footwall of the seam is quartzite, now thoroughly rotted, and the hanging wall is a breccia of quartzite blocks in clay; the breccia probably resulted from slumping caused by decomposition of calcareous layers.

Along the eastern side of the pit, a layer of red clay, 8 to 12 feet thick, containing many lumps of hard manganese oxides and blocks of quartzite and vein quartz, rests on decomposed quartzite. This layer of manganiferous red clay extends beyond the open-cut, and has been found in prospect pits and trenches in the vicinity to have a thickness of 1 to 2 feet. The manganese oxide nodules now present in the surficial red clay, as well as the blocks of quartzite and quartz, evidently were released by erosion of the underlying country rock and manganiferous chert and clay seams and accumulated in the surficial red clay mantle. Thus, the manganese oxide nodules originally were deposited by ground waters in the rock residuum, and during erosion of the deposit have accumulated in the surface cover by reason of their high specific gravity and chemical stability.

The account given by Mills (1871)—the first person to work the deposits—coincides with the independent conclusion of the writer that before the start of mining operations the area of the open-cut was covered by a mantle of red clay containing a high concentration of manganese oxide nodules. He says, "Lying on the upper side of the bed proper was a layer of stiff red clay from one to ten or more feet thick, and imbedded in it were large quantities of the ore, some of which was among the best yielded." The supposed conditions before the start of mining are shown in figure 5. If all of the 5,000 tons of washed ore reported to have been produced from the Cabell deposit came from the open-cut, it is evident that the amount of manganese nodules contained in the material extracted from the pit must have been rather large. A rough calculation of the volume of the pit indicates that it would be necessary for the mined material to contain about 20 percent manganese oxide nodules by volume in order to yield 5,000 tons of shipping product. This material in the pit was composed of manganiferous red clay at the surface, and barren quartzite and manganiferous yellow clay, chert, and quartzite in depth. Present exposures in the pit of manganiferous layers in clay, chert, and quartzite indicate that the amount of manganese nodules mined from these layers must have been a rather minor portion of the total material recovered. The probable leanness of the manganiferous layers in the rock residuum is further indicated by the fact that little underground mining of these layers was done by the early miners. Hence, it is concluded that most of the ore was produced from the surficial red clay layer, which must have contained over 20 percent manganese oxide nodules by volume. If this interpretation is correct, the Cabell deposit, and probably the Bugley deposit, represent unusual cases in this district of exceptionally large accumulations of manganese nodules in the surficial clay and soil. The Cabell deposit appears to be nearly mined out now, although the surficial clay layer on the east side of the pit and the manganiferous seams in the bedrock contain minor amounts of ore that could be recovered by small operations.

The area southwest of the open-cut has been prospected for a distance of about 1,000 feet by shallow pits and trenches. Scattered occurrences of manganese oxides were found in the suficial clay and in quartzite; the surficial clay layer averages 1 to 2 feet thick southwest of the open-cut. Less prospecting has been done to the northeast of the open-cut, probably because no float of manganese ore has been found to encourage test pitting.

BUGLEY

The Bugley mine (loc. 5, pl. 2) is located about half a mile southwest of the Cabell mine on land owned by A. R. Holladay (pl. 3). It was operated at about the same time as the Cabell mine and is reported by Weeks (1886, p. 312) to have produced about 2,000 tons of ore. This ore presumably came from the small open-cuts and underground workings (now caved) that lie several hundred yards northwest of the Holladay residence. The Bugley deposit was prospected by trenches and shallow pits by the Bureau of Mines in 1942. Only sporadic showings of nodules of manganese ore in the surficial clay were found.

Manganiferous chert is present in the dumps from the old workings, but it is not exposed in the open-cuts at the present time. The workings appear to have been rather shallow, and it is possible that much of the ore produced from the deposit was contained in the surficial clays, as in the Cabell deposit.

The Bugley deposit is in the same quartzite bed as the Cabell and Piedmont deposits. Mica schist is exposed to the northwest and southeast of the quartzite outcrops. Because of the few exposures, the width of the quartzite cannot be determined accurately, but it probably is about 300 or 400 feet wide. The presence of soluble calcareous layers in the quartzite is suggested by the strongly flowing spring northeast of the mine.

SIMPSON

The Simpson, or Belmont, mine (locs. 6, 7, 8, 9; pl. 2) is roughly 2¼ miles northwest of Midway Mills, and about 1¼ miles southwest of the Bugley mine. The mine was first worked in 1882 and is said by Weeks (1886, p. 312) to have yielded about 1,200 tons of ore, all of which was shipped to Liverpool, England. Weeks also mentions the Davis mine in Nelson County, which is said to have produced about 1,000 tons of ore. The following quotation from a short-lived mining journal (Anonymous, 1882, p. 104) of the eighties indicates that the Davis mine was the same as the Simpson:

> The same company [James B. White and Co. of Pittsburgh, Penn., operators of the Crimora mine] in connection with John Stambaugh of Pittsburgh, has purchased the mineral rights of the Davis mine on the Simpson farm, 2 miles from Midway Mills, Nelson Co., on line of Richmond and Alleghany Railway, where they have already mined some 500 tons and have the very promising mine there in condition for raising some 10 tons daily.

It is not know whether the 1,000 tons of ore reported from the Davis mine is included in the 1,200 tons produced by the Simpson mine.

In 1919 the mine was operated for a short period by the National Paint and Manganese Co. of Lynchburg, and 41 tons of ore was produced. During 1941 and 1942, the deposit was being prospected by the Virginia Manganese Corp. of Richmond, under the direction of L. M. Lee.

During the eighties, a shaft was sunk to a depth of 165 feet (loc. 7, pl. 2) and is reported by Weeks (1886, p. 312) to have encountered a heavy flow of water. The shaft is now caved and inaccessible; two shallow pits lie nearby (fig. 6). The dumps from these workings are composed mostly of waddy material with small slabby pieces of manganese oxides. A tunnel, now caved, was driven southwest toward the shaft, probably for drainage purposes. In some shallow workings (loc. 6, pl. 2) to the northeast of the shaft, nodules of siliceous manganese oxides were found. At the head of a gully about 100 yards south of the shaft, an inclined tunnel was reopened and some drifting was done by the Virginia Manganese Corp. in 1941–42. Folded, sheared quartzite that is now thoroughly rotted is exposed at the tunnel mouth

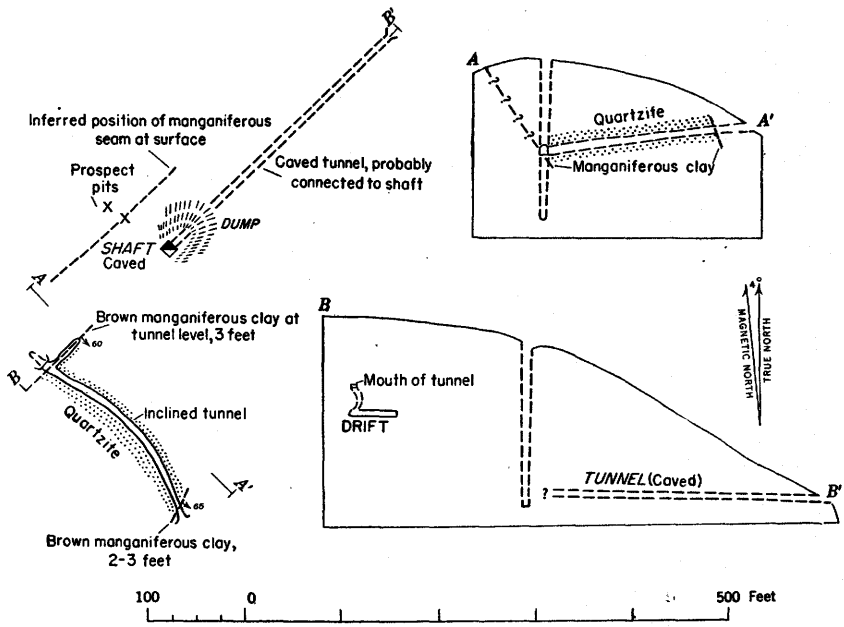

FIGURE 6.—Sketch map and vertical projections of the Simpson mine, Nelson County, Va.

and encloses two seams of dark brown, micaceous waddy clay that strike northeast and dip about 65 degrees southeast. Slabby lenticles of manganese oxides, several inches thick, occur in the westernmost clay seam. The tunnel extends in a northerly direction through about 200 feet of barren, rotten quartzite that is conglomeratic in places. A seam of yellow clay at the face of the tunnel has been followed northeast for about 25 feet. This seam has an average thickness of about 3 feet and dips 60 degrees to the southeast. The clay is of the same type that commonly contains nodular manganese oxides at other mines, but no manganese minerals were seen in this layer.

From the evidence it appears that the Simpson deposit differs from the deposits farther northeast in the same quartzite beds in the following respects: (1) waddy clay with slabby pieces of hard manganese oxide is more abundant at the Simpson deposit, (2) yellow manganiferous chert seems to be absent from the Simpson deposit, and (3) there seems to have been very little accumulation of manganese ore in the surficial red clay at the Simpson deposit.

Within a quarter of a mile southwest of the main Simpson shaft several old prospect pits (loc. 8, pl. 2) have dumps containing scattered pieces of manganese oxides. About a mile southwest along the quartzite ridge from the shaft, and within a distance of 200 yards northeast of U. S. Highway 56, is a group of old caved pits and trenches where manganese oxide minerals occur as thin fracture fillings in quartzite and as nodules. The quartzite is conglomeratic and weathered to loose sand.

A little prospecting has been done along the quartzite ridge ¾ of a mile southwest of U. S. Highway 56, but no manganese minerals are on the dumps. Manganese is not known to occur in the quartzite southwest of the highway.

OTHER PROSPECTS

Two abandoned shallow prospects occur in the southern part of Nelson County. One prospect is an old pit on the quartzite ridge about half a mile southwest of Greenway (loc. 10, pl. 2); siliceous manganese ore is present on the dump. The other prospect is half a mile north of Allen Creek, on the southeast flank of Buck Mountain (loc. 11, pl. 2); several shallow pits revealed chert containing manganese oxide nodules.

AMHERST COUNTY

Although the quartzite member of the Mount Athos formation is rather well-distributed in several belts along the James River in Amherst County (pl. 2), very little manganese ore has been discovered in the county and no production has been recorded. On the other hand, hematitic iron ore was mined from numerous places in the quartzite belts in Amherst County and southern Nelson County during the iron boom of the eighties.

CHRISTIAN PROSPECT AND VICINITY

On the Christian property, about 2 miles northwest of Walker Ford, is a shaft (loc. 12, pl. 2) which is said to have been sunk to a depth of about 60 feet in the late eighties. The shaft caved while being sunk, and a tunnel was started from the gully to the east in order to intersect it; however, local residents state that the tunnel did not reach the shaft. Rotten quartzite is exposed in the road bank near the shaft, but the only signs of manganese oxides consist of pieces of manganiferous brown chert on the dump. Half a mile southwest of the Christian prospect, and on a different quartzite bed about 1,000 feet west of Route 622 (loc. 13, pl. 2), is an old shallow pit with a few scattered pieces of nodular manganese ore.

PROSPECT NEAR GALTS MILLS

On the quartzite ridge, about a mile north of Galts Mills and a mile southwest of Round Top (loc. 14, pl. 2), is a small pit containing pieces of nodular manganese ore and chert. Numerous prospects for specular hematite have been dug in the vicinity.

STAPLETON AREA

Weeks (1886, p. 311) mentions the presence of manganiferous iron ore at Stapleton Mills which gave the following analysis, in percent:

Manganese (Mn)	34.56
Iron (Fe)	22.57
Phosphorus (P)	0.08

The location of this ore was not discovered during the present study. This type of ore would be more likely to be associated with the limonitic iron ores than with the specular hematite ores that have been mined in the neighborhood. About 2 miles northeast of Stapleton on a hill known locally as "Pudding Hill" (loc. 152, pl. 2), are several old opencuts from which limonite was mined. The ore mentioned by Weeks may have come from this locality, although it is not certain that this limonite is manganiferous.

BUCKINGHAM COUNTY

No manganese deposits were recognized during an investigation of the small part of Buckingham County that lies in the James River manganese district; however, manganese ore has been reported to be on the farm of Mrs. W. H. Whalen,[6] 1 mile down the river from Norwood. Watson (1907b, p. 239) mentions the presence of manganese near Willis and Spiers (Spear?) Mountains, which lie to the east of the James River manganese district area shown on plate 1; the nature of these occurrences is not known. A deposit of manganese oxides, said to have been worked in the eighties or nineties, is reported near Curdsville,[7] about 20 miles east of the area shown in plate 1.

APPOMATTOX COUNTY

Manganese deposits occur at various places in the quartzite and marble members of the Mount Athos formation that lie in a belt about 3 miles wide, a short distance east of the James River (pl. 2). Considerable prospecting has been done along this belt, but production amounts to only 327 long tons of washed ore, most of which came from the Stonewall mine during the period 1937–41. Float of nodular manganese oxides and manganiferous chert was discovered in the course of geologic mapping at a number of places in the northern part of the belt where there has been little or no prospecting.

MOORE

The Moore prospect (loc. 15, pl. 2) lies on the east flank of the prominent quartzite ridge known locally as Gowans Hill, about half a mile southwest of the mouth of Wreck Island Creek, on the property of Marvin Moore. Two small prospect pits have been dug in the hillside; the pits are caved and no rock or ore is now visible. A few pieces of nodular manganese ore and numerous large boulders of brown chert containing nodules of manganese oxides are scattered nearby. Mr. Moore (oral communication) states that he has found

[6] Whalen, Mrs. W. H., letter to the Geological Survey, Sept. 14, 1918.
[7] Meadows, B. J., two letters to the Geological Survey, 1933.

float of nodular manganese ore near a bend in Wreck Island Creek, about 2,000 feet northeast of this prospect.

MANGANESE DEPOSITS IN THE VICINITY OF BECKHAM AND GOWANS HILL

Float of nodular manganese ores and brown manganiferous chert were found associated with quartzite at a number of places in the vicinity of Beckham and Gowans Hill. Practically no prospecting has been done in the region.

The westernmost occurrence is on the Nutall estate at the south end of Gowans Hill, where a ledge of quartzite, partly replaced by soft, bluish manganese oxides, is exposed in the bank of a small stream (loc. 16, pl. 2). Some limonitic iron ore was mined nearby years ago, but it is not known whether manganese ore was ever mined.[8]

About a quarter of a mile southeast of Gowans Hill is another belt of quartzite along which float of manganese oxides and chert were found at a number of places in a mile and a half interval between Routes 605 and 623 (locs. 17, 20, and 21; pl. 2). These areas, also on the Nutall estate, have not been prospected. Siliceous manganese oxides are exposed in this same quartzite belt in the bank of Route 623. On the Button property, within a quarter of a mile southwest of Route 623, large pieces of siliceous, nodular manganese oxides and blocks of brown chert are scattered over the ground surface along the same quartzite belt (loc. 22, pl. 2).

Three-quarters of a mile farther southwest along this quartzite ridge, float of nodular manganese ores and ledges of manganiferous chert occur abundantly in the gap cutting through the ridge (fig. 7). The float of nodular ore appears to be confined to an area several hundred feet in diameter on the north side of the gap; no prospecting has been done here (loc. 23, pl. 2). This deposit is said to be on land owned by the Nutall estate. Across the gully to the south is a ledge of yellow-brown chert about 15 feet long and 5 feet wide that contains nodular manganese oxides and fragments of vein quartz (loc. 24, pl. 2). Several shallow pits have been sunk near the chert ledge by Aaron Moore. About 400 feet southwest of this ledge are outcrops of similar manganiferous chert on the nose of the quartzite ridge south of the gap. All these chert outcrops line up in a direction trending N. 75° E. and thus appear to trend across the structure of the quartzite beds, which strike about N. 30° E. at this point. Exposures are insufficient to reveal the structural environment of the chert; it may occur in a fracture cutting across the quartzite beds or it may be in a tight drag fold.

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[8] It is understood from D. G. Myers and J. Carson Adkerson that some prospecting was done in 1953 on the Nutall property, probably at locality 16, pl. 2. It is believed that some manganese ore was shipped from these workings.

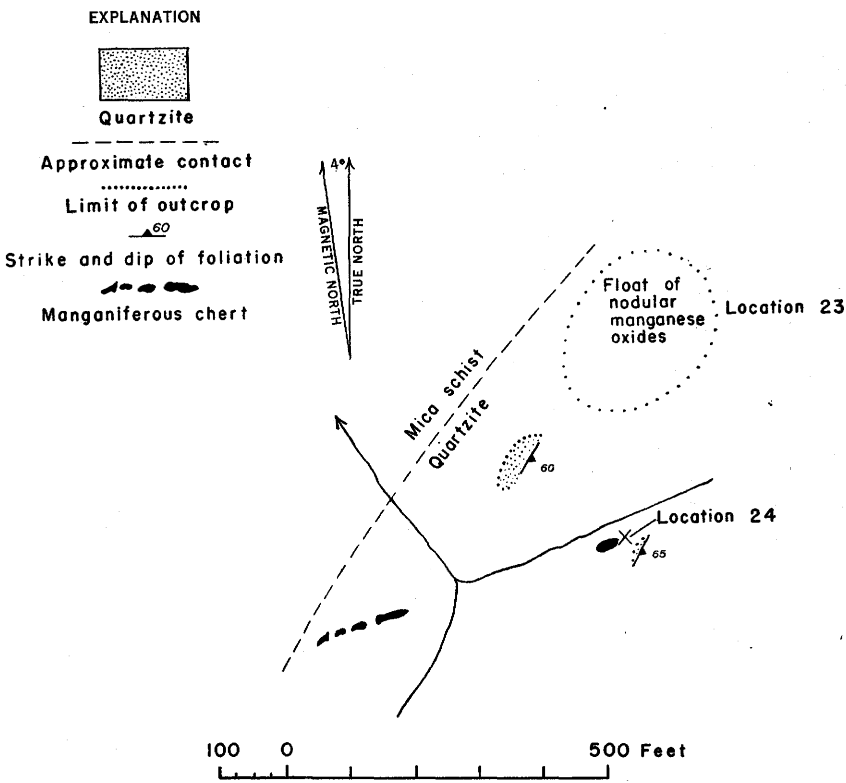

FIGURE 7.—Sketch map of deposit of nodular manganese ore and maganiferous chert on Nutall and Aaron Moore properties, Appomattox County, Va.

