COMMONWEALTH OF VIRGINIA

STATE COMMISSION ON CONSERVATION AND DEVELOPMENT

VIRGINIA GEOLOGICAL SURVEY

ARTHUR BEVAN, *State Geologist*

Bulletin 43

Zinc and Lead Region of Southwestern Virginia

With a Section on the Occurrences of Zinc and Lead in Virginia

BY

L. W. CURRIER

PREPARED IN COOPERATION WITH THE UNITED STATES GEOLOGICAL SURVEY

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STATE COMMISSION ON CONSERVATION AND DEVELOPMENT

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LETTER OF TRANSMITTAL

COMMONWEALTH OF VIRGINIA

VIRGINIA GEOLOGICAL SURVEY

UNIVERSITY OF VIRGINIA

CHARLOTTESVILLE, VA., December 1, 1934.

To the State Commission on Conservation and Development:

GENTLEMEN:

I have the honor to transmit and to recommend for publication as Bulletin 43 of the Virginia Geological Survey series of reports the manuscript and illustrations of a report on the *Zinc and Lead Region of Southwestern Virginia,* with a Section on the *Occurrences of Zinc and Lead in Virginia,* by Dr. L. W. Currier of the United States Geological Survey.

This report is one of several prepared in cooperation with the United States Geological Survey on the geology and mineral resources of Virginia. The physical characteristics and structure of the rocks in, and associated with, the mineralized areas in Smyth and Wythe counties and the geologic relations and economic geology of the mineral deposits are discussed. A part of the report contains a summary of information on other known occurrences of lead and zinc in twelve counties in the Valley and Piedmont provinces of Virginia.

Lead was first mined in this region in 1750 and zinc in 1879. The only report issued by the State on these mineral deposits was that by Dr. Thomas L. Watson, "Lead and Zinc Deposits of Virginia," published in 1905 as Bulletin 1 of the Geological Survey of Virginia, authorized by the Virginia Board of Agriculture and Immigration and the Board of Visitors of the Virginia Polytechnic Institute. Since those studies were made there have been considerable prospecting and mining in the district and notable advances have been made in the interpretation of Valley stratigraphy and structure and in the science of economic geology.

As this report treats in detail of the geology of the mineral belt and gives interpretations of the structure, geologic relations, and origin of the mineral deposits, it should be of interest and value to prospectors, mineral operators, and others interested in the geology and mineral resources of southwestern Virginia.

Respectfully submitted,

ARTHUR BEVAN,
State Geologist.

Approved for publication:
State Commission on Conservation and Development,
Richmond, Virginia, December 18, 1934.
R. A. GILLIAM, *Executive Secretary and Treasurer.*

CONTENTS

PAGE

ILLUSTRATIONS

TABLE

ABSTRACT

The southwestern Virginia zinc-lead region occupies a position within the Great Valley about midway between Roanoke and Bristol. Mines, prospects, and mineral exposures are scattered through a belt about 50 miles long and 3 to 6 miles wide, in which the underlying Shady dolomite beds have been folded, faulted, and highly brecciated by orogenic forces and subsequently have been exposed by erosion.

The area mapped for this report comprises parts of Dublin and Rye valleys which are underlain by large areas of Shady dolomite. It is bounded along most of its south and southeast sides by Lower Cambrian quartzite, which occurs largely as overthrust blocks, and on its northwest and north sides in part by areas of Erwin quartzite and in part by areas of the Rome (†Watauga) formation and higher beds. The belts of outcrop of Shady dolomite show much deformation by folding, faulting, and brecciation.

The zinc and lead minerals occupy zones of brecciation within the Shady dolomite beds, and it is believed that the brecciation of these beds was effected by the same orogenic forces that produced the thrust and associated faults of the region.

Cross faults, probably flaws or "tear faults," and general zones of cross fracturing ("sheeted zones") are present, and their development doubtless contributed to the intense brecciation that facilitated the circulation of mineralizing solutions. It is believed that these solutions rose along faults, possibly cross faults, from fairly deep zones, in contradistinction to the zone near the surface where meteoric waters circulate. Also it is believed that the thick covers of Rome shale beds over the Shady formation may have effectively prevented appreciable deposition of minerals in the higher beds, at least to the extent of forming large ore bodies. No opinion is offered as to the ultimate sources of the mineralizing solutions and their contents.

The characteristics of the breccias are described and their origin discussed. They are believed to be of tectonic origin, directly connected with Appalachian orogeny.

The stratigraphy and structure of the region are described in some detail, with references. The history of zinc-lead mining operations in southwestern Virginia is outlined. A section on the occurrences of lead and zinc minerals in Virginia contains brief statements, derived either from personal observation or from the literature, concerning prospects where zinc minerals have been found, with or without other metals.

Zinc and Lead Region of Southwestern Virginia

By L. W. Currier

INTRODUCTION

Renewed activity in recent years in the zinc and lead mining region of southwestern Virginia has created a demand for geologic information that could not be adequately met by old reports dealing with the region. A new study was planned in the autumn of 1930 by Arthur Bevan, State Geologist, as a cooperative project between the Virginia Geological Survey and the United States Geological Survey. This study was assigned to the writer under the immediate supervision of D. F. Hewett, of the United States Geological Survey, who had studied deposits of generally similar character in southern Nevada and who was keenly interested in the structural and mineralogic features involved. Mr. Hewett spent several days in the Virginia area with the writer in October, 1930, to start the work, and also made a brief visit to the field in April, 1931. In addition, he and the writer spent three weeks in eastern Tennessee visiting and studying several mines and prospects. He was also available for consultation during the office work on the report. Charles Butts, of the United States Geological Survey, who is thoroughly informed on the general stratigraphy of the region, was also very helpful in pointing out typical features and limits of stratigraphic units at the beginning of the field work and again in April, 1931. The State Geologist has facilitated the work in many ways during its progress. The writer is also indebted to Mr. Charles Huddle, of Ivanhoe, resident engineer of the Ivanhoe Mining & Smelting Corporation, who has made available valuable data relating to the Austinville-Ivanhoe area.