In the quartzite belt to the east of the one just discussed, float of nodular manganese ore and brown manganiferous chert were found several hundred yards west of the intersection of Routes 605 and 683 (locs. 18 and 19, pl. 2). No prospecting has been done here. About half a mile southwest of this road intersection are a number of old pits whose dumps have specular hematite and small amounts of manganiferous chert.

SCHOOLHOUSE MINE AND NEARBY PROSPECTS

The Schoolhouse mine (loc. 27, pl. 2) is located at the bend of Route 605, about 800 feet southwest of the intersections of Routes 605 and 667. Three shallow shafts, 20 to 30 feet deep, were sunk at 150-foot intervals along the strike by J. M. Mays during 1938 and 1939. A carload of washed ore (about 35 tons) was shipped, most of which came from the two northernmost shafts. The central shaft is about 20 feet deep, with two short drifts at the bottom, running 2 feet to the southwest and 8 feet to the northeast. Manganese ore occurs as hard, slabby nodules in a zone 1 foot thick at the footwall of a yellow clay seam that is 4 to 5 feet thick and dips steeply southeast.

Rotten quartzite forms the hanging wall of the clay seam, and soft, silvery-green quartz mica-schist, which strikes N. 50° E. and dips 60° SE., lies in the footwall.

An old opencut, 10 feet deep and 20 feet in diameter, occurs about 1,500 feet northeast of the Schoolhouse mine on the next quartzite belt to the west (loc. 25, pl. 2). Rotten, coarse quartzite and mica schist, striking N. 45° E. and dipping 65° SE., and a seam of yellow clay with nodules of siliceous manganese ore are exposed in the pit.

Half a mile northwest of the Schoolhouse mine are two old shallow prospect pits on either side of Route 605 (loc. 26, pl. 2). Pieces of nodular manganese ores and limonite are scattered around the pits. This deposit is in the same belt of quartzite as the Stonewall mine, which lies 3 miles to the southwest.

STONEWALL

The Stonewall mine (loc. 30, pl. 2) is on the quartzite ridge half a mile northwest of Stonewall Creek on property owned by Kern Mays. It is one of the most recently productive mines of the district and was first worked for manganese by J. M. Mays in 1937. The Virginia-Wisconsin Manganese Co. operated the mine during 1938, and in 1939 mining was continued by J. M. Mays. During 1940 and part of 1941 the mine was worked by the Stonewall Mining Co., Inc. of Lynchburg, under the direction of C. W. Ryan. The ore was treated by log washing, screening, and jigging, in a small mill that was erected on Stonewall Creek half a mile from the mine. Mining was stopped and the mill dismantled in the latter part of 1941. The amount of washed ore shipped from the Stonewall mine (including approximately 35 tons shipped by J. M. Mays from the Schoolhouse mine) is listed below:

Year	*Shipper*	*Washed ore (long tons)*
1937	J. M. Mays	30
1938	Virginia-Wisconsin Manganese Co	41
1939	J. M. Mays	75
1940–41	Stonewall Mining Co	150
Total		296

Manganese ore at the Stonewall mine occurs as hard nodules in two seams of yellow clay that strike N. 30° to 40° E. and dip about 70° SE. The principal, or hanging-wall, ore body has been followed by an inclined shaft to a depth of 135 feet below the surface (pl. 4). This ore body has been largely mined out between the surface and the 62 level and has been opened up by the shaft and by small stopes and drifts below the 62 level. The footwall ore body, which lies about 15 feet northwest of the northeast end of the hanging-wall ore body, is smaller and has been mined only above the 35 level.

The hanging wall of the manganiferous clay seams that form the two ore bodies is porous, coarse quartzite (fig. 8), and the footwall is composed of soft, silvery-green mica schist and schistose quartzite. The clay is yellow to brown in color and contains abundant muscovite flakes. Thin stringers of vein quartz are common. The clay is inconspicuously banded by slight color variations and by thin micaceous seams. This layering dips steeply southeast (conformable to the enclosing quartzite and mica schist) and is believed to represent the original bedding or a foliation of calcareous layers which has been decomposed by ground waters. However, no calcareous rocks are exposed in the mine workings.

The manganese oxide nodules have an elongate or slabby shape and occur along the layering of the clay, generally being concentrated in specific layers, as shown in figure 8. Above the clay of the footwall

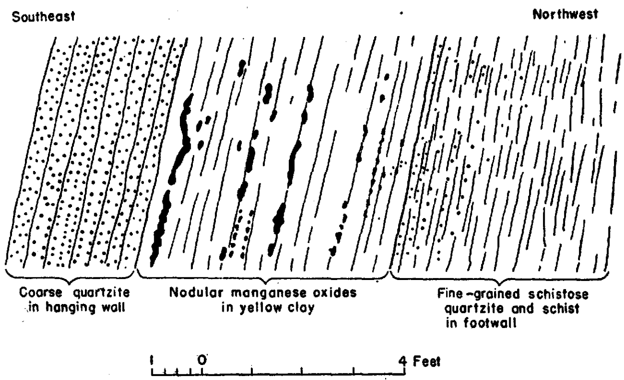

FIGURE 8.—Sketch of southwest face of stope between 62 and 76 levels of the Stonewall mine, Appomattox County, Va.

ore body is a seam of tan, micaceous chert that contains nodular manganese oxides in the same fashion as the clay.

The manganiferous clay seam of the hanging-wall ore body has a length of about 150 feet on the 62 level (pl. 4). The seam ranges from 3 to 5 feet thick for a distance of about 100 feet along its center and pinches down to a thickness of less than a foot at either end. The thickest part of the seam has the highest concentration of nodular ore.

The clay seams of the two ore bodies are thought to be on the same contact of quartzite and mica schist and to owe their present echelon position to tight folds plunging steeply southwest; the interpretation of the structure is shown in plate 4. The features indicating this structure are as follows: The hanging-wall clay seam is underlain by mica schist near its southwestern end (as exposed in the 25-foot long crosscut on the 62 level), but at the northeastern end of the seam 15 feet of quartzite was found in its footwall by the crosscuts on the 35 and 62 levels. The quartzite in these crosscuts appears to be crushed and tightly folded and has lineations plunging steeply southwest. Small tight drag folds in quartzite and schist on the 93 and 130 levels also plunge southwest. The stopes above the 93 level rake to the southwest, and the thin northeastern edge of the hanging-wall ore body was found to be progressively farther southwest on successively deeper levels. These relationships are considered to be strong evidence that the two echelon clay seams represent a single calcareous layer, which was squeezed or sheared out on the limbs of a tight syncline and anticline.

The quartzite-mica schist contact on which the clay seams are localized is probably not the lower contact of the Mount Athos formation, because quartzite is exposed on the surface about 75 feet west of the footwall ore body. The mica schist in the footwall of the ore bodies thus appears to be a schistose layer within the quartzite member of the Mount Athos formation.

The quartzite in the hanging wall of the manganiferous zone has been strongly leached by ground waters; it is now very porous for a horizontal distance of 40 feet from the clay seam on the 62 level. On the 93 level, the clay just beneath the quartzite hanging wall contains blocks of thoroughly rotted quartzite; these quartzite blocks probably slumped into solution cavities and were enveloped by clay as the calcareous layer was decomposed.

The average yield of jig concentrates (washed ore) from the mine dirt or manganiferous clay was found by the Stonewall Mining Co. (Ryan, C. W., personal communication) to be approximately 1 cubic yard of jig concentrates to 15 cubic yards of manganiferous clay; this represents a weight ratio of about 1 to 12. One cubic foot of concentrates was found to weigh 125 pounds and to have a porosity of about 50 percent, thus indicating the nodular ore to have a specific gravity of about 4.

Average analyses of the manganese concentrates shipped from the mine are given below; it will be noted that the ore has a high BaO content. Some platy crystals of barite, light blue in color, were found by one of the miners, but the mode of its occurrence in the deposit is not known.

Analyses of concentrates shipped from the Stonewall mine

	Percent	*Tonnage represented by analysis (long tons)*
Manganese (Mn)	42. 0	247
Iron (Fe)	4. 80	142
Silica (SiO_2)	7. 03	142
Phosphorus (P)	0. 159	101
Moisture (H_2O)	4. 70	101
Barium oxide (BaO)	8. 76	51
Alumina (Al_2O_3)	3. 66	51

The quartzite ridge northeast of the Stonewall mine has been prospected for a distance of about 2,000 feet, by trenches and pits dug by J. M. Mays. In the four pits that were sunk to depths ranging from 10 to 50 feet, yellow manganiferous clay with chert was found in layers 1 to 4 feet thick in decomposed quartzite and mica schist. A cross section of the deepest pit or shaft (loc. 29, pl. 2), 2,000 feet northeast of the Stonewall mine, is shown in figure 9. The trenches were only

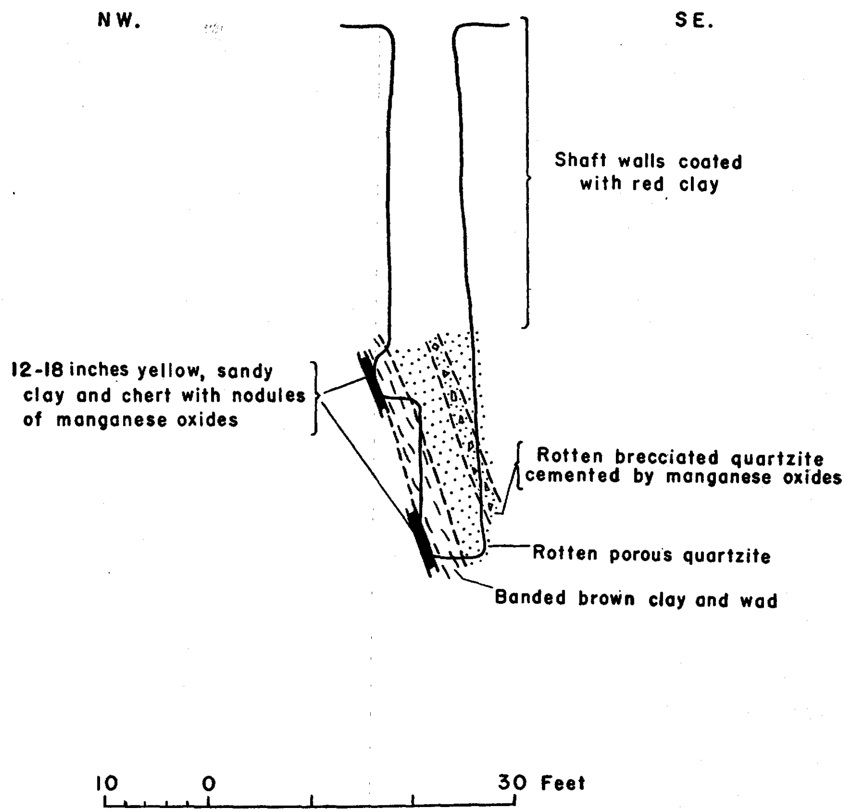

FIGURE 9.—Cross section of prospect shaft (loc. 29, pl. 2) 2,000 feet northeast of the Stonewall mine, Appomattox County, Va.

a few feet deep and did not penetrate through the surficial red clay mantle. Small fragments of hard manganese oxides found in the surficial red clay and on the ground surface indicated that there has been some residual concentration of the hard, resistant manganese oxides at the surface through erosion. This residual concentration has spread the ore fragments away from the steeply dipping manganiferous yellow clay and chert seams from which the fragments were derived, but apparently it has not resulted in large concentration of manganese ore in the surficial clay, as is the case at the Cabell mine in Nelson County.

Several hundred yards southwest of the Stonewall mine manganiferous yellow-brown clay and chert have been found in open-cuts and short tunnels dug by J. M. Mays on either side of Route 613. The manganiferous clay occurs in two distinct zones lying about 200 feet apart (loc. 31, pl. 2); quartzite and biotite-muscovite schist crop out between the two zones.

Limonitic iron ore was mined many years ago from three open-cuts on the contact between quartzite and the graphitic schist member of the Archer Creek formation that lies about 100 yards southeast of the Stonewall mine and the manganese occurrence just described along Route 613.

PROSPECTS SOUTHWEST OF THE STONEWALL

The quartzite belt in which the Stonewall deposit occurs has been prospected for manganese and iron at several places for a distance of about a mile southwest of Route 613. The northernmost working is a shallow open-cut, 150 feet long and 6 feet wide, that was probably worked for its iron deposit many years ago (loc. 169, pl. 2). Blocks of micaceous limonite and some pieces of siliceous manganese oxides are scattered near the pit.

A quarter of a mile farther southwest are three caved shafts in rotten quartzite (loc. 34, pl. 2); small piles of manganese ore and quartzite partly replaced by manganese oxides are heaped on the surface. Farther southwest along the quartzite ridge are several other old shafts and tunnels in which wad and siliceous manganese oxides are exposed (loc. 36, pl. 2). It is not known whether manganese ore was ever shipped from any of these openings.

PROSPECTS IN AND SOUTHWEST OF STONEWALL CREEK VALLEY

The belt of quartzite along the east side of Stonewall Creek valley and the valley to the southwest has been prospected for manganese at about half a dozen places in a distance of about a mile and a half. On the bank of Stonewall Creek, a short distance south of the former site of the Stonewall washing mill on Route 613, a shallow pit has exposed rotten quartzite with two seams of wad, 4 feet and 5 feet thick, and another zone, 4 feet thick, in which thin-bedded quartzite is veined and partly replaced along the cleavage and joints by a network of thin (one-eighth to half an inch in thickness) seams of soft, bluish manganese oxides (loc. 32, pl. 2). Another prospect pit has been sunk approximately 500 feet northeast of the road. The prospect pits along the valley southwest of Route 613 contained some hard manganese oxides and wad (locs. 35 and 37, pl. 2). No ore has been shipped from any of the prospects on this quartzite belt as far as can be determined by the writer.

HANCOCK-FERGUSON

The quartzite belt a quarter of a mile northwest of the Stonewall mine ridge forms the ridge known as Chestnut Mountain. The Hancock-Ferguson mine (loc. 33, pl. 2) is on this ridge about 2,000 feet southwest of Route 613. Two shallow shafts about 60 feet apart were sunk here in 1940 by L. C. Hancock of Lynchburg and W. Ferguson, and about 6 tons of washed ore was shipped. The southernmost shaft was sunk to a depth of about 45 feet through rotten quartzite and quartz-mica schist. In the east wall of the shaft the quartzite is greatly brecciated, which is probably due to slumping into solution cavities. Soft, bluish manganese oxides and clay form the matrix of the breccia rubble, and the quartzite blocks are partly veined and replaced by manganese oxide seams. A trench dug about 800 feet southwest of the shaft exposed red clay and rotten quartzite with some narrow seams of manganese oxides.

CHESTNUT MOUNTAIN

About 1930 some prospecting was done farther southwest along Chestnut Mountain by John W. Woodson of Lynchburg. Two shafts were sunk, one on the knob (loc. 39, pl. 2) and the other on the saddle northeast of the knob; one of the shafts is estimated to be about 90 feet deep. Porous quartzite, with soft, bluish manganese oxides, abundantly disseminated throughout, and some wad were discovered in these shafts. This type of siliceous manganese ore or manganiferous quartzite evidently represents replacement of quartzite by manganese oxides. Considerable float of the siliceous manganese ore is scattered along the east face of the knob. Two shallow pits, which were found to contain soft, bluish manganese oxides, were dug about half a mile southwest along the ridge from the knob (loc. 40, pl. 2). An opencut near the southwestern end of Chestnut Mountain, dug years ago for iron ore, exposed siliceous specular hematite.

Analyses of selected samples of manganese ore from the Woodson prospects are quoted by Furcron (1935, p. 107) from an unpublished report by E. E. Barnard and C. W. Ryan, of Lynchburg, in regard to an examination of the property in 1930. These analyses (Nos. 1 to 3) are repeated below, together with a new analysis of the siliceous ore (No. 4):

Analyses of manganese ore, in percent, from Woodson prospects, Chestnut Mountain, Appomattox County, Va.

	1	2	3	4
Manganese (Mn)	42.05	11.63	21.29	21.0
Iron (Fe)	1.44	29.31	4.35	3.8
Phosphorus (P)	.254	.214	.122	----------
Silica (SiO_2)	8.00	29.04	41.80	----------
Insoluble (SiO_2, etc.)	----------	----------	----------	55.7

1. A picked sample of high grade ore from vein near surface. W. W. Cash, Jr. (Lavino Furnace, Lynchburg), Analyst.
2. A typical sample of wad from the footwall of the vein. W. W. Cash, Jr. (Lavino Furnace, Lynchburg), Analyst.
3. An average sample of the replaced quartz-mica wall. W. W. Cash, Jr. (Lavino Furnace, Lynchburg), Analyst.
4. Sample of siliceous ore (similar to number 3) collected by G. H. Espenshade and R. A. Lindblom, Analyzed by Bureau of Mines.

BILL FERGUSON

The Bill Ferguson mine (loc. 28, pl. 2) is on the quartzite ridge west of Chestnut Mountain and bordering on the James River, about a mile north of the Stonewall mine. The deposit was opened with shallow workings in 1941 and about 25 tons of washed ore is said to have been shipped. Two shafts, about 30 feet apart, were sunk to depths of 30 feet and the ground between the shafts was partly mined. Nodular manganese oxides occur in a seam of yellow clay that is 2 to 3 feet thick and is bordered on the northwest by a layer of rotten mica schist 2 feet thick.

The clay and schist seams are enclosed on both walls by rotten quartzite, whose cleavage strikes N. 35° E., dips nearly vertically, and has a strong lineation that plunges 45° SW. Surficial red clay with pieces of hard manganese oxides is exposed in the upper part of the workings. Wad and soft, bluish manganese oxides were found in two shallow pits dug in the same quartzite belt about 1,500 feet to the northeast. Two old pits are located several hundred feet southwest of the Bill Ferguson mine; considerable limonite and brown chert are scattered nearby.

G. CABELL PROPERTY

A mile and a half southwest of the Bill Ferguson mine, float of hard manganese oxides is found in the same quartzite belt on the G. Cabell property (loc. 38, pl. 2).