The field work in the area mapped was done during a month and a half in October and November, 1930, and three and a half months in the spring and summer of 1931. During the field season of 1931 the writer was capably assisted by H. E. Thomas.

In the spring of 1934, the writer directed a brief program of additional field work in the area under the auspices of the Public Works Administration. The field work at this time was done by Messrs. Benjamin Gildersleeve and Robert A. Laurence. Mr. Gildersleeve carried the mapping westerly from the west ends of Rich and Short mountains, and also investigated the broader structural relation of the Brushy mountain area, carrying the traverse along the north side of this ridge easterly and southerly to the vicinity of Cedar Springs. Mr. Laurence traversed the west, north, and east sides of Lick Mountain. The klippe character of these ridges was demonstrated by this work, although time available did not permit a complete detailed mapping of the local areas involved.

Mr. Gildersleeve mapped also the local area of Hampton shale at New Castleton School.

OBJECT OF REPORT

The purpose of this preliminary report is to describe the major features of the stratigraphy and structural geology of the southwestern Virginia zinc-lead area in their mutual and regional relations, as an aid to persons who are engaged in mining or prospecting or are anticipating such activities and to others who are interested in the scientific aspects of Appalachian metalliferous regions. Limitations of time and denial of access to the most important underground workings have prevented the presentation of a more complete report at this time.