CAMPBELL COUNTY

The belt of manganese deposits extends southwestward through Campbell County for a distance of about 30 miles from the Appomattox County line east of Lynchburg to Altavista and Leesville on the Roanoke River. Manganese mining and prospecting has been far more active in Campbell County than elsewhere in the district. The first recorded production in the county was from the Leets mine, near Mount Athos, in 1880 (Weeks, 1886, p. 310–311). The Campbell

County mines have produced over 40,000 long tons of washed ore, or more than 80 percent of the total production of the district. About 30,000 tons was shipped from the Piedmont mine; other large producers have been the Saunders mine and the Leets mine. The rest of the county's production has been from a dozen or so smaller mines, of which only four—the Theresa, Mortimer, Bishop, and Lucas—are known to have shipped over 500 tons of ore. There was considerable prospecting activity in the county just before and during World War II; the operation of the Otter River Mining Co. on a group of properties near Lynch was one of the more ambitious enterprises. During 1942–1943, the Piedmont, Bell, Mortimer, Russell Den Hollow, and Saunders mines were explored by the Bureau of Mines.

Two of the Campbell County mines have the distinction of being the deepest mines in the district; the Leets mine reached a depth of 312 feet before it was closed in 1935, and the Piedmont mine workings extended to about 240 feet below the surface when shut down in 1918. The ore extracted from the other mines came from workings at shallow depths; few were more than 100 feet deep.

JOSHUA CREEK

The quartzite belt extending southwest from Chestnut Mountain was prospected many years ago on either side of Joshua Creek (loc. 42, pl. 2). On the northeastern side of the creek can be seen an open-cut and a tunnel with dumps containing slabby pieces of manganese ore and quartzite that is veined and partly replaced by manganese oxides; no nodular ores were seen. The dumps were partly reworked by screening in 1941, and about a carload of ore was shipped. The other prospect, a caved shaft, is on the ridge 1,000 feet southwest of Joshua Creek; a few pieces of manganese ore are scattered nearby.

MOUNT ATHOS

Two caved shafts, about 100 feet apart, are located on the crest of Mount Athos midway between Joshua Creek and Slippery Creek (loc. 43, pl. 2). Thin stringers of soft, bluish manganese oxides occur in a zone about 10 feet thick of red clay and rotten quartzite. Blocks of yellow-brown chert with nodular manganese oxides are present on the dumps.

PROSPECTS BETWEEN JOSHUA CREEK MINE AND OLD TAVERN PROSPECT

A small amount of shallow prospecting has been done on the two quartzite belts between the Joshua Creek mine and the Old Tavern prospect, located 2 miles to the south (locs. 44 and 46, pl. 2). Wad and a small amount of nodular ore were found at the northern prospect; wad appears to be the principal manganese mineral at the southern prospect.

OLD TAVERN

Two shafts, now caved, were sunk about 1915 near the old tavern at the bend in the old Richmond-Lynchburg stagecoach road (loc. 48, pl. 2). Rotten quartzite, red clay, and micaceous wad occur on the dumps, and quartzite is exposed in one of the shafts. There is no record that any ore was ever shipped. The same quartzite ridge has been prospected at two places (locs. 45 and 47, pl. 2) between the Old Tavern mine and the county line, about a mile to the northeast. The two large open-cuts near the county line are said to have been dug about 1900. Wad is the predominant manganese mineral present at all these prospects.

RYAN

Some prospecting for manganese was done in 1930 and 1931 by J. D. Ryan at a point about half a mile south of the Old Tavern prospect and half a mile northeast of Archer Creek (loc. 49, pl. 2). Three shafts had been put down many years before in a search for iron ore. Ryan sank his southernmost shaft to a depth of 85 feet in a clay seam with quartzite walls. Bluish, siliceous manganese oxides, quartzite, yellow-brown chert, and specular hematite, are present on the dumps. Manganese minerals were encountered in the clay at a depth of 40 feet according to Mr. Ryan's son (oral communication); the ore shoot appeared to plunge southwest, and was followed by an incline for 25 feet. The other shaft sunk by Ryan is about 100 yards to the northeast and is said to have reached a depth of 65 feet; siliceous manganese ore also occurs on the dump of this shaft.

LEETS

The Leets mine (also known as the Whitman, Mount Athos, or Smithson mine) is located on the nose of a hill overlooking Archer Creek, about 1¼ miles upstream from its mouth (loc. 50, pl. 2). The property is owned by J. B. Trent of Lynchburg. The mine was worked as early as 1880, and may possibly have been worked before that date. Britton (1881) described operations at a manganese mine "three or four hundred yards south of the Norfolk and Western R.R." near Mount Athos; this description very probably refers to the Leets mine. The mine was being worked by two drifts in the hillside at that time. The recorded production from 1880 to 1888 was 1,216 tons, but the total production at this time may have been larger because Weeks (1885, p. 310) states: ". . . next to the Crimora mine (which had produced some 50,000 tons of ore up to 1885) this Mount Athos mine yielded the largest amount of high-grade manganese of any mine in the country." Operations at the mine were apparently discontinued during the late eighties or early nineties. The Leets mine seems to have been idle until 1933 when it was reopened by Mr. Smithson of the

Southern Mines and Metals Co., Inc. and operated until 1935, when the shafts and buildings were destroyed by fire. A shaft was sunk to a depth of 312 feet, about 185 feet below the elevation of Archer Creek mine, or about 120 feet below the level of the James River (fig. 10).

Most of the ore mined by Smithson was taken out between 200 and 230 feet below the surface. The recorded production during this period of operation is 975 long tons of washed ore.

Analyses of some of the ore shipped from the Leets mine by the Southern Mines and Metal Co. to the National Paint and Manganese Co. of Lynchburg are given below:

Analyses of manganese ore shipped from Leets mine, 1933–35

	Percent	Tonnage represented by analysis (long tons)
Manganese (Mn)	45.2	412
Iron (Fe)	5.0	370
Silica (SiO_2)	11.8	370

The mine workings are now caved and inaccessible and little can be seen of the mode of occurrence of the ore. On the northwest wall of the open-cut by the main shaft, coarse quartzite is exposed with a rolling structure that strikes N. 30°–60° E. and dips vertically (fig. 10).

The Leets mine was visited several times by D. F. Hewett of the Geological Survey during its operation by Smithson. Hewett observed that manganese oxide nodules occurred in seams of micaceous clay enclosed in quartzite in the lower part of the mine. The following description and map (fig. 11) of the geology on the lowest level, the 300-foot level, are taken from Hewett's field notes (1934).

The country rock on the 300-foot level is feldspathic quartzite with zones of chlorite schist 1 foot thick. The quartzite strikes N. 20°–30° E., and dips 80°–90° SE. It has a persistent parting and breaks into slabs 3 to 12 inches thick. On the lower levels it is coherent but breaks into sand after exposure in the mine workings. No marble was found in the mine, although blue marble is exposed in Archer Creek about 500 feet northwest and 400 feet southeast of the tunnel mouth. On the 300-foot level there are four ore zones in which manganese oxides occur as streaks and slabs in micaceous clay. The main ore zone, 15 to 20 feet thick, is the farthest to the southeast. This zone yielded the ore in the upper part of the mine and was explored to a depth of 230 feet. The middle two zones are thin seams of clay and sand and contain little ore. The northwestern zone was in timbered ground at the time of Hewett's visit, and he was unable to verify the mine operator's report that it contained manganese oxides. The main

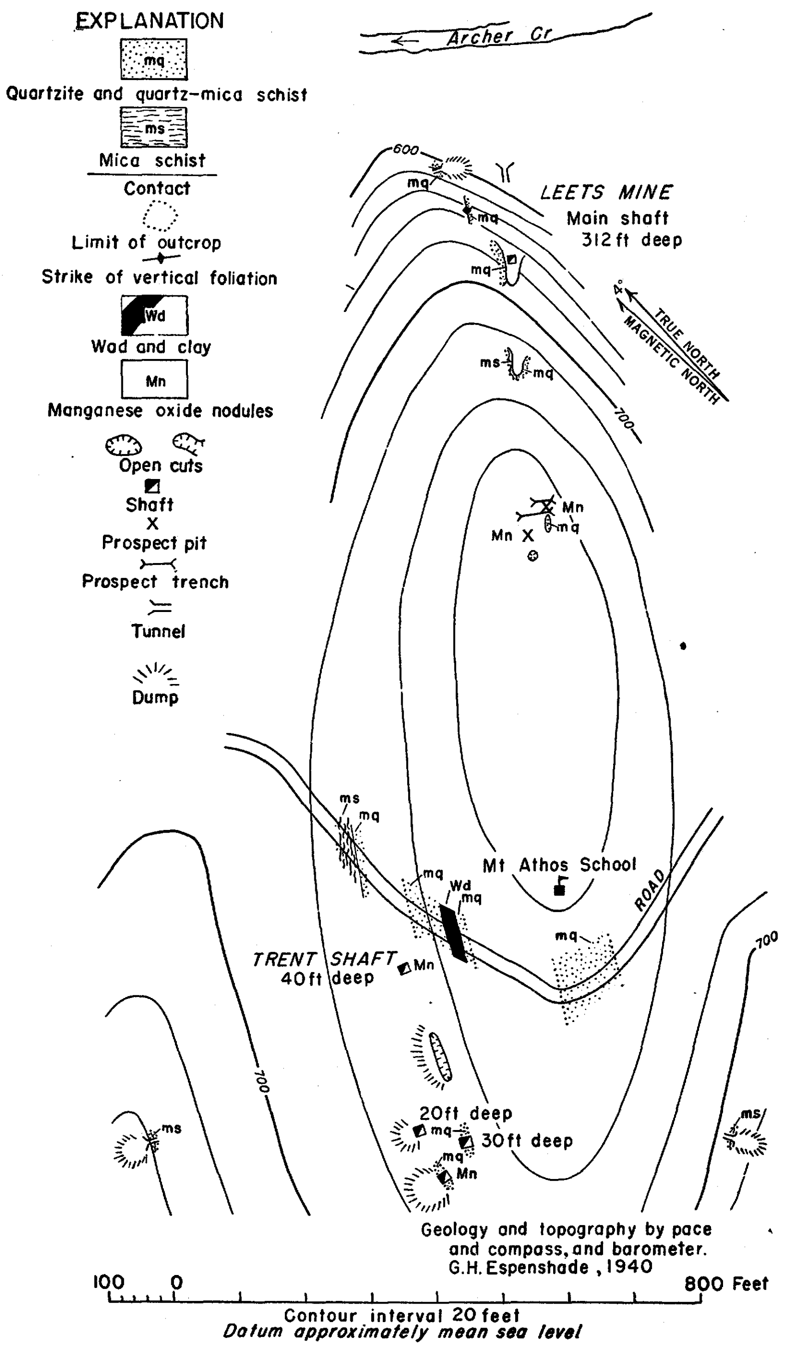

FIGURE 10.—Geologic map of the Leets mine area, Campbell County, Va.

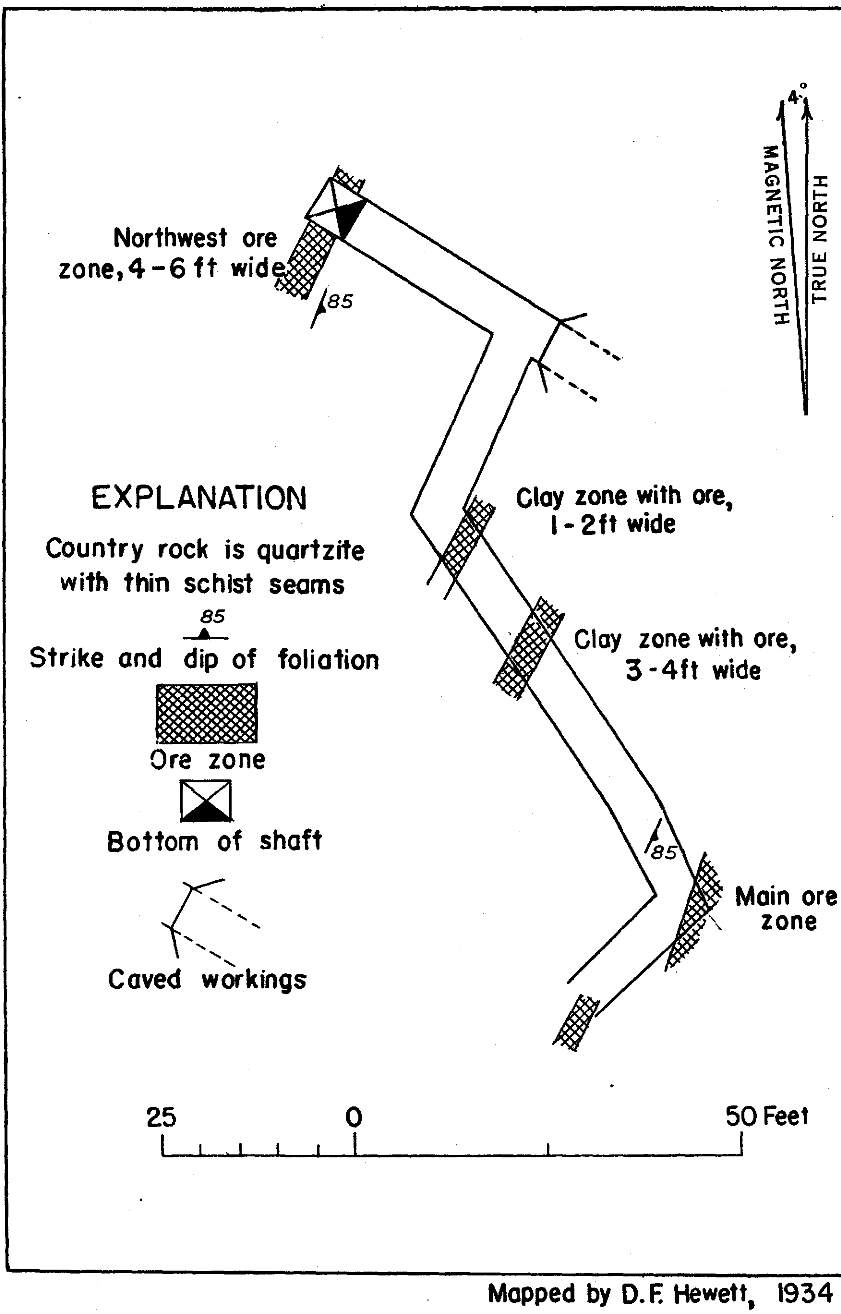

FIGURE 11.—Map of the 300-foot level of the Leets mine, Campbell County, Va.

ore zone and the fractured quartzite yielded a strong flow of water. The ground was very heavy and required close timbering.

The manganese ore on the 300-foot level of the Leets mine, 120 feet below the level of the James River, is the deepest occurrence of manganese oxides known in the district. Because it is believed that the ground-water table at the time the ore deposit was formed was considerably higher relative to the present outcrop of the deposit than is the present table, it appears that ground water solutions must have descended along permeable channelways to depths of several hundred feet below the table (Hewett, 1935).

The quartzite containing the Leets deposit cannot be traced to the northeast of Archer Creek, and it is probable that this quartzite bed is cut out to the northeast by faulting (pl. 1). A few shallow prospects have been dug on the ridge between the main shaft and the Mt. Athos schoolhouse to the southwest (fig. 10). In the road cut near the schoolhouse, several zones of red clay and wad in rotten quartzite and quartzite conglomerate are exposed. Four old caved shafts and an open-cut (loc. 51, pl. 2) are located several hundred feet southwest of the road. Rotten quartzite is exposed in two of the shafts, and some pieces of nodular manganese oxides are scattered on the dump. Considerable work was done here in former years, but it is not known whether any ore was produced. In the gully to the northwest, a tunnel has been driven southeast toward the ridge, and another tunnel driven northwest from the gully on the southeastern side of the ridge. Neither of these tunnels seems to have cut the ore zone. During 1941 a shaft was sunk by J. B. Trent to a depth of about 40 feet just south of the schoolhouse road. Yellow, micaceous clay with some nodular manganese oxides was found, but the manganese content appears to have been small.

A shallow prospect pit on the same belt of quartzite, about 2,000 feet southwest of these diggings and just north of U. S. Highway 460 (loc. 54, pl. 2) has exposed brecciated quartzite and vein quartz cemented by manganese oxides. The quartzite ridge, lying 1,000 feet to the east of the Leets mine, has also been prospected for manganese by shallow pits at several places (locs. 52 and 53, pl. 2), and some manganese oxides and limonite have been discovered.

DRINKARD AND NEARBY PROSPECTS

The Drinkard (Hebert) prospect (loc. 60, pl. 2) lies on the same quartzite belt as the Leets deposit, about ¾ of a mile southwest of U. S. Highway 460, on property owned by L. W. Drinkard. It was prospected during 1940–41 by J. D. Hebert of Roanoke, Virginia, who sank a shaft to a depth of 43 feet and dug several shallow trenches. The shaft opened up a seam about 5 feet thick of yellow and red clay containing hard manganese oxides, wad, and limonite. The clay seam strikes N. 30° E., dips 85° SE., and is enclosed in decomposed, micaceous quartzite.

About 200 yards southwest of the Hebert shaft is a group of three old prospects pits showing quartzite partly replaced by manganese oxides. In an old shallow digging 2,000 feet northeast of the Hebert shaft porous quartzite containing brown manganese oxides is exposed (loc. 59, pl. 2). On the next belt of quartzite to the east, several shallow shafts dug many years ago exposed quartzite partly replaced by manganese oxides, and brecciated vein quartz cemented by iron and manganese oxides (loc. 61, pl. 2). Two caved pits are located about ¾ of a mile west of the Hebert shaft in the belt of quartzite that forms the Mount Athos ridge (loc. 58, pl. 2); no manganese minerals are visible on the dumps.

PIEDMONT

The Piedmont mine (loc. 57, pl. 3), also called the Lerner or Myers mine, is on the flanks of a low hill between Little Beaver Creek and U. S. Highway 460, about 10 miles east of Lynchburg. Iron ore was mined from a number of pits near here during the 19th century and was smelted at the old Oxford iron furnace on Beaver Creek about half a mile north of the mine. The mining and prospecting for iron ore apparently led to the discovery of the manganese deposits, which were mined from about 1890 to 1918. D. F. Hewett (1916, p. 49–54) examined the mine in 1914 and 1915 and gives the following account of the history of operations:

> Manganese was first mined here in the early nineties by the Lerner Mining Co. from pits near the Josephine shaft. From 1902 to 1912, under the ownership of the Piedmont Manganese Co., ore was drawn from the Josephine shaft to a depth of 105 feet, but the most vigorous development took place from 1912 to 1914. During this period the lessee, the Piedmont Manganese Corporation of New York, built a narrow-gage tramway from the mill to the Chesapeake & Ohio Railway, extracted ore to a depth of 150 feet from the Josephine shaft, and sank the new Oxford shaft 190 feet deep. The Oxford Mining and Manganese Co. sank the Oxford shaft to 208 feet in 1915 and mined ore to that level. The present owner is sinking the same shaft with the intention of mining the deeper ores. It is reported that the total yield from the Josephine shaft between the 105- and 190-foot levels was 5,052 tons, and the total production from all workings on the hill about 30,000 tons of washed ore.

Several other shafts and tunnels had been dug in the manganiferous zone to the northeast of the main ore body prior to Hewett's examination (pl. 5).

Since then, the main ore body has been mined to a depth of 10 or 15 feet below the 208 level. D. G. Myers, present owner of the property, reports that a winze was sunk 25 feet below this mined portion and was still in ore. A shaft was also sunk 1,500 feet northeast of the Oxford shaft from which some pyrolusite is said to have been mined (loc. 56, pl. 2). In 1918 the property was explored by diamond drilling by the Bethlehem Steel Co. Mining operations were suspended the same year as a result of decline in the price of manganese, and the mine was inactive from then until 1945 or 1946 when the Myers Chemical Co. started mining wad (probably from near loc. 56) for the manufacture of manganese sulfate to be used in fertilizer. The main workings are now caved and inaccessible. The Bureau of Mines explored the property by diamond drilling, trenching, and test-pitting in the spring of 1942, and again by several diamond-drill holes in late 1943.

The Piedmont has been the most productive mine in the district with a yield of about 60 percent of the total production. Although the main deposit was relatively small in size, it was favored with an unusually high manganese content because the yield of washed ore was between one-third and two-thirds of the weight of mined material.

Mining and exploratory work at the Piedmont mine have shown that the manganiferous zone containing the main ore body and other deposits to the northeast is along the contact of quartzite (which forms the hanging wall of the ore zone) and marble. Rock exposures in the vicinity of the Oxford and Josephine shafts are few and consist of isolated outcrops of quartzite and tough muscovite schists containing garnet and magnetite (pl. 5). Marble does not crop out near the shafts, but it is well exposed with thin beds of quartzite in Little Beaver Creek, 700 feet southwest of the Josephine shaft. The mine workings and exploratory drilling have given considerable information on the distribution of quartzite and marble, which has provided the basis for locating the approximate positions of formation contacts on the surface (pl. 5). The general strike is about N. 30° E., with apparently minor local deviations from this trend. The formations dip to the northwest at 60° to 80° as a rule. Near the surface, the widths of both the quartzite and marble seem to vary, from 30 to 60 feet for the quartzite, and from 70 to 90 feet for the marble.

The main ore body is an elongate lens with its longest dimension (more than 200 feet) down the dip, and a strike length of about 125 feet. Maximum thickness of the lens is 25 to 30 feet. The deposit strikes about N. 20° E. and dips from 70° NW. to nearly vertically beneath the quartzite hanging wall. Marble forms the footwall of the ore body and extends from the Oxford shaft to the ore body on the 208 level. The deposit appears to have changed very little, either in shape or in ore content, from the surface to the bottom of mining (pl. 6).

The Piedmont mine was visited by Harder (1910, p. 38–40) in 1909 when it was being operated on the 80-foot level of the Josephine shaft. He gives the following account of the occurrence of the ore:

The ore occurs in kidneys or large masses and is mainly in the form of granular pyrolusite, either massive or with concentric structure. Crystalline pyrolusite and amorphous steel-blue psilomelane are associated with it but are much less abundant. Lenses of quartz, fragments of unaltered rock, and cavities lined with botryoidal surfaces likewise occur in the ore masses. The ore locally may compose 85 or 90 percent of the ore-bearing clay, forming a nearly solid body with interestices filled with clay, while elsewhere more than half the layer may be clay in which the ore is embedded in lumps. The micaceous clay footwall is light brown, dark brown, or gray, by layers, and is residual from mica schist. The layers and schistosity have the same strike and dip as the ore-bearing layer. The footwall clay is similar to the clay associated with the ore and grades imperceptibly into it.

Harder wrongly identified the hanging wall quartzite as granite; the true character of this formation was recognized by Hewett during his examinations. The nature and occurrence of the ore as observed by Hewett (1916, p. 52) are described below:

In addition to sporadic pockets northeast of the mill, the southern belt contains two considerable masses of ore. The more southwestern and larger has been mined through the Josephine and Oxford shafts, and the other through shafts marked 5 and 6 [pl. 5]. These two masses are separated by an area of unaltered barren mica schist. Masses of soft manganese-bearing clay and wad were found in the tunnels at the point marked 4, but these tunnels have not yet disclosed much hard ore. The writer's observations of the larger deposit were confined to a part of the 208-foot level of the Oxford shaft, the Josephine shaft having been abandoned in 1913. The map showing the extent of the workings from these two shafts [fig. 6 of Hewett's, simplified in pl. 6, A of this report] is based on surveys by the company. The explorations from these shafts to a depth of 208 feet and for a horizontal distance of 175 feet show that manganese ore and clay formed a well-defined lens that pitched steeply to the southwest along the planes of schistosity. The maximum width of successively lower levels has ranged from 22 to 30 feet, and according to the maps of the several levels ore has been mined for a distance of 125 feet and explored a short distance farther. All the material from the lens was mined, and the yield of washed ore ranged from one third to two thirds of the weight of mine dirt. The average yield is considerably higher than any other on record from mines west of the Blue Ridge.

The diamond-drilling projects of the Bureau of Mines in 1942 (holes 1, 2, and 3), and 1943 (holes 4, 5, and 5A), were directed to explore the extension of the main ore body beneath the old mine workings (pl. 6). Drill hole 1 cut the contact between quartzite and marble at a depth about 170 feet vertically below the 208 level or about 135 feet below the bottom of the winze sunk in ore by the Myers family (pl. 6, B). No manganese oxides were found in this hole, and the quartzite and marble were found to be quite fresh and unaffected by ground water action; core recovery in this interval was practically complete. The manganiferous zone was cut in drill hole 3, between 18 and 34 feet beneath the 208 level, and in drill hole 4, between 43 and 48 feet below the 208 level (pl. 6, B and D). Core recovery in the ore zone in these holes was very poor; only a few pieces of hard manganese oxides were recovered in drill hole 3, and not much information was obtained on the nature of the ore body. Drill hole 2 penetrated old workings above the 208 level and the hole was stopped (pl. 6, C). Drill holes 5 and 5A were drilled from the southeast side of the deposit to test the possibility that the dip of the ore body reversed below the 208 level; these holes were entirely in footwall mica schist and marble (pl. 6, E).

Although drilling did not succeed in providing information about the size and grade of the ore deposit below the 208 level, it showed that the ore deposit probably pinches out somewhere in the interval of about 125 feet vertically between the ore zone intersection of drill hole 4 and the quartzite-marble contact cut in drill hole 1 (pl. 6, B). These two drill holes also show that the quartzite-marble contact becomes steeper in depth, perhaps dipping steeply to the southeast. Drill hole 3, on the other hand, indicated a flattening of the ore zone below the 208 level to a dip of about 35°. This low dip is difficult to reconcile with the dip of 60° to 70° indicated within a short distance by drill hole 4; possibly the thick part of the ore zone penetrated by drill hole 3 may lie in a minor fold where dips are more gentle than normal. Drilling further indicated that the quartzite is considerably thinner in depth than is suggested by the few surface outcrops. In drill hole 1 only 10 feet of quartzite was intersected; this corresponds to a true thickness of about 5 feet.

Smaller deposits have been prospected and mined to the northeast of the main ore body along the contact between quartzite and marble. D. G. Myers (oral communication) stated to the writer that a crosscut to the north from the Oxford shaft at the 70-foot level went through about 40 feet of wad into sand spotted with pea-size pieces of soft, bluish manganese oxides. This occurrence would probably lie about 100 feet to the northeast of the northeastern end of the main ore body. Ore was also mined about 400 feet farther northeast, from shafts 5 and 6 (pl. 5), and has been found 1,500 feet northeast of the main deposit, beyond the limits of the area shown in plate 5. The manganiferous zone beyond the main deposit was also explored by the Bureau of Mines by trenches and by two test shafts. Test shaft 1, 180 feet south of the deposit, was sunk to a depth of 16 feet, and a crosscut driven in both directions; wad with sparse pieces of hard manganese ore was found in the crosscut. Test shaft 2, 300 feet northeast of the main deposit, was put down to 45 feet; a crosscut at the bottom was in wad streaked with red clay. The crosscuts of both shafts had quartzite in their northwest faces and mica schist in the southeast faces. The wad zone cut in both crosscuts probably represents the full width of the marble beds at these two localities.

The grade and extent of the main deposit beneath the old mine workings is conjectural and can be satisfactorily determined only by following the ore downward by mine workings, either by reopening the Oxford shaft or by sinking a new shaft nearby. Core drilling has not proved to be a successful method of exploring these deposits in which hard manganese oxide nodules and masses are irregularly distributed in soft clay. The manganiferous zone appears to have been fairly well explored on either side of the main deposit for a distance of 450 feet northeast of the Oxford shaft and 180 feet southwest of the Josephine shaft, and it is unlikely that an undiscovered deposit exists in this stretch of ground that is comparable in size to the main ore body. If exploration is undertaken in the future, it might best be directed toward the unexplored part of the manganiferous zone, lying northeast of the tunnels, marked 4, and southwest of the old shaft, marked 10, toward Little Beaver Creek (pl. 5). The marble belt is wide and persistent here, and it is possible that deposits of wad, similar to those found in the crosscuts from the Bureau of Mines test shafts, may be found at other places along the marble belt.

Hewett (1916, p. 54) has discussed the origin of the Piedmont deposit; he pointed out that it probably was formed in early Tertiary time and that this deposit of superficial origin persists to a depth of more than 130 feet below the nearby stream. He concluded that the deposit was formed by replacement of quartz-mica schist, and that the manganese was probably not derived from the adjacent wall rock, because they are fresh and their micas do not contain manganese. The present study has shown, however, that the marble at the Piedmont mine has a low manganese content (see table 2), and it is now believed that the source of manganese was beds of marble and calcareous quartzite that have been completely weathered away. The manganiferous ground water solutions replaced clay that was probably residual from marble and quartz-mica schist.

The lenticular shape of the main deposit (elongate down the dip) and the high manganese content suggest that the ground water solutions were confined to a rather restricted channelway in which circulation was deep while the deposit was being formed. This deep circulation along pronounced but restricted channels may be attributed partly to local stratigraphic (presence of calcareous quartzite) and structural conditions and partly to favorable surface drainage conditions during the period of origin. Evaluation of the relative effects of these different factors is impossible to determine, because the local drainage conditions of early Tertiary time are, of course, unknown, and the present geologic conditions are not known in sufficient detail. Although minor flexures appear to exist, and the quartzite is variable in thickness and perhaps in carbonate content as well, these features cannot be recognized from mapping of surface outcrops alone because of the very poor exposures. Hence, our knowledge of the Piedmont deposit provides very little specific information to guide the search for similar deposits elsewhere in the region. It may be possible that the marble and calcareous quartzite have a higher manganese content at this point than is usual for the calcareous beds of the Mount Athos, or that local ground water conditions were especially favorable during the period of manganese deposition. On these assumptions then, the quartzite-marble belt extending a mile or more to the southwest and northeast of the Piedmont mine might well be regarded as favorable prospecting ground.

HARVEY

The Harvey mine (loc. 63, pl. 2), lying about 1¼ miles southwest of U. S. Highway 460, was opened between 1910 and 1915; it is reported that about 100 tons of ore was shipped. The mine was visited by Hewett (1915) in 1915 when a two-compartment shaft had been sunk to a depth of 80 feet. Several shallow diggings lie within a few hundred feet of the shaft, which is now caved and inaccessible. Quartzite is the most abundant material on the dump. Hard manganese oxides occur as disseminations in a coarse quartzite and chert, as fracture fillings in quartzite, and as botryoidal coatings about an eighth of an inch thick on quartzite and chert. The manganese oxides forming fracture fillings and surface coatings evidently were deposited in open spaces.

About 2,000 feet southwest of the Harvey shaft, on the same quartzite ridge, is an old pit, 15 feet deep, in quartzite and red clay (loc. 64, pl. 2). A small pile of hard, micaceous manganese oxides lies near the pit. Half a mile northeast of the Harvey shaft is an old digging that exposed sandy wad (loc. 62, pl. 2). Several thousand feet farther northeast, seams of impure wad are exposed in the same quartzite belt along the abandoned stretch of U. S. Highway 460. This quartzite belt was also prospected years ago to the north of the highway (loc. 55, pl. 2). The northernmost of these pits was cleaned out about 1940 by J. D. Ryan, exposing a 10-foot thickness of red clay and micaceous sandy wad with irregular stringers of soft, bluish manganese oxides, ½- to ¾-inch thick. This locality is probably the one mentioned by Hewett (1916, p. 51–52) where a 40-foot shaft was sunk some years prior to 1915. Hewett noted that wad appeared to be the principal manganese mineral occuring at this particular locality.

LINDSAY

About 2 miles southwest of the Piedmont mine, the same quartzite belt has been prospected for iron and manganese on the W. T. Lindsay property near the Norfolk and Western Railroad. Pieces of likely looking manganese ore are scattered around an old prospect pit 30 feet south of the tracks (loc. 66, pl. 2), but there are no exposures to reveal the nature of the deposit. Four old pits dug for iron ore (loc. 186, pl. 2) are located several hundred feet east of the manganese prospect; siliceous limonite with a prominent relict schistosity is present on the dumps. Several hundred yards northeast of these prospects are some old shallow trenches in which iron and manganese oxides associated with quartzite and chert were found.

About 1/4 of a mile southwest of the railroad is another group of old shallow prospects that exposed limonite and manganese oxides (loc. 67, pl. 2). Both white and blue marble are exposed downstream from these prospects; nearby is an abandoned marble quarry and a kiln where marble was burned for lime. Wad is well exposed across a width of 100 feet in the nearby road cut. Doubtless, the wad was formed from the decomposition of white marble, and it is believed that a considerable thickness of white marble is present here. Farther southwest along the strike, white and blue marble are exposed at numerous places along Beaver Creek Valley. About a mile southwest of the prospects described above, W. T. Lindsay (oral communication) reports that hard manganese oxides are frequently plowed up on the east side of the quartzite belt. Barite has been found in white marble at a number of places along Beaver Creek Valley; these occurrences are described under the Carson barite mine.

A group of shallow pits has been dug half a mile northeast of the railroad on the extensions of the belt toward the Piedmont mine (loc. 65, pl. 2). Wad was found in two of the pits, but the other pit was dug in mica schist in which manganese minerals appeared to be very scarce.

NEIGHBOURS

The Neighbours mine (loc. 70, pl. 2) is on the nose of a quartzite ridge about 3 1/2 miles north of Rustburg along the South Boston line of the Norfolk and Western Railroad. Some mining was done here in 1938 by L. R. Neighbours, owner of the property, and during 1940 and 1941 by the Otter River Mining Co.; about 60 tons of ore is said to have been shipped. The ore was mined from a shaft about 50 feet deep and from several tunnels near the crest of the ridge. Slabby nodules of manganese oxides occur in a seam of yellow clay that is enclosed in quartzite and dips 70° to the southeast. In an open-cut near the shaft, the following section across the strike of the manganiferous seams and the wall rocks is exposed:

	Rock description	*Thickness (feet)*
(Northwest)..	Crumbly, white quartzite	12
	Brown clay and rotten schist	6
	Crumbly, white quartzite	18
	Streaked wad and yellow-brown clay	6
	Streaked yellow-brown clay with thin slabby nodules of manganese oxides.	1½
(Southeast)..	Quartzite, partly replaced by manganese oxides	1 to 2

About 700 feet southwest of the shaft, an open-cut, 150 feet long, was dug on the east slope of the ridge. A highly contorted seam of streaked wad and yellow clay, 10 feet thick, is exposed in the cut. Thin seams of soft, bluish manganese oxides occur along the banding of the wad and clay.

Barite has been found on the Neighbours property about ¾ of a mile to the south.

GREEN

The Green prospect, owned by J. A. Green and adjoining the Neighbours mine on the northeast (loc. 69, pl. 2), was prospected many years ago, and again in 1940 by a series of shallow trenches dug by the Otter River Mining Co. Slabby nodules of manganese oxides were found in red clay in several of the trenches. Exposures are poor, but it is probable that the mode of occurrence is similar to that of the Neighbours mine.

BETHEL

The Bethel or Stevens prospect (loc. 68, pl. 2) lies on another quartzite belt to the north of the Green prospect. This ridge was prospected many years ago by half a dozen pits and shafts between Highway 501 and the Norfolk and Western Railroad. The pits are all caved now, and no exposures are visible; nodular ore and yellow clay lie on several of the dumps.

DODSON

The Dodson prospect (loc. 72, pl. 2) is on a branch of Beaver Creek, about 1½ miles southwest of the Neighbours mine. Several caved shafts near the stream show wad and brown clay, but no hard manganese oxides. On the edge of the valley (about 800 feet to the west) is an open-cut (loc. 189, pl. 2), in which there are large blocks of botryoidal limonite that appear to be manganiferous.

JACK MOUNTAIN

The prominent ridge of Jack Mountain is underlain by several broad belts of quartzite, in which manganese deposits appear to be very scarce. The only occurrence noted was just northeast of the peak, where a shallow pit (loc. 71, pl. 2) had been dug in quartzite partly replaced by manganese oxides.

BELL

The Bell mine (loc. 73, pl. 2) is on the top of a prominent knob overlooking the headwaters of Flat Creek, about 6 miles south of Lynchburg and a mile west of U. S. Highway 29. The deposit was first mined in the winter of 1939 by R. K. Bell, owner of the property. Production to October 1941 amounted to 114 long tons of washed ore, which was washed by hand and sold to the National Paint and Manganese Co. of Lynchburg. The manganiferous zone was explored for about 100 yards by 3 shafts and 2 open-cuts. Nearly all of the ore was mined from the northwesternmost shaft, 54 feet deep, and from an open-cut just north of the shaft (pl. 7). Each of the two shafts to the south were 17 feet deep, and the open-cut between them was about 6 feet deep. In the spring of 1942 the property was explored by the Bureau of Mines by means of bulldozer trenches.