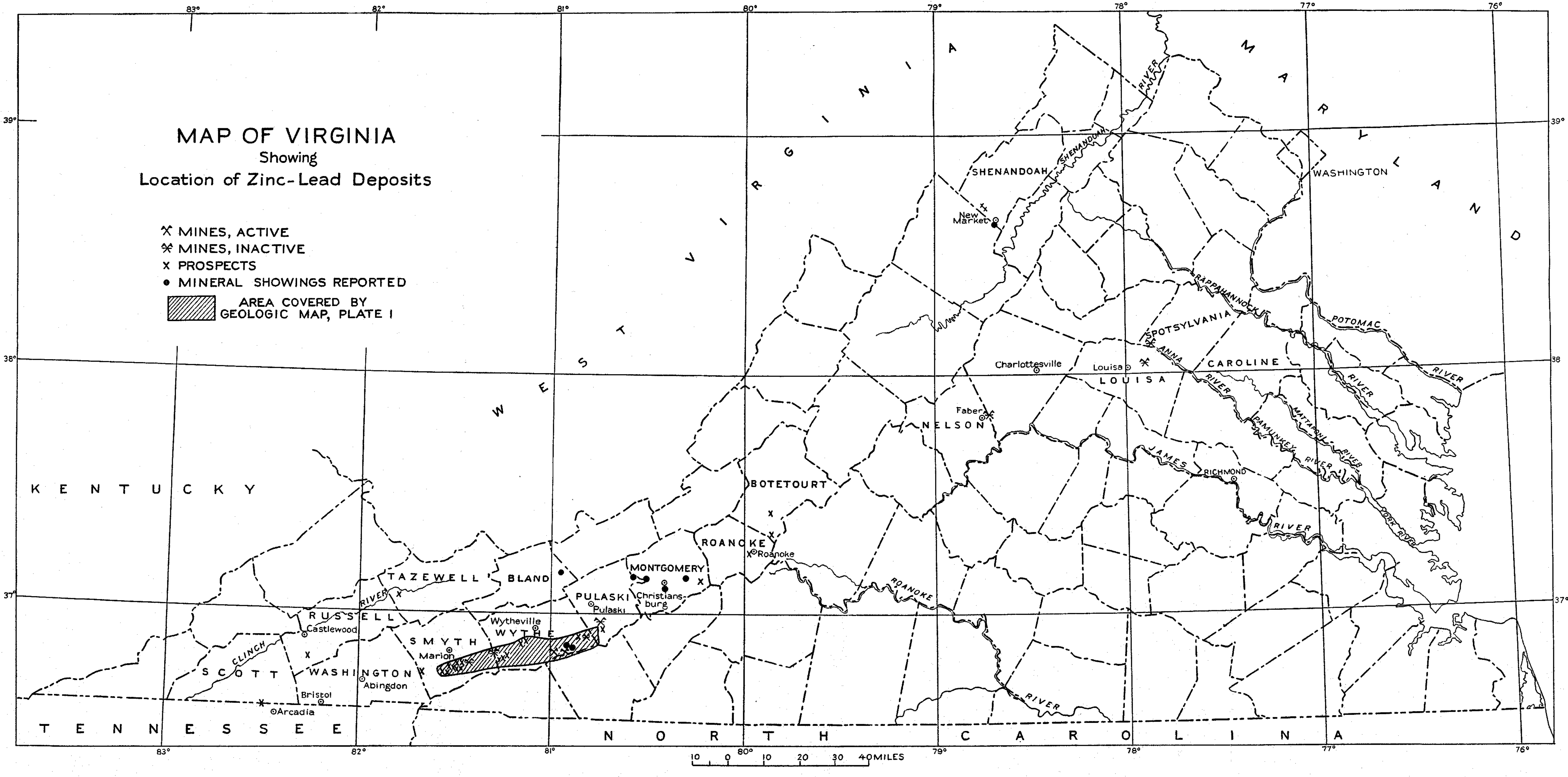
AREA COVERED BY REPORT

The area covered by geologic mapping in preparation for this report is about 55 miles long and from 2 to 7 miles wide. It extends from the eastern border of the Max Meadows quadrangle, in longitude 80° 45′, to a point about 12 miles southwest of Marion, in the Abingdon quadrangle, at approximately longitude 81° 40′. It follows the lines of outcrop of the Shady dolomite in the part of the Valley of Virginia bordering and immediately north of the southwestern extension of the Blue Ridge, within the latitudes 36° 42′ and 36° 50′. The strip so mapped is not of uniform width, as it was found desirable to examine areas of the Shady dolomite that include known prospects. The area is shown on the index map, Plate 3.

The eastern half of the area is included in the Max Meadows and Speedwell quadrangles, topographic contour maps of which have been surveyed by the State of Virginia in cooperation with the United States Geological Survey. The western half is included in the uncompleted maps of the Rural Retreat and Marion quadrangles, and for this part of the area surveyed maps of only the roads and streams of the quadrangles were available, so that the geologic mapping of this part of the area was necessarily less detailed than would have been the case had complete contour maps been available.

HISTORY

Zinc deposits have long been known to exist at many places in western and southwestern Virginia. With only a few exceptions the reported occurrences are confined to the Appalachian Valley and Ridge



MAP OF VIRGINIA
Showing
Location of Zinc-Lead Deposits
MINES, ACTIVE
MINES, INACTIVE
X PROSPECTS
• MINERAL SHOWINGS REPORTED
AREA COVERED BY GEOLOGIC MAP, PLATE I
WEST VIRGINIA
MARYLAND
KENTUCKY
TENNESSEE
NORTH CAROLINA
WASHINGTON
SHENANDOAH
New Market
SPOTSYLVANIA
CAROLINE
Charlottesville
Louisa
LOUISA
Faber
NELSON
RICHMOND
BOTETOURT
ROANOKE
Roanoke
MONTGOMERY
Christiansburg
PULASKI
Pulaski
BLAND
TAZEWELL
RUSSELL
Castlewood
Wytheville
WYTHE
SMYTH
Marion
WASHINGTON
Abingdon
SCOTT
Bristol
Arcadia
POTOMAC RIVER
RAPPAHANNOCK RIVER
SHENANDOAH RIVER
NORTH ANNA RIVER
MATTAPONI RIVER
PAMUNKEY RIVER
YORK RIVER
JAMES RIVER
ROANOKE RIVER
CLINCH RIVER
10 0 10 20 30 40 MILES
83° 82° 81° 80° 79° 78° 77° 76°
39° 38° 37°

province, known also as the Great Valley, where the underlying limestones and dolomites apparently favored localization of zinc and lead minerals. At comparatively few points are these minerals known to be sufficiently concentrated to warrant exploitation. Indeed, systematic and continuous mining has been carried on only in the vicinity of Austinville, on New River, where the mine of the Bertha Mineral Co. is located. At Ivanhoe, about 2½ miles west of this point, the Ivanhoe Mining & Smelting Corporation is obtaining zinc ores from small shallow workings in the clay overburden, with the expectancy of deeper mining at some future time. Considerable prospecting has been done by pits and drill holes in the Austinville-Ivanhoe district. At numerous more remote points, all included within the Valley from Bonsacks, 6 miles east of Roanoke, nearly to Holston Mill, 6 miles southwest of Marion, some prospecting has been done, partly by drilling but mostly by pits and shallow shafts.

Oxidized zinc ores of high quality were mined for several years at Bertha, 7 miles northeast of Austinville, where systematic zinc mining in Virginia is reported to have begun. At Cedar Springs, 14 miles southwest of Wytheville, zinc blende ores were mined for a short time, and at Sugar Grove several shafts were sunk on a lead vein from which, it is reported, 30 carloads of ore were shipped. The index map of southwestern Virginia (Pl. 3) shows location of mines, prospects, and reported occurrences of zinc and lead minerals.

Lead mining in Virginia probably began about 1750, when Colonel Chiswell, a British officer, commenced operations at Austinville, in Wythe County. He has, indeed, been credited with the original discovery at the point between Austinville and Ivanhoe where New River crosses an anticline in the Shady (Lower Cambrian) dolomite and has exposed this formation in a high bluff (Pl. 4, A) that clearly displays the structure at close range. At this place sulphides of lead, zinc, and iron, with associated white coarse gangue dolomite, are rather abundantly disseminated in the lower "ribbony," dark dolomite member of the Shady dolomite. Here Chiswell started a tunnel a few feet above the river level, but apparently this operation was abandoned after he had penetrated the rock for about 25 feet. He continued production of lead ore at Austinville through a period of 25 years, until the beginning of the Revolutionary War, when, being an ardent Tory, he became involved in political difficulties. His property—if, indeed, he ever held title—reverted to the State of Virginia. It is reported that between 1776 and 1780 General Washington detailed men to work this mine to provide lead for the use of his armies. Some time between 1780 and 1800 the lands were bought by Stephen and Moses Austin, who later rented the property to Captain Newel. Newel was probably the first to work the carbonate of lead, which was then abundant.

James Mease,[1] writing in 1807, refers to these mines as belonging to the American Lead Mine Co., and makes the following interesting statement:

"The lead ore is dug from the mines, smelted into pigs, and manufactured into shot and sheet lead on the same spot, a circumstance which is not to be met with in any other part of the world. . . . The company have employed a number of the most experienced English workmen, all of whom agree that these mines appear to have an inexhaustible quantity of ore; for having as yet dug about 100 feet from the surface of the earth, they find the ore, as they go deeper, increases both in quantity and purity. This induces a belief that if they could go from 200 to 300 feet, the ore would be found in much greater abundance, and superior quality."

In 1805 the property reverted to the State and was sold at public auction. From then until 1838 little mining was done.

In 1838 the Wythe Lead Mines Co. was formed, acquired the property, and began systematic development. A crosscut adit from the bluff to the ore body was started in 1839 and completed to a length of 1,527 feet in 1851. From 1838 to 1848, 6,511,450 pounds of lead was produced. In 1848 a new company, the Wythe Union Lead Mine, was formed, and during the period 1848-1858 it produced 7,613,634 pounds of lead. The Union Lead Mine Co. was incorporated about 1860, and it is said that until 1864, when the plant was destroyed by Federal troops, this company furnished most of the lead used by Confederate armies east of Mississippi River. The estimated production from 1858 to December 17, 1864 (the date of destruction) was 5,750,000 pounds. In 1864 also zinc ores were sent to Petersburg, Va., for trial smelting, and shortly after the war definite shipments of oxidized zinc ores were made. In October, 1865, the production of lead ores was resumed. The Wythe Lead & Zinc Mining Co. acquired the property about 1874 and sold it in 1902 to the Bertha Mineral Co., which has since become a subsidiary of the New Jersey Zinc Co.

Oxidized zinc ores were discovered in the Bertha territory, 6 to 8 miles northeast of Austinville, as early as 1866, by David S. Forney, and the Bertha open-cut mines were first opened in 1879. Chief among the properties operated in the following two decades were those of the Bertha Zinc & Mineral Co., Manning & Squiers, and the Falling Cliff tract. Production from the area continued to 1898, when the Pulaski Iron Co. leased the properties for the mining of limonite iron ores, with which the zinc ores are associated. During the progress of iron mining some zinc was produced, and in later years there was some reworking of tailings. In 1902 the Bertha Mineral Co. opened a surface cut in the "soft" ores near Delton, and produced oxidized ores for about a year and a half.

[1] Mease, James, A geological account of the United States, p. 419, Philadelphia, 1807.

At Ivanhoe the last decade has seen considerable prospecting and some development. Mining on the iron properties of the New River Mineral Co., just west of Ivanhoe, dates from the early seventies, and it is reported that in the course of operation much oxidized zinc ore was shipped. Lately these properties have come under the ownership of the Ivanhoe Mining & Smelting Corporation, which is producing oxidized zinc ores from shallow workings at Ivanhoe. An 80-foot shaft was sunk into sulphide ore but is not now worked. Since 1925 others have prospected, chiefly by drilling, in the Ivanhoe area.

The valley from Cedar Springs nearly to Adwolf, more especially at Cedar Springs and Sugar Grove, has, in past years, been the scene of prospecting and some mining. There was a brief period of shallow mining at each of these localities, chiefly within the decade 1897-1907. The operations at Sugar Grove were for the mining of lead ore (galena), and it is reported that 30 carloads were shipped. Later a rather elaborate concentrating plant was erected, but it appears that little mining was done at this time, and the mine has since been abandoned.

At present the only shaft mining for lead or zinc in Virginia is that done by the Bertha Mineral Co., at Austinville.

GEOGRAPHY AND GEOMORPHOLOGY

The area mapped comprises parts of Dublin and Rye valleys, divisions of the Valley of Virginia, and extends from Reed Junction, on the eastern edge of the Max Meadows quadrangle, southwesterly and westerly across the Speedwell and Rural Retreat quadrangles nearly to Adwolf, about 12 miles southwest of Marion, in the Abingdon quadrangle. This strip is about 55 miles long and averages about 4½ miles in width, covering a total area of approximately 250 square miles.

Essentially it is an area within which the Lower Cambrian (Shady) dolomite is exposed, this formation appearing in several generally parallel strips along the valley. The area is limited on the south by Dry Pond, Poplar Camp, and Iron mountains, or their associated ridges, which are the southwestern extensions of the Blue Ridge. Within the area are several ridges from 2 to 10 miles long, chiefly among which are Foster Falls, Lick, Henley, Sand, and Brushy mountains. All these mountain ridges are composed of Lower Cambrian quartzites and quartzitic shales, rocks of superior resistance to erosion in this region, as shown in Pl. 18, A. The ridges are steep-sided and narrow-crested and rise generally to altitudes of 2,700 to 3,500 feet. The intervening valleys are comparatively broad, more uniform in altitude, and underlain by the much less resistant dolomites, limestones, and shales of the Shady and Rome formations. The area underlain by the Rome formation commonly has characteristic low, short ridges with rounded crests, such as Sanders, Raper, and Chestnut ridges, near Laswell, or the groups of still shorter ridges on the north side of New River between Allison and Reed Junction and on the north side of Cripple Creek from Gleaves Knob to Cedar Springs. Gleaves Knob (Pl. 5, A) is capped with Erwin (Lower Cambrian) quartzite. The lower and flatter portions of the valley floor are consistently underlain by the soluble limestones and dolomites of the Shady formation, and it is in these parts of the valley that the known deposits of zinc and lead occur.