The manganiferous zone occurs in schistose quartzite just west of the contact between quartzite and greenish mica schists that carry disseminated martite and specular hematite. The strike of the zone generally is about N. 40° W. to the southeast of the main shaft, but it seems to swing abruptly west and southwest to the northwest of the shaft; this change in strike is probably due to folding. Southeast of the shaft, the zone is roughly 15 feet wide and consists of schistose wad with a seam about 3 feet thick containing slabby pieces of hard, manganese oxides. The zone becomes 30 to 50 feet wide over a length of 100 to 150 feet where the strike bends westerly near the main shaft and open-cut, and it appears to become much thinner farther west. The wide part of the zone is mostly wad with an irregular seam of yellow clay, 1 to 10 feet thick, containing nodular ore. The strike of the quartzite and the wad and clay seams here is variable, ranging from N. 40° E. to N. 40° W.; these irregular strikes are probably due to drag folding (as interpreted on pl. 7), but they may result in part from slumping during weathering.

Some fairly large lumps of ore, weighing as much as 300 pounds, were taken from the open-cut and shaft, according to Mr. Bell (oral communication). The ore from the Bell mine seems to have a somewhat higher manganese content than the average ore shipped from the district. A lot of 6.97 tons contained 50.2 percent Mn, whereas much of the ore shipped from other mines in the district contained between 40 and 45 percent Mn; a lot of 2.19 tons of the Bell ore contained 7.2 percent SiO_2 and 1.9 percent Fe.

The Bell deposit is believed to lie approximately on the axis of a large tight fold, which is one of the series of close folds that appear to underlie this quartzite ridge (pl. 1.) The axial planes of the folds strike northwest, and probably dip nearly vertically; the fold axes plunge southeast. If the stratigraphic sequence of the region has been determined correctly, the Bell deposit lies along the trough of a tight syncline that plunges southeasterly beneath the greenstone south of the mountain. Small drag folds subsidiary to the main fold probably exist and complicate the local structure of the deposit.

The Bell deposit crops out at an altitude of 1,060 feet, which is several hundred feet higher than other productive manganese mines in the district. At the time the deposit was formed, the quartzite belt may have formed a hill standing above the general level of the early Tertiary peneplain. Thus, deep circulation of ground waters in the quartzite would have resulted. The combination of these circumstances of close, plunging folds and deep ground water circulation would be particularly favorable for the formation of the Bell manganese deposits and the two other known deposits on the ridge.

PROSPECT SOUTH OF THE BELL

At the base of a quartzite spur 2,000 feet south of the Bell mine, yellow clay with thin seams of wad is exposed in a shallow prospect pit (loc. 75, pl. 2). This manganese showing appears to be nearly on the crest of a plunging anticline.

MADDOX

The Maddox mine (loc. 74, pl. 2) is on a spur on the north side of the quartzite ridge, half a mile west of the Bell mine. The property, owned by O. F. Maddox of Lawyer, was worked briefly in 1939 by Robert Adams and about 10 tons of ore was shipped. A shaft was sunk to a depth of 30 feet and four shallow trenches dug within 100 feet of the shaft. A seam of yellow clay, 3 to 4 feet thick, contains rather siliceous, hard manganese ore. Quartzite, striking N. 15° W. and dipping 70° SW., forms the walls of the clay seam. The Maddox deposit appears to be on the flank of a southeasterly plunging syncline.

On the spur about 1,000 feet southwest of the Maddox mine, dark brown, manganiferous soil and float of brecciated quartzite cemented by manganese oxides are found in an orchard. This locality had not been prospected at the time it was examined.

McGEHEE

The McGehee or Arthur mine (loc. 77, pl. 2) is about 1½ miles southeast of Lawyer on a quartzite knoll overlooking Smith Branch. The property was owned in 1941 by G. C. McGehee of Lynchburg. Manganese ore was mined here by a Mr. Hancock about 1916 from an open-cut and shallow underground workings, and it is reported that 3 or 4 carloads of ore were shipped. In 1941, McGehee dug several trenches and three shafts to depths of 20, 25, and 35 feet with short crosscuts from the bottoms; a small quantity of ore was shipped. A crosscut from the 25-foot shaft driven underneath the old open-cut located quartzite enclosing a seam of wad and a yellow clay seam with nodular manganese ore. Micaceous wad with streaks of white and yellow clay was found in prospects on the hill slopes above Smith Branch, several hundred feet north of the open-cut; brecciated quartzite cemented by manganese oxides occurs east of the open-cut.

Marble crops out in Smith Branch just north of the mine and also in the valley a short distance southwest of the mine, where white and pink micaceous marble is exposed at intervals of approximately 500 feet across the strike. The marble is manganiferous, as determined by blowpipe test, and yields a chocolate-covered, loamy soil.

Large blocks of manganiferous limonite are scattered around some old, shallow iron diggings on the gentle valley slope about 3,000 feet northeast of the mine (loc. 190, pl. 2). A sample of this limonite collected by G. C. McGehee had the following analysis:

Percentage analysis of manganiferous limonite from McGehee property

[A. K. Crabill, analyst, E. J. Lavino and Co., Reusens, Va.]

Manganese (Mn)	12.43
Iron (Fe)	41.50
Silica (SiO_2)	8.46
Phosphorus (P)	0.771

About a mile up Smith Branch from this last locality, chert is exposed intermittently for about 1,000 feet in ledges as much as 20 to 30 feet wide. The chert is composed of brown, red, or gray small fragments and irregular chunks; it has the appearance of a deposition breccia. Blobs of white to yellow clay and stringers of bluish-white opalescent silica are present. Irregular streaks of hard, black manganese oxide are present in the chert near the northeastern limits of the outcrops (loc. 76, pl. 2). A little chalcopyrite and malachite were also found in the chert. This occurrence of chert is the most extensive one discovered in the district. This brownish variety of chert resembles the brown chert that is so common in many of the manganese deposits in the district, but the brecciated appearance and variable color of some of the fragments are unique. The association of chert with quartzite (an association similar to the occurrence of chert elsewhere in the region) suggests that the chert along Smith Branch may also have originated in some way from the decomposition of calcareous quartzite or marble.

MORTIMER

The Mortimer or Wood mine (loc. 83, pl. 2) is south of a westerly bend in Flat Creek, about 3 miles northeast of Evington. Some work was done here prior to 1907, but the major period of activity was in 1918 when the Mortimer mine and the Pribble mine, 2,500 feet farther southwest, were operated by the Virginia Ores Corp. During that period 525 tons of ore was shipped from the two mines. Prospecting was also carried on many years ago at various places northwest and north of the Mortimer shaft. Some of these localities were again prospected in early 1942 by the Columbia Manganese Co., and by the Buerau of Mines between August 1942 and February 1943.

The Mortimer mine was visited by D. F. Hewett (1918) in 1918; at that time the shaft had been sunk to a depth of 165 feet. It was reported that water had been encountered at a depth of 140 feet. Hewett noted that ore was found in the shaft at the following depth intervals: 40 to 80 feet, 95 to 123 feet, 135 to 165 feet. Wad is the predominant manganese mineral on the dump and must have been abundant underground. In 1942 a shaft was sunk about 100 feet northeast of the main shaft by the Bureau of Mines to a depth of 38 feet, and although a crosscut was driven toward the southeast, the ore zone of the main shaft was not found (Montgomery, 1949). Some pits, located a few hundred feet farther northeast, are said to have been dug for iron ore in the eighties or nineties; limonite is present on the dumps.

Along the road west and northwest of the deep shaft, two groups of prospects (locs. 81 and 82, pl. 2) were explored many years ago and again in 1942 by the Columbia Manganese Co. and by the Bureau of Mines. Most of the work was done at the northern group (loc. 81, pl. 2), where four shafts were sunk to depths of 21, 31, 34, and 46 feet respectively; crosscuts and drifts were driven from the bottom of the shafts (Montgomery, 1949). Some nodular ore in clay, manganese oxides in quartzite, and abundant wad were found. A small mill was erected by the Columbia Manganese Co. in Flat Creek valley to the north, and some material from the old dumps was treated by washing and screening; 2 tons of the hand-picked screened material was sold to the National Paint and Manganese Co., Lynchburg.

In the gully about 500 yards southwest of the locality just described, seams of wad in mica schist and quartzite are exposed in the stream bed. About a mile north of the Mortimer shaft, on the north side of Flat Creek, two old shafts (loc. 79, pl. 2) were dug in coarse micaceous quartzite; soft, bluish manganese oxides and limonite are scattered on the dump. One of these shafts probably is the one described by Hewett (1918) as being 35 feet deep in which 2½ to 3 feet of hard manganese ore was found. About 1,000 feet west of these diggings, several shallow prospects (loc. 80, pl. 2) contained thin stringers of friable manganese oxides in a seam of yellow clay and wad, 1 foot thick, near the contact of mica schist and quartzite. The two localities described above were trenched by the Bureau of Mines in 1942 (Montgomery, 1949).

North of Yellow Branch, and about a mile northeast of the Mortimer mine, several shallow pits (loc. 78, pl. 2), sunk about 1940, exposed quartzite partly replaced by soft manganese oxides.

PRIBBLE

The Pribble mine (loc. 84, pl. 2), about half a mile southwest of the main shaft of the Mortimer mine, apparently is on the same manganiferous zone. It also was explored by the Virginia Ores Corporation in 1918, and ore was mined from an open-cut about 80 feet long, 20 feet wide, and 20 feet deep (Hewett, 1918). About 150 feet southwest of the open-cut, a shaft was sunk to a depth of 30 feet. The actual amount of ore shipped from the Pribble property in 1918 is not recorded because it was included with the production of the Mortimer mine; however, the two mines together are said to have shipped 525 tons of ore.

In the spring of 1941 the property was operated by Leghorn and Mitchell. The old open-cut was enlarged by dragline excavation to a length of 500 feet (extending northeasterly along the strike), and to a width of 60 feet and depths of 20 to 40 feet. About 200 feet southwest of this cut, a second open-cut was dug to a length of about 200 feet in a southwesterly direction. It is said that about 20 tons of ore was shipped.

In the main open-cut, extending N. 25° E. nearly on the local structural trend, a wide zone of clay with thin wad stringers was exposed along the western half of the pit, and wad seams and rotten quartzite with friable, bluish manganese oxides and clay seams were exposed along the eastern side of the pit. A section across the open-cut, about midway between the ends of the cut, is shown in figure 12. The principal manganese oxide minerals are wad, and soft, powdery, bluish manganese oxides occurring as stringers and seams in wad and quartzite; nodular ores are very scarce. Limonite is present in the clay seams along the eastern side of the pit.

The dump of the old shaft, about 50 feet east of the cut and near its southern end, contains coarse, white marble with half-inch seams of brown carbonate; a sample of the white carbonate contained 0.85 percent MnO and a sample of the brown carbonate contained 0.47 percent MnO (table 2). The relationship of the marble to the quartzite and manganiferous zone is unknown, for marble is not exposed on the surface; it is probable that the clay and wad zones in the pit are underlain by calcareous beds. The streaked clay in the pit is contorted (perhaps

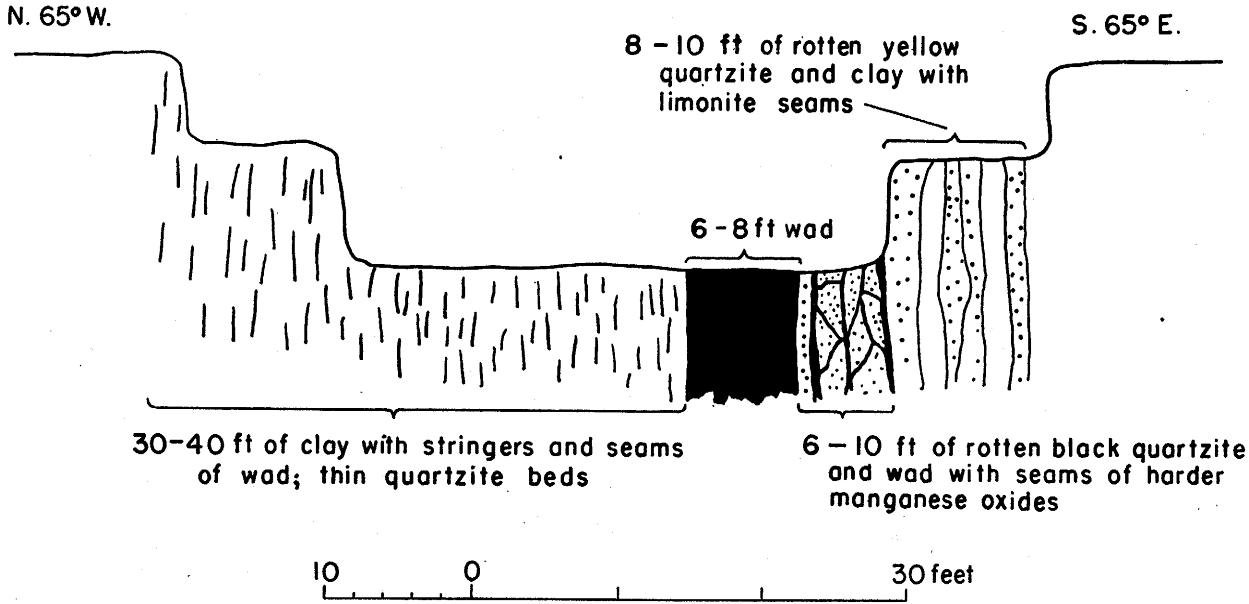

FIGURE 12.—Section through northern open-cut of the Pribble mine, Campbell County, Va.

in part relict from folded bedding in calcareous rocks) and is slickensided (probably a result of slumping during weathering).

A seam of wad and clay, 10 to 15 feet wide, in the southern open-cut is exposed for a length of about 200 feet. Quartzite predominates about 50 feet to the west of the wad and clay seam. The quartzite is folded into minor drag folds that plunge steeply southwest and are cut by irregular quartz veins. Both the quartzite and quartz veins are crushed, cemented and partly replaced by friable, bluish manganese oxides.

PHILLIPS

The Phillips manganese mine (loc. 87, pl. 2) is on the southeastern slope of a wooded hill, 2½ miles east of Evington. The property is owned by R. Bass Phillips, who states (oral communication) that the first work was done in the eighties or nineties when a shaft was sunk to 105 feet, and several carloads of ore was shipped. About 1916 the Phillips brothers sank a shaft 43 feet deep at a point 100 feet northeast of the old shaft and shipped 13 wagon-loads of ore. In 1938 a shaft was put down between these two shafts to a depth of 25 feet by Holland and Sargent, and about 5 tons of ore was shipped. Some work was done in 1941 by Mitchell and in 1942 by J. L. Latellier.

The manganiferous zone is 4 to 6 feet thick and consists of seams of yellow clay, 4 to 18 inches thick, containing nodular ore separated by layers of barren schist, 3 to 8 inches thick. The nodular ore on the western side of the zone is very siliceous and appears to be a replacement of quartzite or quartz-mica schist.

In 1941 a shallow pit and trench (loc. 86, pl. 2), 1,500 feet east of these workings, were sunk by Mitchell and Leghorn. Nodular ore in yellow clay and chert and seams of soft, bluish manganese oxides in quartzite were found. Halfway between this locality and the Pribble mine, on the same quartzite belt, some prospecting was done many years ago (loc. 85, pl. 2); wad appears to have been the principal manganese mineral found.

HALL

The Hall prospect (loc. 101, pl. 2) is 2 miles southwest of the Phillips property, on the edge of Route 696. A 20-foot shaft put down in 1941 by John Hall, of Evington, disclosed a 3-foot seam of wad with scattered pieces of hard ore. The quartzite wall rock is the southern continuation of the easternmost quartzite belt on the Phillips property. White marble is exposed in this quartzite on the Arthur farm, three quarters of a mile northeast of the Hall prospect. Barite has been mined from the same quartzite belt at the Phillips barite mine (loc. 214, pl. 2) southwest of the Hall prospect, and also at the Saunders barite mine (loc. 215, pl. 2) on a quartzite belt east of the Arthur farm.

TROUBLESOME CREEK

On the easternmost quartzite belt in this part of the region, small pieces of hard manganese oxides can be found along a path at a point (loc. 100, pl. 2) on the western side of Troublesome Creek and a mile northeast of the Hall prospect. John Hall, of Evington states, (oral communication) that he prospected here many years ago, but his work was not seen. The soil is dark brown and probably was formed from manganiferous marble; no marble is exposed along this quartzite belt.

HADEN

The Haden prospects (locs. 103 and 104, pl. 2) are about 3 miles southeast of Evington, on the east side of Flat Creek and just north of Otter River. The property was prospected during 1940 and 1941 by the Otter River Mining Co. by means of 24 trenches and two shallow shafts.

Two manganiferous zones were discovered by trenching. Wad is the principal manganese mineral in the western zone, where most of the trenching was done; the wad was found with quartzite and dark-brown loamy soil (typical of the soil derived from marble) over a distance of ¼ of a mile. Chert and hard manganese oxides have also been found in the same zone nearly a mile northeast of this explored interval (loc. 102, pl. 2). White marble is exposed at intervals for 200 yards across the strike immediately north of the prospect. In the zone several hundred yards to the east, ferruginous manganese oxides were found in two shallow shafts, and small pieces of hard manganese oxide in the surficial red clay were found in trenches southwest of these shafts.

PROSPECTS NORTHEAST OF EVINGTON

The quartzite belt about a mile east of Evington has been prospected and mined for manganese at many places for a distance of about 5 miles north of Otter River. Most of the manganese production has come from the Saunders and Russell Den Hollow workings, which are described in succeeding sections. The quartzite belt has been prospected at several places for about 1½ miles northeast of the Russell Den Hollow mine by adits, pits, and open-cuts (locs. 88 and 89, pl. 2). It is not known whether any production of consequence has come from these workings. Slabby pieces of manganese oxides, manganiferous quartzite, wad, and chert are found on the various dumps. Two parallel manganiferous seams are present in the quartzite near the northern end of the belt.