New River enters the area from the south through a deep gap cut across the quartzite ridge just above Ivanhoe. Its course at this point is northwestward, which is at right angles to the general regional trend of the rocks but within the valley it has adapted its course to the regional trend, about N. 55°-60°E., and flows in this direction through the eastern part of the area. Along this course the channel has rather broad meanders, probably an inheritance, in part at least, from an earlier stage when the stream flowed sinuously over a flood plain that is now represented by a gravel-covered terrace level above the present valley floor. Regional uplift of this earlier valley level doubtless caused a quickening of the current and hence increased its vertical erosive power, allowing it to entrench its somewhat meandering course in bedrock.

A. Part of the Austinville Basin looking from a point 1¼ miles northeast of Ivanhoe. The bluff displays a section across the axis of the Austinville anticline. Beyond the river is the Bertha Mineral Co.'s property. The Barndollar prospect shafts are on the lowland at the right. Poplar Camp Mountain is in the right background.

B. Panoramic view between the gap through Poplar Camp Mountain (right) and the base of Hematite Mountain at Jackson Ferry (left). From a point one-third of a mile west by south of Jackson Ferry. Shows topography characteristic of the Valley where underlain by the Shady dolomite. The ridges are composed of very resistant quartzite.

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B. Panoramic view between the gap through Poplar Camp Mountain (right) and the base of Hematite Mountain at Jackson Ferry (left). From a point one-third of a mile west by south of Jackson Ferry. Shows topography characteristic of the Valley where underlain by the Shady dolomite. The ridges are composed of very resistant quartzite.

The bends may not be entirely of such derivation; the position of some of them may have been due in part to zones of crossfaulting or shearing, as is suggested by conditions at the bends between Foster Falls and Reed Junction.

Near Jackson Ferry, at Foster Falls, and at Barren Springs Ferry the river has developed rapids on the harder rocks in the channel. At Jackson Ferry and Foster Falls the river flows across a prominent anticline and has cut through its structure exposing a core of hard Erwin quartzite. At Barren Springs Ferry the same quartzite, brought to its position by faulting, is exposed in the rapids.

The chief tributaries of New River are Little Reed Island Creek, which enters the area from the south across the quartzite ridges of Poplar Camp and Dry Pond mountains and joins the river at Reed Junction; Reed Island Creek, which also flows across the regional trend of the formations and joins the river on its north side about 5 miles west of Reed Junction; and Cripple Creek, which extends eastward for 24 miles from its source, about 3 miles east of Sugar Grove, and joins New River near Ivanhoe. A narrow, low saddle forms the divide between Cripple Creek on the east and the South Fork of Holston River on the west. Thus, from a point about 3 miles east of Sugar Grove the regional drainage flows eastward by way of Cripple Creek, New River, and Kanawha River to the Ohio and westward by way of the Holston and Tennessee rivers, also to the Ohio. New River, Little Reed Island Creek, and Cripple Creek are of great importance to the industrial development of the area, as the Radford Division of the Norfolk & Western Railway follows New River across the area, with branches to Sylvatus and Speedwell along Little Reed Island Creek and Cripple Creek, respectively. That part of the area west of Speedwell is without railroad transportation. The main roads are good throughout the region.

The valley floor, as represented by the summits of the lower knobs and ridges, has an altitude of 2,200 to 2,300 feet in the eastern part of the area and rises to 2,400 or 2,500 feet in the general vicinity of Speedwell; farther west it rises more abruptly and attains 3,000 feet in the Sugar Grove region. These altitudes are marked in part by a series of discontinuous terrace levels. This valley-floor level is not to be confused with the lower benches and flood plains of the present river systems. The present streams have for a long time been cutting into and lowering the earlier valley floor, as represented by the features just cited, and have entrenched themselves into the floor. In places this entrenchment is deep, as in the Barren Springs region, where the present flood-plain level of New River is more than 300 feet below the valley floor. In general, the valley-floor level represents the highest outcrop for the weaker rocks of the valley—the Shady and Rome formations—

and as these formations are everywhere beveled by it, this level may be considered a partial peneplain. Stose[2] has called this the Valley-floor peneplain. In general it is, perhaps, less marked, less uniform, and less extensive than many peneplains because of interruption rather early in its development by the regional uplift that activated the entrenchment of the present streams. Other peneplain levels are defined by Stose,[3] but they have no direct bearing on the purpose of this report and are not discussed. The reader is referred to Stose's report for a more detailed discussion of the geomorphology of the entire Valley and Ridge province.

[2] Stose, G. W., and Miser, H. D., Manganese deposits of western Virginia: Virginia Geol. Survey Bull. 23, p. 23, 1922.
[3] Idem, pp. 19-22.

STRATIGRAPHIC GEOLOGY

GENERALIZED SECTION

The formations of southwestern Virginia that are exposed in the zinc-lead area belong to the Lower and Middle Cambrian series. Detailed work in this area has disclosed a greater degree of local variability in lithology and thickness of the Rome (†Watauga) formation and Shady dolomite than has hitherto been recorded for the region. The following is a somewhat generalized columnar section for the area covered by this report.[4]

Generalized geologic section for the zinc and lead section of southwestern Virginia