RUSSELL DEN HOLLOW

The principal workings of the Russell Den Hollow mine (loc. 90, pl. 2) lie on both sides of a ravine cutting across the quartzite belt about half a mile northeast of State Highway 24. The property is owned by the Saunders family of Evington. Mining was in progress at various periods between 1890 and 1918 by different operators, some of whom also worked the Saunders mine to the southwest. The last extensive operation seems to have been under the direction of the American Ores Co. in 1916. The production of manganese ore from the Russell Den Hollow workings is unknown, because it has not been recorded separately from that of the Saunders mine. It is probable, however, that the Russell Den Hollow production does not amount to more than 10 percent of the total production of the two mines, which is believed to be between 8,000 and 9,000 tons.

The principal workings on either side of the ravine consist of a number of tunnels and shafts, now caved, and several open-cuts. The ore occurrences are not exposed now, but it is evident from the distribution of the diggings in a belt about 200 feet wide across the strike of the quartzite that there must be several parallel manganiferous seams. Abundant micaceous wad and small slabby pieces of soft manganese oxide are present on the various dumps.

Several hundred yards southwest of these workings is another group of prospect tunnels and pits. This part of the quartzite belt was prospected by means of three bulldozer trenches and a test pit by the Bureau of Mines in 1942 (pl. 8). The middle trench (No. 6) exposed eight manganiferous seams in the quartzite, which consisted of clay with manganese oxide nodules, wad, and siliceous manganese oxides and ranged in thickness from 6 inches to 4 feet. The easternmost manganiferous zone in trench 6, apparently along the main contact between quartzite and mica schist, was explored by test shaft 3 (pl. 9), which exposed a thin seam of yellow clay with manganese oxide nodules underlying barren yellow clay and mixed wad and clay. In trench 5, to the southwest, considerable ferruginous mica schist was found in the quartzite, which suggested that the structure might be complicated by folding or faulting.

The quartzite belt is fairly well exposed farther southwest in the road cut of State Highway 24 (pl. 8). A seam of manganiferous clay about 12 inches thick is exposed just below the contact of quartzite and mica schist.

SAUNDERS

The Saunders mine (locs. 92 and 93, pl. 2), also known as the Spring Hill, Evington, or Flat Creek mine, is about a mile east of Evington on property owned by the Saunders family. The first mining operation seems to have been in the eighties by Robert Wood, who did considerable prospecting and mining in this part of the district.[9] The

[9] Most of the information on the history of the Saunders mine and the nature of the ore deposit underground comes from Fleming Saunders, one of the owners, and John Hall, who has conducted small leasing operations at the mine for many years.

Saunders family worked the mine from about 1900 to 1903 or 1904, when it was leased to the National Paint and Manganese Co. and worked under the direction of a Mr. Cuthbert. This company worked the mine very actively until 1907; the washed ore was shipped to its mill in Lynchburg where it was ground for use as a pigment in paint, ceramic materials, and other processes. After 1907, the mine was again operated by the Saunders family for about a year and a half. The property has been worked fairly continuously since then in a small way by a number of local lessees, principally members of the Hall, Logwood, and Ould families; the washed ore has been shipped to the National Paint and Manganese Co., Lynchburg, and to the Lavino furnaces at Reusens, Va.

The total recorded production of the Saunders mine and nearby properties amounts to 4,075 long tons of washed ore. This figure, however, is apparently incomplete, because production of the Saunders mine up to 1906 was 6,000 to 7,000 tons, according to Watson (1907 b, p. 241). About 2,000 tons of washed ore is reported to have been shipped since 1906; this figure includes production of the Russell Den Hollow mine and possibly some production from other mines in the vicinity. The total production for the Saunders and other mines appears to be between 8,000 and 9,000 tons.

In 1942 the Saunders property was explored by the Bureau of Mines by means of bulldozer trenches, test pits, and diamond-drill holes.

The manganese zones, or "leads" as they are locally called, at the Saunders mine lie along the contact of quartzite and mica shist, and in quartzite just west of the contact (pl. 8). In general, the contact strikes N. 35° to 45° E. and dips 60° to 70° SE. Some rather abrupt deviations from these trends are interpreted to be caused by close folding.

The principal ore body consists of two nearly parallel seams of yellow clay containing nodular manganese oxides. This ore body was mined mostly from two tunnels driven southwest from the northeastern end of the ridge (pl. 8). It is reported that the tunnels were 900 to 950 feet long and that ore was mined throughout this length except for a barren interval that extended from about 200 to 300 feet southwest of the tunnel mouth. The original tunnel on the ore body was driven from an elevation of about 635 feet. When operations were resumed by the Saunders family in 1907, a second tunnel was driven southwest along the ore body at a level about 15 feet lower than the first tunnel. The general relationships of the mine workings are shown diagrammatically in figure 13. In the northern part of the tunnels, the ore body consisted of a single manganiferous seam with quartzite in the footwall and mica schist in the hanging wall. Farther southwest, two manganiferous clay seams (separated by 6 to 8 feet

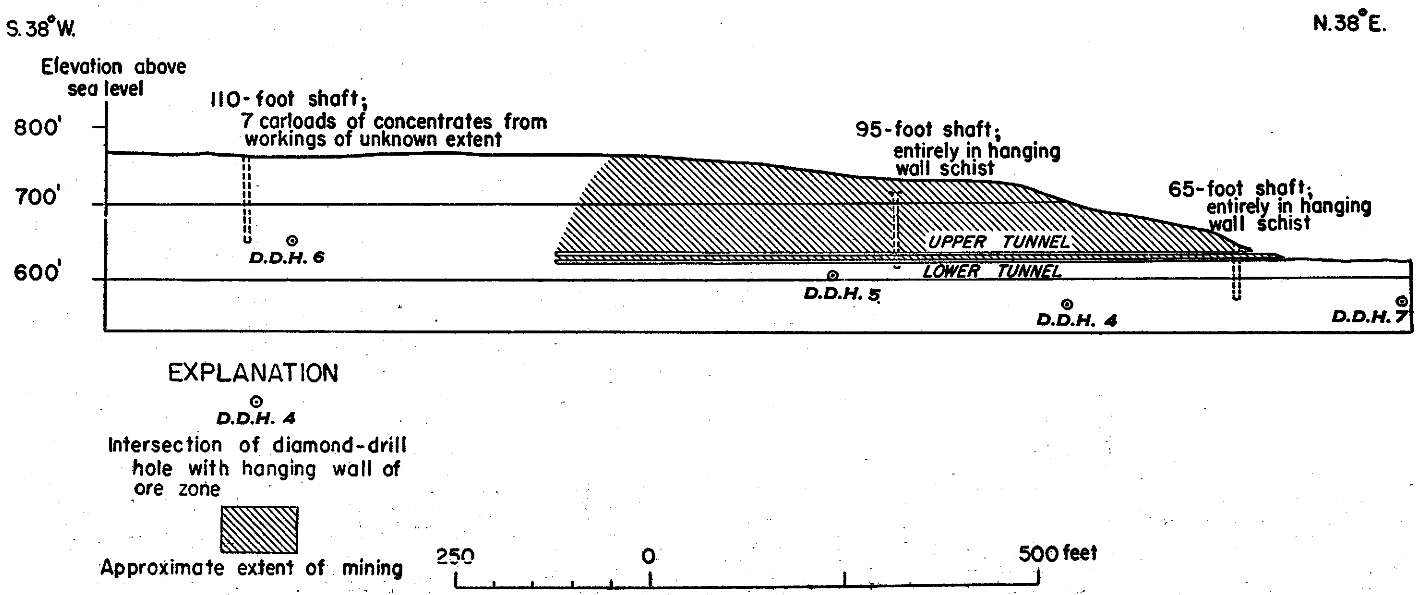

FIGURE 13. Longitudal projection showing principal mine workings and drill hole intersections, Saunders mine, Campbell Co., Va.

of quartzite) were mined. The seams are said to have averaged about 5 feet thick and to have consisted in places of nearly massive manganese oxides. In the southwestern face of the workings, the ore appeared to have been cut off by a structure that dipped or plunged toward the southwest. Supporting pillars of ore left near the surface have been mined out since abandonment of the tunnel workings, and the ore body is now essentially mined out above the lower tunnel level (fig. 13). Attempts were made to open the ore body below the lower tunnel by a two-compartment shaft sunk near the tunnel mouth to a depth of 65 feet in the hanging-wall schist and by another shaft (450 feet southwest) sunk 95 feet in the hanging-wall schist. Evidently, neither of these shafts reached the ore body.

Southwest of the tunnel face, ore has been mined near the surface by numerous shallow workings for a distance of nearly 1,000 feet to the boundary line with the Wood property. Most of the mining was done about two hundred yards southwest of the tunnel face from an open-cut and underground workings of a shaft 110 feet deep (pl. 8). About seven carloads of ore (about 300 tons) are said to have been produced from this shaft. Southwest of these workings, the contact between quartzite and mica schist seems to curve convexly toward the west, and at several places the outcrops have strikes that deviate from the normal trend; these features are probably caused by close folding.

The exploration program of the Bureau of Mines in 1942 was laid out to explore the ground beneath the tunnels that had yielded most of the ore in the past and also to explore the ground southwest and northeast of the tunnels. According to Fleming Saunders (personal communication), about 450 tons of washed ore was produced from the lower tunnel and the pillar (10 to 12 feet thick) between the lower and upper tunnel. In other words, a block of ground about 950 feet long, 15 to 20 feet high, and 5 to 10 feet thick, yielded about 450 tons of washed ore. Because the ore body had never been mined below the lower tunnel, it seemed reasonable to assume that the ground beneath this tunnel might contain several thousand tons of recoverable manganese concentrates. Accordingly, four diamond-drill holes were put down; three of the holes (pl. 10) explored beneath the level of the lower tunnel. Each of the drill holes penetrated the manganiferous zone at the contact between mica schist and quartzite, but core recovery in this zone was negligible and little could be learned from the drilling sludge in regard to the nature of the zone. Several small fragments of manganese oxides were recovered in drill hole 7, which indicated that the manganiferous zone probably extends at least 150 feet northeast of the mouth of the lower tunnel.

The bulldozer trenches and test pits southwest of the tunnel face exposed manganiferous clay and wad seams in quartzite, some of which might yield small tonnages of washed ore if worked by the hand methods that are practiced by the local lessees. Although the exploration program did not succeed in discovering workable ore bodies of consequence, the drilling results cannot be regarded as conclusive because of the very poor core recovery in the manganiferous zone. Exploration and development of the ground below the lower tunnel could probably be done best by shafts and drifts; it is very likely that considerable water would be encountered.

The four diamond-drill holes yielded some interesting information on the distribution and characteristics of the formations (pl. 10). A ferruginous mica schist, containing specular hematite and martite, had been determined by surface examination to lie immediately in the hanging wall of the quartzite and to occur as layers within the quartzite. This ferruginous schist was discovered in all the drill holes to lie just above the manganiferous zone and beneath tan muscovite schist containing biotite porphyroblasts partly altered to chlorite. Quartzite was found beneath the manganiferous zone in all the holes, and tan, micaceous marble was found in quartzite at the bottom of drill hole 6. This is the only known occurrence of marble at the Saunders mine; no marble was reported from the old tunnel workings. The biotite-muscovite schist resembles the schist member of the Mount Athos formation that normally lies stratigraphically below the quartzite member. If these relations prevail at the Saunders mine, the biotite-muscovite schist is older than the structurally underlying quartzite, and the formations are overturned.

WOOD

The Wood mine (loc. 94, pl. 2), owned by Arnie Wood, of Sweetwater, Tenn., adjoins the Saunders property on the southwest. This mine has been prospected and mined intermittently through the years, and the efforts have resulted in numerous shafts, pits, and tunnels. The following account of the history of its operations has been furnished principally by John Hall, of Evington (oral communication). About 1916 a shaft was sunk to a depth of 127 feet near the Wood-Saunders property line by a Mr. Hancock. More water was encountered than the pump could handle and the shaft was abandoned. The National Paint and Manganese Company, of Lynchburg, sank a shaft about 35 feet deep in 1923. Since then, the Hall family has mined from several places on the property, and in 1941 they sunk a shaft 58 feet deep near the northern boundary line. Also in 1941, a Mr. Mitchell did some shallow open-cut work by means of a dragline and dug some shallow prospect pits. There is no record of the amount of ore shipped from the Wood property, because its production apparently has been grouped with that of the Saunders mine.

The quartzite and manganiferous zones extend southwest from the Saunders property, and at least two zones, or "leads," have been mined on the Wood property. The easternmost zone consists largely of wad, about 15 feet wide, that carries stringers of soft, manganese oxides. To the west of the wad zone are two seams of manganiferous yellow clay. Several underground crosscuts by the Halls have shown a 20-foot seam of yellow clay carrying scattered manganese oxide nodules. About 50 feet southwest of the crosscuts, nearly massive manganese oxide nodules were found over a width of 3 to 4 feet in yellow clay.

BURTON

The Burton property (locs. 95 and 96, pl. 2) is just south of the Wood tract, about 1½ miles southeast of Evington. The property was prospected in 1923 by the National Paint and Manganese Co. with an 80-foot shaft, and the Otter River Mining Co. prospected between 1939 and 1941 with about 35 trenches and several test pits. It is not known whether any manganese ore was ever shipped from the Burton property.

Two beds of manganiferous quartzite cross the Burton land in a southwesterly direction. The westernmost of these quartzite belts is the extension of the same manganiferous quartzite that has been mined on the Saunders and Wood properties. Within this belt are at least two manganiferous zones that are about 70 feet apart and extend for a distance of nearly 1,000 feet. The eastern zone consists of yellow clay with nodular manganese oxides and has a thickness of about 5 feet. The western zone is mostly wad with some red clay and pieces of slabby manganese oxides; its thickness is also about 5 feet.

The manganiferous zone in the eastern quartzite belt is about half a mile south (loc. 96, pl. 2) of the above occurrences. This zone was explored with a series of trenches by the Otter River Mining Co. and was traced for a distance of about 800 feet south of Route 694. Two leads of manganese ore were found, lying about 300 feet apart. In the western lead, considerable sandy wad is present in the northern part, and some nodular manganese oxides occur in the southern part. Yellow clay and chert with nodular manganese oxides predominate in the eastern lead, although wad is also present.

Barite occurs in the eastern quartzite belt and has been mined very extensively at the Hewitt barite mine, ¾ of a mile to the southwest, where considerable white marble accompanies the quartzite. Barite was also found in an old prospect shaft located approximately on the continuation of the easternmost manganese zone, a short distance north of Route 694.

LANGHORNE

Manganese ore has been found at several places on the property of J. S. Langhorne, to the south and west of the Burton property. Apparently, no manganese ore has ever been shipped from here. The manganiferous quartzite that crosses the Saunders, Wood, and Burton properties also extends across the Langhorne property. About 1/4 of a mile south of Route 694, siliceous manganese oxide and chert were discovered in a 15-foot shaft (loc. 98, pl. 2). Just north of the Otter River, a short tunnel, driven about 1915 (loc. 99, pl. 2), exposed two thin seams of wad containing small slabby pieces of manganese oxides; micaceous limonite has also been found in this quartzite belt, which is a short distance south of Route 694 (loc. 198, pl. 2).

Part of the southern manganese zone of the Burton property is on the Langhorne tract and was prospected some years ago by Mr. Langhorne's father by means of a tunnel and shallow shaft (loc. 97, pl. 2).

TEATES

The Teates mine (loc. 91, pl. 2) is in the village of Evington, a short distance west of the crossing of Route 682 and State Highway 24. Manganese ore was mined here from a small open-cut by W. W. Teates about 1905, and it is reported that two carloads of ore was shipped. Wad, siliceous manganese oxide, and chert are found on the dump. Siliceous manganese ore in yellow clay was found several hundred feet northeast of the open-cut in a shallow shaft sunk about 1920 by C. D. Maddox.

ANTHONY

Manganese ore has been found in several shallow pits on the Anthony property (loc. 105, pl. 2) a short distance south of Otter River on the extension of the westernmost quartzite belt of the Langhorne property. White marble occurs in the quartzite and is exposed over a width of 10 to 15 feet in a small quarry on the south bank of the river. Dark brown, manganiferous soil of the type derived from white marble extends southward from these exposures.

THERESA

The Theresa mine (loc. 106, pl. 2), also known as the Halsey or Otter River mine, lies at the northwest foot of Scott Mountain about half a mile south of the Otter River. The mine was worked as early as 1908. In 1917 and 1918 it was operated by J. B. Guernsey, and it is reported that 702 tons of ore was shipped at that time. Most of the ore appears to have been mined from a tunnel located near the mouth of a gully emptying into Tardy Branch. According to W. F. Tweedy (oral communication) a shaft was sunk to a depth of 9 feet, and a drift was run 168 feet southwest from the shaft. The ore zone is reported to have been continuous along the drift with an average width of 4 feet. Some ore was mined above the drift but none was mined below. Quartzite with seams of soft, bluish manganese oxides, 1 to 6 inches thick, is exposed in a small open-cut around the shaft. Wad, friable manganese oxides, and manganiferous limonite and chert are present on the dump. The quartzite in the open-cut strikes about N. 40° E. and dips 30° SE. Such low-angle dips are characteristic of the broad area of quartzite underlying Scott Mountain and appear to be associated with gentle, open folds rather than with the tight folds that are typical of the region.

On the hilltop 300 feet southwest of the tunnel is an old shaft, said to be about 100 feet deep, that apparently did not intersect the ore zone. Several hundred yards farther southwest, on land owned by W. F. Tweedy, are a number of shallow shafts, and pits that found wad and manganiferous limonite (loc. 200, pl. 2).

TARDY AND FRAZIER

The Tardy and Frazier workings (loc. 107, pl. 2) are on the western flank of Scott Mountain, about 3,000 feet southwest of the Theresa mine. Manganese ore was found in a shaft sunk about 1917, and two carloads of ore are said to have been shipped at that time. The Otter River Mining Co. prospected the two properties between 1939 and 1941 by means of trenches and a shallow shaft sunk near the old shaft.

Occurrence of manganese ore appears to be restricted to the vicinity of the old shaft on the Tardy property, but the deposit is no longer exposed and its nature is not evident. Decomposed quartzite, nodular manganese oxides, and brecciated quartzite with a limonitic matrix are present on the dump. In the open fields south of this locality, extensive trenching found greenstone; there was no sign of quartzite or manganese ore. The contact between quartzite and greenstone trends southeasterly; the greenstone apparently overlies the quartzite (pl. 1).

GRASTY

The Grasty mine (locs. 110–113, pl. 2) is one of six adjoining properties (the Grasty, Mayhew, Bishop, Merritt, Dews, and Arthur properties) lying about 1¼ miles northwest of Lynch that were owned or leased by the Otter River Mining Co. Some mining and prospecting were done at several places on these properties toward the end of the last century. The Otter River Mining Co. began exploration of the Grasty and adjoining tracts about 1938 and continued work until 1942 under the direction of W. F. Maginnis; operations ceased in 1943. The area covered by these six properties has been prospected more extensively than any other comparable area in the district. About 17,000 feet of trenches were dug (mostly by a ditch-digging machine), 14 shafts were sunk, some exploratory drifts and crosscuts were driven, and numerous shallow pits were dug by the Otter River Mining Co. It is believed that the total amount of washed ore shipped from these properties between 1938 and 1943 did not exceed 200 tons.

In the spring of 1940, a detailed geologic and topographic map was made by the writer and W. R. Wagner of an area of about 2 square miles covering the six properties (pl. 11), and the more important underground openings were mapped. Additional information was obtained during a reexamination of the area in the fall of 1941.

The Grasty mine is the easternmost of the six properties and has been prospected and developed by seven shafts and numerous trenches and pits (pl. 11). The principal manganiferous zone occurs in a gully near the northern end of a lenticular quartzite belt. Three shafts were sunk with connecting underground workings that explored the zone to a depth of 93 feet and for a distance of nearly 400 feet along the strike (pl. 12). These workings were flooded and partly caved during very heavy rains in August 1940.

Two disconnected manganiferous lenses were discovered that apparently occur at the same general stratigraphic position along the contact of quartzite and mica schist. The southwestern lens is about 120 feet long and has an average thickness of 4 to 5 feet; it has a local thickness of as much as 10 feet. The lens is composed of sandy clay with rather siliceous nodular ore. It strikes about N. 30° E., and dips 70° SE. beneath a quartzite hanging wall. The maximum vertical extent of ore appears to be about 60 feet, because no ore was found on the lowest mine level (pl. 12). The northeastern lens is separated from the southwestern one by 50 feet of barren ground and is considerably smaller in size. Nodular ore occurs in three seams, 1 to 4 feet thick, enclosed in clay and sand between quartzite hanging wall and micaceous wad footwall.

The quartzite and schist country rock are now thoroughly decomposed to rotten blocks of quartzite, sand, and micaceous clay. Lenticular blocks of marble several feet thick, that doubtless are residual from marble beds which have been largely dissolved by ground waters, are present both above and below the manganese zone. The marble is white to gray in color with a coarsely crystalline texture and contains disseminated pyrite and chalcopyrite. Beds in the hanging-wall quartzite above the main manganiferous zone are a breccia of angular blocks of rotten quartzite in a clayey matrix. The brecciation is evidently the result of slumping caused by ground water leaching of soluble constituents.

To the southwest of these workings, manganese ore has been found in lesser amounts in shafts 4, 5, and 6 near the eastern contact of the quartzite lens. Thin zones of wad, as much as 3 feet thick, were discovered by trenching along the western contact of the quartzite to the west of the main workings. Wad and mica schist were also found in shaft 11, several hundred yards farther west. About 2,500 feet southwest of shaft 11, a zone of micaceous wad has been prospected by a group of trenches and by shaft 7 (just across the boundary line of the Mayhew property). Although the abundance of dark brown soil suggests the presence of marble, none is exposed.

Barite is present along the eastern contact of the main quartzite lens on the Grasty property at points about 100 yards southwest of shaft 4 and about 400 yards southwest of shaft 5. Many years ago barite was mined from a group of workings about 1,000 yards northeast of shaft 1.

MAYHEW

The principal occurrence of manganese on the Mayhew property is the zone of micaceous wad prospected in shaft 7, sixty-five feet deep, and its underground workings (pl. 11, see discussion of Grasty property above); some thin seams of soft, manganese oxides, several inches thick, occur in the wad. About 200 yards southeast of shaft 7, another zone of wad with slabby manganese oxides has been opened by trenches on the southern end of the main quartzite belt that extends southwest from the Grasty tract. The westernmost manganese lead on the Mayhew property is on the quartzite ridge, 400 to 500 yards west of shaft 7, where hard manganese oxides have been found in several trenches and pits as fissure fillings and as the matrix of brecciated quartzite and vein quartz.

BISHOP

The Bishop property (locs. 119–122, pl. 2) adjoins the Mayhew property on the southwest and west and lies at the southwestern edge of the area shown in plate 11. The Bishop mine is one of the earliest manganese mines in this part of the district; Watson (1907b, p. 241) states that 13 tons of manganese ore was shipped to England in 1885, and that about 700 tons was shipped in 1893. Copper is also reported to have been mined in former years, but production probably was negligible. Exploration by the Otter River Mining Co. consisted of over a dozen trenches and shaft 8 (35 feet deep).

Two manganiferous zones were prospected by the Otter River Mining Co., and manganese ore has been found at several other places by older prospects. The easternmost zone has been thoroughly prospected by trenches and by shaft 8. Considerable wad was found over a length of 800 feet, and seams of soft manganese oxides (1 to 3 feet thick, enclosed in quartzite) were found over a length of about 100 yards. The abundant chocolate-colored soil exposed in the trenches is interpreted to indicate the presence of white marble in this quartzite belt, although none is exposed. A lens of white marble crops out in the bed of Pocket Creek, however, about 200 yards to the west; a sample of this white marble analyzed 0.31 percent MnO (table 2). An old tunnel prospect for copper lies midway between these localities. This copper prospect is particularly noteworthy because it yields crystalline turquoise; it is the only known occurrence in the world (Schaller, 1912; Robinson, 1942). This mineral can be found now only as scarce, small fragments in the loose dump material.

The western manganese lead on the Bishop tract is on the same quartzite ridge as the western Mayhew lead. Manganese oxides also occur here as fracture fillings and as breccia matrix in quartzite and vein quartz.

MERRITT

The Merritt property (locs. 108 and 109, pl. 2) is in the northern part of the area shown in plate 11. Three manganese leads were discovered and prospected rather extensively by the Otter River Mining Co. On the easternmost lead, nodular ore was discovered in several trenches about 300 yards northeast of shaft 11, but it could not be determined whether the ore was in place or whether it was float. Specular hematite was found in quartzite in older prospects at a point a few hundred feet to the south.

The middle manganese zone was prospected by shafts 9 and 10, a short tunnel, and more than 20 trenches. This lead was found to be a narrow layer of wad containing thin slabby pieces of manganese oxides. Its average thickness is only about 10 inches; however, it persists for 1,800 feet along the strike. Thin seams of barite were found about 100 yards northeast of shaft 10. Dark brown soil along much of this quartzite belt indicates that calcareous beds are present, although no marble is exposed.

The westernmost manganese lead is associated with a narrow, persistent bed of schistose quartzite. Extensive trenching revealed only thin stringers and small nodules of hard ore with several seams of wad, 1 to 2 feet thick.

DEWS

The Dews tract, southwest of the Merritt property, has been explored by trenches and by two shafts (loc. 117, pl. 2) with connecting underground workings at a depth of 35 feet (fig. 14). A zone of wad was discovered that was about 20 to 30 feet thick in the underground openings and 50 feet thick in one of the trenches. Seams of soft manganese oxide, 1 to 2 feet thick, are present in the wad and in

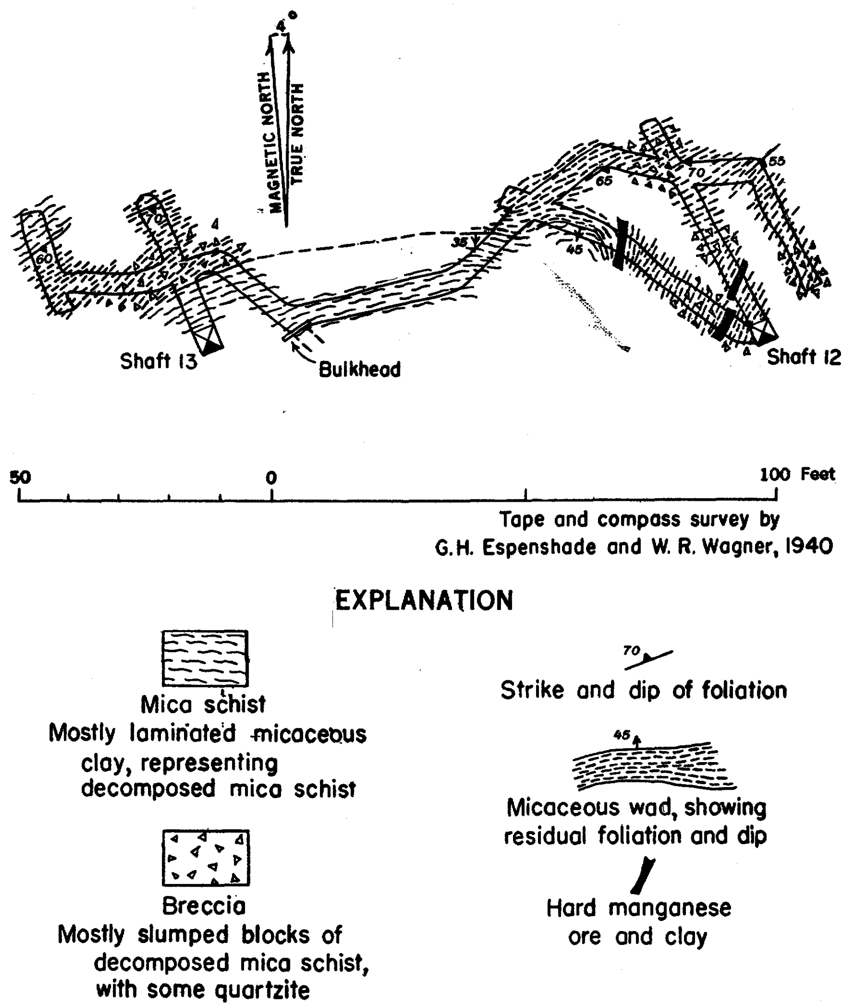

FIGURE 14.—Map of the 35-foot level, Dews mine, Campbell County, Va.

rotten quartzite; some brown chert also occurs. Soft, decomposed mica schist forms the hanging wall and footwall of the manganiferous zone. Breccia fragments of decomposed mica schist are distributed through the ore zone and are most abundant near the walls of the zone; this appears to be a slump breccia caused by ground water leaching.

The strike of the ore zone is about N. 80° E., which is more easterly than that of any of the other manganese "leads" in the vicinity. Cross folding, or faulting, may be the reason for this unusual structural trend. Geologic relationships are impossible to determine, however, because of the scarcity of outcrops. A large area, located on the drainage divide to the north and east of the Dews deposit, is completely devoid of exposures (pl. 11).

ARTHUR

On the Arthur property (loc. 118, pl. 2), southwest of the Dews tract, a zone of manganese oxides has been traced in a belt of quartzite and mica schist for a length of 1,600 feet. Wad is the predominant manganese mineral and is most abundant in the southern two-thirds of the belt where it occurs as layers of nearly pure wad as much as 10 feet thick and as layers of impure wad mixed with sand and clay as much as 40 feet thick. Shaft 14, near the southern end of the belt, is 30 feet deep.

BRAGG

The Bragg prospect is about 3 miles northeast of Leesville, which is located just north of the Roanoke River. The prospect was not seen by the writer and does not appear on plate 2; it is believed to lie northeast of the Bragg barite mine (loc. 221, pl. 2). The property was under lease to the Otter River Mining Co. during the period 1940–1941, and it is reported that manganese occurs on the property. Quartzite and white marble are exposed at the south end of the property along State Highway 43.

LUCAS

The Lucas, or Leesville, mine (loc. 125, pl. 2) is about a mile north of the village of Leesville on property owned by H. S. Lucas. Manganese was first mined about 1885, when 30 tons of ore was shipped, according to Watson (1907b, p. 241). Mr. Lucas (oral communication) states that the mine was operated by Robert Wood, who also worked the Saunders and other manganese deposits in the region in the late 19th century, and that ore was shipped to the National Paint and Manganese Co. in Lynchburg. Some mining was done about 1911 by Mr. Lucas, and about 30 tons of ore was shipped. During these periods, it is probable that most of the mining was done in a large open-cut and in underground workings from a shaft said to be 80 feet deep. In the summer of 1942, the property was prospected by H. B. Hash of Roanoke, Va.

The manganese zone occurs near the contact of quartzite and mica schist; no exposures are now visible. Micaceous wad and friable manganese oxides are present on the dump. Many blocks of streaked pink and white marble are located several hundred feet southwest of the open-cut on the dump of a tunnel driven westward toward the manganese zone. A sample of the pink carbonate analyzed 0.36 percent MnO (table 2).

About three fourths of a mile southwest of the Lucas mine are a tunnel and several shafts in the same quartzite belt (loc. 126, pl. 2).

Wad and friable manganese oxides occur on the dumps of these workings. A similar deposit in a quartzite belt about a mile east of Leesville (loc. 124, pl. 2) has been prospected by shallow diggings.

PERROW

The Perrow mine (loc. 127, pl. 2) is 3 miles southwest of Leesville, approximately on the boundary between Bedford and Campbell County. A shaft about 80 feet deep was sunk many years ago, perhaps in the eighties, and some ore is said to have been shipped. Between 1912 and 1915, H. S. Lucas (oral communication) states that he sunk another shaft 78 feet deep close to the old shaft for a Mr. Smithson and shipped about 50 tons of ore. Other pits and shafts, now caved, were put down in the vicinity.

The geology of the region south of Leesville to the Perrow mine was not mapped. It seems probable that the Perrow deposit is in an extension of the quartzite belt in which the Lucas deposit occurs. The manganese zone of the Perrow mine also is near the contact of quartzite and mica schist, and wad and friable manganese oxides are found on all the dumps of the Perrow mine.

IRON MINES AND PROSPECTS

HISTORY AND PRODUCTION

Iron ore was mined at numerous places in the district during a period of more than a hundred years (apparently beginning about the time of the Revolutionary War and ceasing about 1882). A good account of the mining operations and a description of the iron deposits, based to a considerable extent on old reports and records not generally available now, has been given by Furcron (1935, p. 81–104). The important features of his historical account are summarized below. The earliest record of iron manufacture in the region appears in a statement by Jefferson in 1781 to the effect that 1,600 tons of pig iron was being produced annually from local limonite ores at the Ross or Oxford furnace near Little Beaver Creek, Campbell County. In the early nineteenth century limonite ores were worked at various places, principally along a belt extending from near Mount Athos northeast to near the mouth of Stonewall Creek, and were smelted in local charcoal furnaces. The William Ross, or Lagrange furnace on Stonewall Creek in Appomattox County was shut down in 1843, and the nearby Stonewall furnace was abandoned in 1845. The Elk Creek furnace, on Allen Creek in Nelson County, also operated on limonite ores during this period and was finally shut down in 1850. Apparently, the Ross or Oxford furnace was last operated during the Civil War. Probably most of the limonite ore mined during this era was smelted in the local furnaces, but some ore is said to have been shipped to the old Westham furnace (later known as the Powhatan Iron Works), which was located 10 miles from Richmond.

Iron mining in the district was revived in 1879 with extensive development of specular hematite deposits in a belt extending along the western side of the James River for about 17 miles from Galts Mills to near Greenway. Mining activity expanded very rapidly, and by June 1880, nineteen iron mines were being worked along the river between Lynchburg and Greenway. By that time, more than $600,000 had been spent in purchasing and developing these properties, and over 500 men were working in the mines. The district attracted much attention and financial speculation for a brief period, but apparently by 1882 operations had ceased altogether. Closing of the mines, after this short flurry of activity, was doubtless due mainly to the high costs entailed in working small, rather low-grade deposits and to overcapitalization of the mining enterprises. Competition with the higher grade ores from the deposits being developed in the Lake Superior iron ranges was also probably a decisive factor. Production records for this period are incomplete; it is reported that 57,124 tons of ore was produced from Campbell, Amherst, and Nelson Counties during 1880, but this figure has been said to be too low. Some ore was smelted locally in Lynchburg, but much of it was shipped to Pittsburgh and to other northern furnaces. Magnetite ore has been mined in more recent years in Pittsylvania County, which is southwest of the James River belt (Watson 1907b, p. 472–474).

DESCRIPTION

Because of the few exposures and caved conditions of the mine workings, studies of these deposits at the present time yield little information beyond a knowledge of the distribution of the deposits (pls. 1 and 2), and the character of the ore and country rock as shown by the material on mine dumps. The major geologic features (as observed by the writer) and the highlights of the mining operations (as summarized by Furcron [1935, p. 81–104] from the records of Frazer, Campbell, and others) are presented below.

NELSON AND AMHERST COUNTIES

The specular hematite-magnetite deposits in the Mount Athos formation are more abundant than limonite deposits along the western side of the James River in Nelson and Amherst Counties and were worked extensively in the short-lived mining boom of the eighties. Most of the mining in these counties was done in the neighborhood of Greenway, Riverville, Stapleton, and Galts Mills. The quartzite member of the Mount Athos formation appears to have unusually large outcrop widths at these localities, and at several places it appears to be folded into rather complex, tight folds (pl. 1). The plunging nature of some ore lenses, as described by Frazer (1883), may bear some relation to these folds.

Mining operations in the eighties were conducted by Adams Scott and Company, and Dover Mining Company, and the Central Virginia Iron Co. The steeply dipping specular hematite deposits were worked mostly by underground methods; the earlier operations on limonite deposits were open-cuts. At the Greenway, or DeWitt, mines (locs. 133–135, pl. 2) over a dozen openings were made along a low quartzite ridge northwest of Greenway. Several thousand tons of ore were shipped to the Westham furnace prior to 1880, and in March 1880, production was at the rate of 50 to 75 tons daily. In June 1881, the principal mine (on what was called the No. 16 vein) was opened to a depth of 170 feet by several shafts and had been stoped along a strike length of 450 feet, according to a longitudinal section of the mine workings in Frazer's report (1883).