Series	Formation		General Character	Thickness Feet
Upper (?) Cambrian ...... Middle Cambrian	Elbrook dolomite		Largely light-gray to white fine crystalline or dense, massive dolomites, with some thin beds of limestone, and an occasional thin red shaly bed, especially near the base. Except for some even-bedded platy dolomite and limestone beds near the base, the formation is characterized chiefly by rather massive, pure dolomites.	1,200+
Middle Cambrian	Rome (†Watauga)		Characterized by red shales, prominently sun-cracked and ripple marked, and red quartzitic sandstones; a considerable proportion of interbedded dolomites; subordinate thin limestones.	2,000 - 2,500
Lower Cambrian	Shady dolomite	Ivanhoe limestone member	Local dense, massive limestone, including subordinate dolomite beds; and few thin red shaly or sandy partings; in Austinville basin (see p. 36) probably represented in part by a series of fossiliferous limestone beds alternating with crystalline dolomites. Grades at base into saccharoidal member.	0 - 550
		Saccharoidal dolomite member	Persistent series composed chiefly of gray and white dense and crystalline dolomites, generally thick-bedded but locally platy and shaly; the most distinctive variety is nearly white and of saccharoidal texture; thin limestone beds present in places. In southern part of Austinville basin the upper part is probably represented by a series consisting largely of sandy dolomite, calcareous sandstone, limestone, breccias and crystalline dolomites.	[a]800 - 1,150
		Patterson limestone member	Chiefly dark-gray dense limestone and dolomite, both with a characteristic type of "ribbon" structure; ribbon limestone and dolomite mutually gradational in all directions, and gradational into overlying saccharoidal member. At base transition beds of dark-gray sandy dolomite or of light-gray crystalline dolomite (Sugar Grove area).	700±

A dagger (†) preceding a geologic name indicates that the name has been abandoned.
[a] Does not include estimate of thickness of upper Shady in Austinville Basin, for which see text and Plate 9.

[4] For definition of terms denoting lithologic characteristics used in description of rocks, see Appendix.

Generalized geologic section for the zinc and lead section of southwestern Virginia—Con'd

Series	Formation	General Character	Thickness Feet
Lower Cambrian	Erwin quartzite	Mostly thick-bedded blocky white or gray quartzite; contains some thin-bedded and shaly material, especially near the top; in places the quartzite is dark gray and highly ferruginous, weathering to a deep-brown color. Locally, at the top, gray dolomitic sandstone beds transitional with overlying formation.	500 - 800 (estimated)
	Hampton shale	Gray, more or less slaty and in places schistose shale, with very subordinate intercalated beds of quartzitic sandstone.	Not determined
	Unicoi formation	Chiefly quartzite and conglomeratic quartzite.	

LOWER CAMBRIAN QUARTZITE SERIES

The Lower Cambrian quartzite series of southwestern Virginia is divisible into the following formations named in descending order: Erwin quartzite, Hampton shale, and Unicoi formation. The Unicoi formation and, except at Castleton school, the Hampton shale have not been studied or mapped separately for this report. In places where the lower two formations are absent, the Erwin has been mapped separately, but elsewhere all three formations are included in a map unit, designated as "Lower Cambrian quartzite." (See Pl. 1.) In general the Unicoi formation will be found only in the large overthrust masses of the Iron and Poplar Camp mountain ridges which form the southern boundary of the area.

UNICOI FORMATION

The Unicoi is the lowest Paleozoic formation of southwestern Virginia and directly overlies the pre-Cambrian crystalline complex. Cuts along the highways through gaps in the Iron Mountain and Poplar Camp ridges expose all formations from Erwin quartzite to pre-Cambrian crystalline schists. The schists are too remote from the zinc region to be considered in this report. The Unicoi beds are closely folded with Hampton shale and Erwin quartzite in the ridges along the southern boundary of the area but have no distinctive relation to the zinc deposits and were, therefore, not mapped separately during this investigation.

The Unicoi formation is composed of gray and brown (ferruginous) quartzite, quartzitic conglomerate, sandstone, slaty (argillaceous) sandstone, and arkose and in places shows interbedded amygdaloidal lavas. The thickness of the formation is stated to be 1,750 to 2,000 feet.[5]

About 5 miles south of Speedwell, along the highway, and about half a mile south of the crest of Iron Mountain, an exposure shows amygdaloidal lava beds within Unicoi conglomerate and quartzite.

HAMPTON SHALE

The Unicoi formation is overlain by the Hampton shale. Although for the most part the Hampton is composed of shale, it contains some intercalated beds of quartzite, more abundantly near the top, which resemble some beds found in the overlying Erwin quartzite. Indeed, there seems to be no persistent and sharp limit between the two formations, and it is probable that the upper shale layers would be found to grade laterally into beds assignable to the lower Erwin. In general, however, the marked predominance of thin-bedded material, chiefly shale, distinguishes the formation, especially where it underlies a considerable thickness of fairly massive quartzite beds. There are shaly zones near the top of the Erwin quartzite, but so far as observed they are nowhere of great thickness. Plate 5, B shows some massive beds interstratified with predominant shale.

Although the rocks are dominantly medium to dark gray and argillaceous, weathered exposures show yellow, brown, and even reddish colors, due to oxidation of the iron content. Doubtless the more sandy, thicker bedded layers show this to a greater degree than the rest. In places the shale is slightly schistose and displays fine mica plates.

It was impracticable to map the Hampton shale as a separate unit, because of the time needed and the lack of significance in relation to the area as a zinc- and lead-bearing region. Where it appears, it has been mapped with the Erwin quartzite and Unicoi formation.

Exposures of the Hampton are generally to be found in the road cuts well within the gaps across the mountain ridges along the southern border of the area. It is exposed, for example, in the gap made by New River about 2 miles south of the ferry at Ivanhoe, just within the gap at Poplar Camp, and in the gap made by Dry Run about 2¾ miles south of Speedwell. Exposures also appear about 2 miles north of Sugar Grove along the highway that crosses Brushy Mountain, between Sugar Grove and Marion. Gray sandy shales, slightly schistose, weathering yellow, red, and brown, exposed between New Castleton School and the base of Poplar Camp Mountain, apparently belong to this formation, for they are similar to shale beds found in the quartzite ridges to the south and southeast, and to shale beds exposed between quartzite beds on the north side of Lick Mountain, but the correlation is not certain.

[5] Stose, G. W., and others, Manganese deposits of the west foot of the Blue Ridge, Virginia: Virginia Geol. Survey Bull. 17, p. 14, 1919.

No attempt was made to determine the thickness of the formation in this area. Others record the thickness as varying from 400 to more than 600 feet, but because of the relative weakness of the beds and the ease with which they are repeated by folding, as well as the probable lateral gradation into massive quartzite, it is difficult to obtain an accurate measure of the thickness.

ERWIN QUARTZITE

The Erwin quartzite is the formation next above the Hampton shale. In part it has been mapped with the underlying Cambrian rocks, but in places, where a discrimination added to the local structural interpretation, it has been mapped as a separate unit.

The most characteristic feature of the Erwin is the presence of dominant thick-bedded and massive quartzite. Although characteristically the formation is a clear white quartzite, in this area it is commonly dark colored. It appears brown on weathered surfaces. Locally the freshly broken rock may be dark reddish brown owing to oxidation of its high iron content, as may be seen at the bend of the highway to Jackson Ferry half a mile southeast of Galena. Here the top beds of the Erwin are exposed in conformable contact with the Shady dolomite. About 20 feet of transition beds separate the two formations. The dark, "warty" (nodular), and "ribbony" Shady dolomite contains an abundance of pyrite. Iron ores were mined on top of the ridge practically at the Shady-Erwin contact. Along the road section the shaly to blocky Erwin quartzite (Pl. 6, A) is highly ferruginous with limonite and also contains pyrite. In part the fresh rock is dark gray. A section of the exposure at this point is as follows:

Geologic section 1.—Section of Erwin quartzite and transition beds in lower part of Shady dolomite at bend of highway half a mile southeast of Galena, Va.

	Feet
Shady dolomite:	
Dolomite, dark gray, "warty"; imperfect ribbon structure	4
Concealed interval	5
Dolomite, dark gray, slightly "warty"	5
Dolomite, gray, very fine crystalline	4
Dolomite, light gray, fine crystalline	6
Dolomite, dark gray, slightly sandy	8
Dolomite, light gray, sandy	15
Sandstone, gray dolomitic	3
Erwin quartzite:	
Shaly quartzite, ferruginous; glauconitic streaks at top	3
Quartzite, dark gray in part, highly ferruginous with limonite and pyrite	15

In this area thin-bedded, platy to shaly sandstones are abundant. Generally the shaly portions are of distinctly arenaceous character, but thin beds of argillaceous quality are not wanting. The thick-bedded white quartzitic portions are in part conglomeratic with a content of very small, well-rounded pebbles. Plate 7, A shows both massive and shaly beds in an exposure at the west end of Henley Mountain.

The formation is generally nonfossiliferous in this region. Rarely scolithus tubes are found.

The Erwin quartzite is everywhere highly resistant to weathering and erosion and makes up most of the higher ridges of the area. The ridges thus formed stand prominently above the adjoining valley areas and have comparatively steep sides of fairly uniform gradient, and narrow crests. Commonly they rise 400 to 1,000 feet above the general valley level. This formation largely forms Dry Pond, Foster Falls, Ewing, Lick, Sand, Henley, Bowling Green, Chestnut Ridge, Pond, Rich, and Brushy mountains and part of the Iron Mountain and Poplar Camp Mountain range along the southern border of the area. Gleaves Knob is capped by the formation. Along the slopes of all these ridges exposures are rare, except in the transecting gaps or well up on the mountain sides and near the crests, because the apron of talus and slope wash along the flanks is so thick, broad, and extensive. In places this apron extends for 2,000 feet or more from the steep slope of the ridge. This condition has made it impossible to observe the contact with younger formations for many miles along the southern border of the valley. Some of the more easily accessible points where the formation may be seen in good exposures are at the east end of Foster Falls Mountain in the gap made by Periwinkle Branch; half a mile southeast of Galena (Geologic section 1); along the road in the gap about 1½ miles south of Ivanhoe; at Eagle Cliff on Cripple Creek, between Ivanhoe and Cripple Creek; in the road cut at the west end of Henley Mountain (Pl. 7, A); at the gap south of Sugar Grove; and along the highway transecting the ridges 4 to 5 miles southeast of Adwolf, near the western limit of the area. At all these points the exposure is at or near the contact with the overlying formation. The following section appears at the last mentioned locality:

Geologic section 2.—Section of Erwin quartzite along highway 4 miles southeast of Adwolf

	Feet
Shady dolomite.	
Erwin quartzite:	
Quartzite, white, massive, coarse grained	10
Quartzite, gray, platy to thick blocky	29
Concealed interval	3
Quartzite, gray, platy to thick blocky	28
Quartzite, gray, thin platy	5
Quartzite, gray, platy to massive	54
Concealed interval	5
Quartzite, white, chiefly massive	30
Concealed interval	29
Shale, quartzitic, slaty, dark gray	47
Quartzite, white, weathering light brown, massive	5
Quartzite, gray, shaly	5
Quartzite, light gray, chiefly blocky and massive; some shaly partings	70+

SHADY DOLOMITE (LOWER CAMBRIAN)