Mining activity at Riverville was confined mostly to two belts of quartzite west of the village; more than 50 mine workings can be found within 1½ miles of Riverville (locs. 141–149, pl. 2; fig. 4). The No. 1 shaft on this belt was 157 feet deep to the lowest level, which had a drift length of 400 feet, according to Frazer. An attempt was made to open these deposits at greater depths by driving a tunnel at canal level from the bend of the river, but this canal crosscut seems to have been advanced only 300 feet. Production from the Riverville mines in 1880 was at the rate of 50 to 75 tons daily; most of the ore went to a furnace in Lynchburg.

At Riverville, the westernmost belt of iron deposits is in quartzite that may be locally calcareous, because marble is present on one of the dumps, and the quartzite fragments on the dumps commonly have the brown porous appearance indicative of leached calcareous quartzite. A very persistent quartz-tourmaline vein, which can be traced for about 2,000 feet by float, occurs in schist in the Riverville area near the iron deposits; it is not believed to have any genetic relationship to the iron deposits.

Near Stapleton, specular hematite was mined in the eighties by Thomas Dunlap at the Maud mines (locs. 153–155, pl. 2), 1¼ miles up Partridge (Porridge) Creek from the river. Mining was mainly from several tunnels driven into the hillside at different elevations. The principal iron deposit was said to have been 1 to 2 feet thick, and Frazer (1883, p. 205) notes that it was terminated by a barren quartz body that plunged to the southwest. This structural feature is probably related to the tight folding that causes the quartzite to be exposed for nearly half a mile across the strike (pl. 1). The quartzite is similarly folded at Round Top, several miles to the southwest, where the workings of the Round Top and Lone Pine mines (locs. 156–160, pl. 2) are located. A small amount of lean ore is said to have been shipped from the Lone Pine mine in 1881.

Limonite deposits on the north side of the river were worked mainly in the vicinity of Allen Creek and supplied the old Elk Creek furnace, which was abandoned in 1850.

APPOMATTOX AND CAMPBELL COUNTIES

Most of the iron mining in Appomattox County seems to have been near Stonewall Creek (locs. 164, 165, 168, 169, pl. 2), where limonite deposits were mined at numerous places in a belt several miles long early in the 19th century. The principal deposits are in graphitic schist that carries pyrite (from which the iron in the limonite may have been derived). The ore was smelted in the two charcoal furnaces on Stonewall Creek, and the blue marble that forms the valley of Stonewall Creek was used as the flux. Limonite deposits on the Nutall property (loc. 161, pl. 2) near Beckham also provided some ore. Specular hematite and magnetite deposits were mined on the Ferguson and Isbell properties (locs. 166, 167, pl. 2) and on the south end of Chestnut Mountain (loc. 171, pl. 2). Magnetite was found in marble at the copper prospect (loc. 224, pl. 2) on Wreck Island Creek; specular hematite occurs nearby as thin stringers in white marble in the quarry now operated by the State of Virginia for agricultural lime.

In Campbell County, limonite ores were worked extensively at the Oxford and Piedmont mines (locs. 181–183, pl. 2), near Little Beaver Creek, and were smelted in the old Oxford or Ross furnace. These deposits also occur in graphitic schists and were mined from several open-cuts in a belt nearly half a mile long. The accumulations of limonite ore appear to have been among the largest in the region. Their proximity to the Piedmont manganese mine, the largest manganese deposit known in the district, suggests that conditions may have been especially favorable in this locality either for the formation of limonite and manganese deposits, or for their subsequent preservation from erosion. Limonite deposits were mined at several places to the northeast, between the Oxford mine and the Stonewall Creek deposits. Numerous limonite deposits were mined and prospected farther southwest to the Roanoke River in Campbell County. Considerable limonite occurs at the Oliver mine (loc. 202, pl. 2) and at several places in the vicinity of Scott mountain, a short distance south of Otter River. Specular hematite ore was mined by the Birmingham Iron Co. during the eighties in Campbell County near Archers Creek, at the south end of Mount Athos, and on the Merritt property near Lynch in the southwest corner of the county.

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BARITE MINES AND PROSPECTS

HISTORY AND PRODUCTION

Most of the information given here on barite mining operations in the district is summarized from the accounts of Watson (1907a) and Edmundson (1938). Barite was apparently first produced in 1874 from the Hewitt mine, which was worked almost continuously from then until 1904; it was reopened later (date unknown) and mined until it was abandoned in 1933. The Hewitt mine has been the principal source of barite in the district, and according to Edmundson (1938, p. 33), this mine was the most important producer in the state. Other productive barite mines in this area are the Mattox, Phillips, Haden, and Bragg. The most recent activity in the district seems to have been the prospecting of the Carson deposit in 1937.

Barite has also been mined for many years in Pittsylvania County, southwest of this district. After abandonment of the Hewitt mine, the Barium Mining Corp. (last operators of the mine) moved the plant equipment to Pittsylvania County and worked a group of deposits near Toshes.

According to records in the files of the Virginia Geological Survey, production of barite from Campbell County during the period 1911–1935, inclusive, amounted to 102, 917 short tons of barite; ore was produced each year except during 1921 and 1922. The quantity of barite produced from 1874 through 1910 is unknown, but it must have been substantial. No barite production is recorded from the county since 1935. Probably 90 percent or more of the total production of Campbell County came from the Hewitt mine.

DESCRIPTION

The dozen or so barite mines and prospects in the district are in the southern part of the area. Several deposits are located along the valley of Beaver Creek and one of its tributaries near Rustburg; the other deposits occur farther southwest, between Evington and the Roanoke River (pls. 1 and 2). At all of these localities, barite occurs in the white marble member of the Mount Athos formation and in the overlying surficial and residual clays.

Because the exposures are sparse, little can be added to the description of the barite mines and prospects given by Edmundson (1938, p. 30–36). The deposits near Rustburg, on the Lindsay (loc. 206, pl. 2), Carson (locs. 207, 208, pl. 2), and Neighbours (loc. 209, pl. 2) properties, were prospected by shallow pits and tunnels. Thin veins of barite, a few inches thick, were found in marble; Edmundson states that at least two veins of greater thickness were found at the

Carson mine. Production from this group of deposits seems to have been negligible.

In the vicinity of Evington and north of Otter River, barite deposits have been worked in five different belts of the Mount Athos formation, from west to east across the strike as follows: (1) Haden mine (loc. 210, pl. 2), (2) Hewitt (loc. 212, pl. 2) and Burton (loc. 211, pl. 2) mines, (3) an unnamed (Phillips?) prospect (loc. 213, pl. 2) east of Flat Creek, (4) Phillips mine (loc. 214, pl. 2), and (5) Saunders mine (loc. 215, pl. 2). Operations at the Hewitt mine were the most extensive. It was mined by underground workings to a depth of 160 feet from 1874 until 1904, when excessive water resulted in closure of the mine. After reopening at an unknown later date, the mine was worked as an open-cut, which was 1,800 feet long, 200–300 feet wide at the top, and 100 feet wide at the bottom when work was stopped in 1933. Total production is unrecorded, but it was probably about 100,000 short tons of barite. Quartzite is exposed in the western wall of the cut, marble veined by barite in the bottom of the pit, and mica schist on the eastern wall. Evidently, a large portion of the material that was mined consisted of loose pieces and blocks of barite in black clay, or "umber" residual from marble, although some barite veins in marble were probably mined also. Edmundson (1938, p. 33) says that a lens of barite, about 20 feet thick, yielded over 200 tons in 1932, but he does not make clear whether the lens was in marble or in residual clay. He states further, "Since the last mining at the Hewitt encountered consolidated bedrock containing no commercial quantities of barite, it is most probable that the reserves are largely exhausted."

The other productive deposits north of Otter River near the Hewitt mine are the Phillips, from which four carloads of ore was shipped in 1931, and the Haden, which is said to have yielded over 2,500 tons of barite. The Phillips mine was worked in 1930 and 1931 by means of several shafts to a maximum depth of 60 feet and by an open-cut 12 feet deep. The Haden mine was worked as an open-cut 200 feet long and 30 feet wide. Edmundson (1938, p. 33–34) says that barite from the Phillips mine is reported to have had a relatively high iron content, but that ore from the Haden mine was exceptionally high grade.

Barite mines and prospects in Campbell County, south of Otter River, are the Mattox (locs. 216, 217, pl. 2), Grasty (locs. 218, 219, pl. 2), Wood (loc. 220, pl. 2), Bragg (loc. 221, pl. 2) and Cundiff (the latter is not shown on pls. 1 and 2). Edmundson (1938, p. 35–36) says that large quantities of barite are reported to have been produced from the Mattox and Bragg mines. Pratt (1902, p. 915–916) stated in 1901 that the Mattocks mine (probably the Mattox) had not been worked in recent years because of water interference.

COPPER MINES AND PROSPECTS

HISTORY AND PRODUCTION

Furcron (1935, p. 109–111) states that copper was mined in the Glades, Amherst County, and along Wreck Island Creek, Appomattox County, before the Revolutionary War. The ore from the Glades mines (locs. 222, 223, pl. 2) was ground and shipped to England, according to Rogers (1884, p. 88); the copper ore from the Wreck Island Creek mine (loc. 224, pl. 2) is said to have been smelted locally. Some work was done in the Glades area about 1880, in 1917–18, and again about 1945. Copper ores are said to have been mined many years ago at the old Bishop mine (loc. 225, pl. 2) in southern Campbell County. The recorded production of copper ore from the district amounts to only 15 tons, which was shipped from the Glades mine in 1880; in all probability, the unrecorded production was negligible.

DESCRIPTION

The copper deposits in the Glades along the west foot of Buffalo Ridge have been prospected at several places for a distance of 2 miles along the strike. The deposits were first mined before the Revolutionary War by a Colonel Chissel, according to Rogers (1884, p. 88). The locality was known as the "Folly" at the time of Rogers' visit, but he doesn't state whether this derisive name refers to the mining enterprise or not. Some work was done here in 1880, by Thomas Dunlap, during the iron mining boom, and 15 tons of copper ore was shipped at that time. During 1917–18, the main shaft, said to be 300 feet deep, was cleaned out by the Buffalo Ridge Development Co., but no ore was shipped. Some prospecting is also said to have been done here about 1945. The nature of the deposits is now evident only from the material on the dumps of the different shafts. The altered peridotite, or soapstone, that forms extensive belts west of Buffalo Ridge is the country rock of the copper deposits. Bornite and chalcopyrite occur as stringers and small lenses with tremolite. Furcron believed that the copper occurrences were either in Lynchburg gneiss, or at the contact of gneiss and greenstone, but all of the country rock examined by the writer appears to be peridotite, serpentine, or soapstone.

Copper is also said to have been mined along Wreck Island Creek, about 2 miles above its mouth, and smelted nearby before the Revolutionary War. Campbell (1882, p. 42, 119) states that magnetite was discovered in the eighties during a search for copper. According to Furcron, mineralization consists of stringers and disseminations of pyrite, hematite, and chalcopyrite in marble; he observed bornite and chrysocolla in a specimen of oxidized ore. No copper minerals were visible here at the time of the writer's visit, but in the marble quarry about 0.8 of a mile to the southwest, chalcopyrite and sphalerite are disseminated through narrow zones in the marble, and thin lenses of specular hematite are also present.

Chalcopyrite and pyrite are disseminated through white marble in very minor amounts at other localities in the region. At the Bishop manganese mine in southern Campbell County, attempts were made many years ago to mine what is probably a deposit of this type. The locality is noted as having the only known occurrence of crystalline turquoise (Schaller, 1912; Robinson, 1942), which is present as small aggregates of minute radiating crystals; very little of the mineral now remains scattered through the dump material.

In the area of Triassic sedimentary rocks that extends southwest from Rockfish River, copper has been found on the Dolan property (not shown on pl. 2) as malachite and small grains of bornite with small, irregular lenses of quartz and calcite.

STONE QUARRIES

White marble and quartzite beds in the Mount Athos formation, blue marble, greenstone, and the Lynchburg gneiss have been quarried for various purposes at numerous places in the area, as shown on plate 2. The larger quarries are along and near the James River east of Lynchburg, at the northern end of Jack Mountain, 1½ miles northwest of Evington, and along the Roanoke River west of Altavista. Two quarries were being operated in the area in 1942 by the State of Virginia, one produced white marble from along Wreck Island Creek for agricultural limestone, and the other produced quartzite from near the mouth of Slippery Creek for use as road metal. White and blue marble have been used mostly for making agricultural lime, as flux in the old iron furnaces, and in masonry construction; the other kinds of rock were quarried largely for railroad and highway ballast.

The occurrences of marble are described in detail by Furcron (1935, p. 60–81). The marbles vary widely in physical and chemical characteristics. The blue marble is usually fine-grained and may contain such impurities as micaceous and graphitic seams, quartzitic beds, disseminated pyrite, and irregular lenses of vein quartz; some beds are gradational to limy schist. Furcron cites analyses of blue marble by Britton in which $CaCO_3$ ranges from 65.10 to 82.45 percent, $MgCO_3$ from 2.10 to 6.02 percent, and SiO_2 from 10.98 to 26.90 percent. The white marble is usually coarsely crystalline and commonly contains schistose and quartzitic beds, and disseminated chalcopyrite and pyrite. Some white marble beds in the northern part of the area are dolomitic; Furcron gives an analysis of dolomitic marble from near Warminster that contains 54.83 percent $CaCO_3$, 33.52 percent $MgCO_3$, and 5.50 percent SiO_2.

FUTURE OUTLOOK FOR MINING

MANGANESE

An appraisal of the district's reserves of manganese ore must be based largely upon the geologic characteristics of the deposits and upon past prospecting and mining experience, because the amount of ore actually blocked out is not significant. The mode of origin of the deposits is of fundamental importance in this connection. As the manganese oxide minerals in this district seem to have been deposited by ground waters during an earlier erosion cycle, it follows that their depth below the present surface depends on their original depth below the old peneplain surface and the amount of subsequent erosion. It seems likely that minable amounts of manganese oxides do not persist to depths greater than about 350 feet; some deposits may be bottomed at much shallower depths, where ground water circulation was shallow or where the deposit has been considerably eroded since its formation. It must be realized, therefore, that below depths of several hundred feet the amount of ore will diminish and mining costs will increase, largely because of the need for greater ground support and additional pumping.

Other pertinent geologic characteristics are the lateral extent of the deposits, and the grade or content of manganese oxide nodules in the mine dirt. Only a few deposits have been found to be more than 6 feet in thickness or more than several hundred feet long; many deposits have smaller dimensions. The average grade is one part by weight of manganese oxides recoverable by washing, to 10 or 15 parts of mine dirt; in a few deposits, as in the Piedmont and Saunders, the grade was found to be higher.

Although there are numerous deposits of manganese oxides in the district, many of them are small and of relatively low grade. Half a dozen deposits of exceptional size or grade have yielded about 90 percent of the district production. The average yield of the remaining productive deposits has been only a few hundred tons of washed ore.

From available information on all of the individual deposits, it is concluded that the total reserves of hard manganese oxide ore in the district are probably not more than 10,000 long tons of washed ore. These reserves are distributed in about 30 deposits and are estimated to a depth of 100 feet beneath the surface—except for the Piedmont (Campbell County) and Saunders mines, where ore is known to extend below present mine workings. Under normal economic conditions, probably not much of this ore could be mined at a profit; production would be small and erratic, as it has been since 1920.

If exploration and mining in the district were stimulated by very high prices for manganese ores during a national emergency (prices considerably higher than during World War II) production from the district probably would increase, and new discoveries might be made that would increase estimates of the ore reserves. Even under the most favorable conditions, however, it is unlikely that the district could produce more than several thousand tons of washed ore annually for more than a few years.

If suitable methods are developed for beneficiating the wad ores, these ores may at some future time be considered as a source of manganese. Little information is available on the size or grade of these deposits. They appear to have a larger lateral extent, but to be much shallower, than the deposits of hard manganese oxides. Individual deposits probably range in size from 10,000 to 30,000 tons and have an average grade of 5 to 10 percent manganese. Probably, at least a dozen wad deposits of this size exist in the district. Thus, the total reserves of manganese contained in such ores may be several times the amount of manganese in the nodular ores. Exploration and sampling would be necessary to determine the reserves of wad ores in the district.

A few generalizations may be made about the localities that seem to be most favorable for future exploration for hard oxides and wad ores. In the region of Beckham and Gowans Hill, Appomattox County, float of hard manganese oxides is found in approximately a dozen places, but scarcely any prospecting has been done. On the premise that the larger and better grade deposits were formed under the most favorable geologic conditions, the search for these deposits might best be emphasized in the vicinity (within a mile or two) of such deposits as the Leets, Piedmont (Campbell County), Saunders, and others. Wad deposits seem to be directly associated with the larger bodies of white marble. Deposits, known or considered to have large amounts of wad, are the Simpson, Old Tavern, Piedmont (Campbell County), Lindsay, Bell, McGehee, Mortimer, Pribble, Russell Den Hollow, Bishop, Dews, Arthur, Lucas, and Perrow mines.

IRON

The reserves of iron ore in the district are small. The limonite deposits, formed by circulating ground waters, are shallow and do not persist in depth; the larger limonite deposits have essentially been mined out. The specular hematite deposits are interbedded with quartzite and schist and can be expected to persist in depth with little change in size or grade. However, these deposits are small in size, and the ore is highly siliceous.

BARITE

An appraisal of the future possibilities for barite mining in the district is difficult because of the scanty information on the geologic characteristics, the size and grade of the deposits, and the past production of individual deposits. Although most of the deposits seem to be small, the Hewitt mine yielded about 100,000 tons of barite. Possibly the Hewitt deposit was the only one of large size, or there may be others awaiting discovery. Any exploration program probably should be conducted on a modest scale in the vicinity of known deposits, and a special effort should be made to ascertain the geologic characteristics of the deposits, as well as their size and grade. It must be borne in mind that barite occurs both as fragments in the surficial and residual clays derived from the weathering of calcareous rocks and as veins in marble. The overlying clays should first be trenched and test-pitted to sample and delineate the near-surface accumulation of barite. If indications of good-sized veins are found, they can be explored by deeper test pits, and later by drilling, should such a program seem to be warranted.

COPPER

The reserves of copper ore in the district are judged to be insignificant.

STONE

Quartzite, greenstone, and marble are abundant in the region and could be quarried more extensively than in the past. Both white and blue marble are of widespread occurrence and are particularly abundant along both sides of the James River. A number of good quarry sites can be found with marble beds at least 100 feet thick, favorable topographic conditions, and adequate transportation facilities.

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INDEX

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