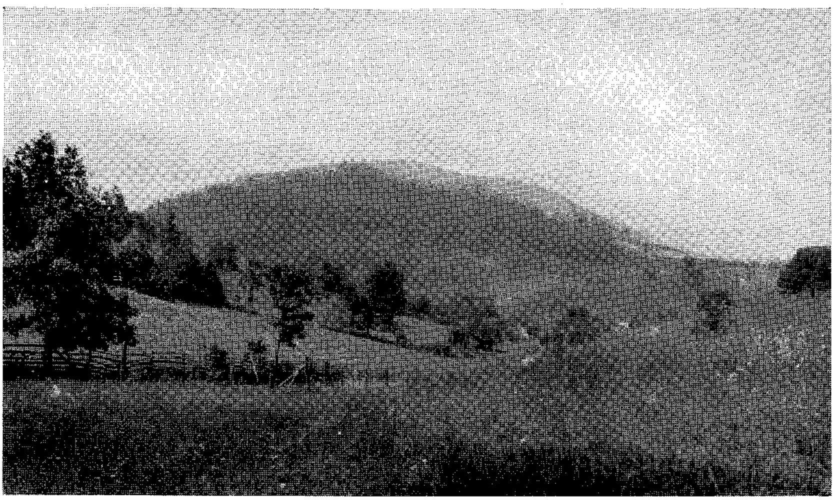
GENERAL FEATURES

The Shady dolomite overlies the Erwin quartzite conformably. Transitional sandy dolomite beds, varying in thickness and lithologic character, are here included with the Shady.

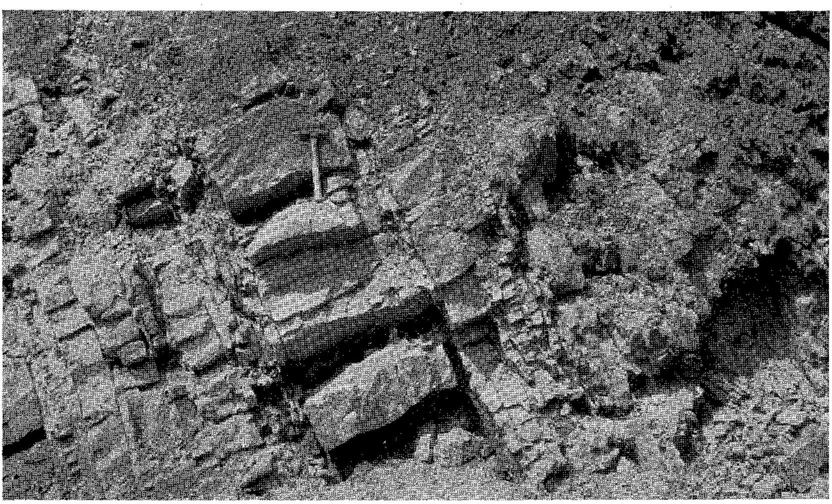
The Shady is divisible into three members on the basis of persistent lithologic characteristics and sequence. The lower, the Patterson limestone member, was named by Charles Butts[6] from the extensive exposure at Patterson. The middle member, which alone is persistent throughout the area, is composed of crystalline dolomite, in part of characteristic saccharoidal appearance, and is referred to as the saccharoidal dolomite member. It is probably the only persistent representative of the Shady throughout the Great Valley region. The upper member, here named the Ivanhoe limestone member, is restricted as a recognizable unit to the general synclinal basin extending from Huddle, about 3½ miles west of Ivanhoe, to Bertha, about 6 miles northeast of Austinville. As a mappable unit, however, it is limited to the area between Huddle and Galena.

Deep secular decay is characteristic of the Shady formation, especially below the Valley-floor peneplain. The resulting extensive, thick clay mantle has caused a paucity of exposures over large areas. The effect of weathering and leaching is illustrated in Plate 6, B.

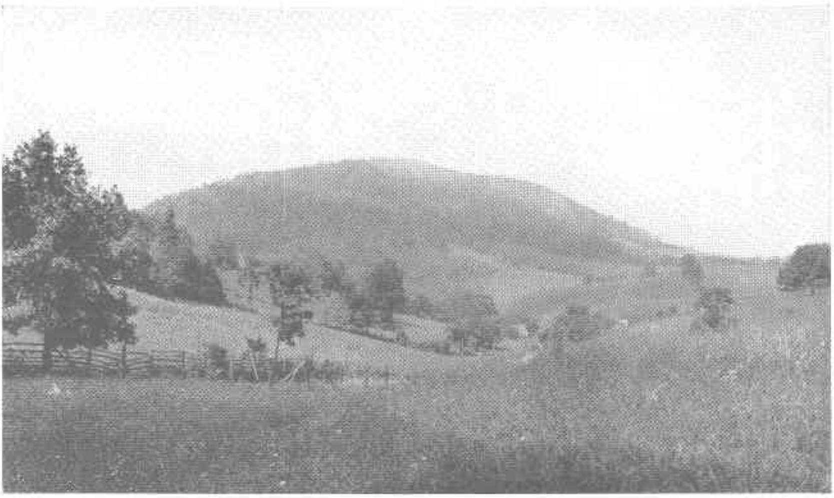
[6] Unpublished data.



A. Gleaves Knob. The cap consists of resistant Erwin quartzite, the base of Rome beds, and the intermediate portion of the Patterson limestone member of the Shady dolomite. The abrupt change in slope near the top marks the approximate position of the higher of two thrusts that crop out in the north (right) side of the knob.

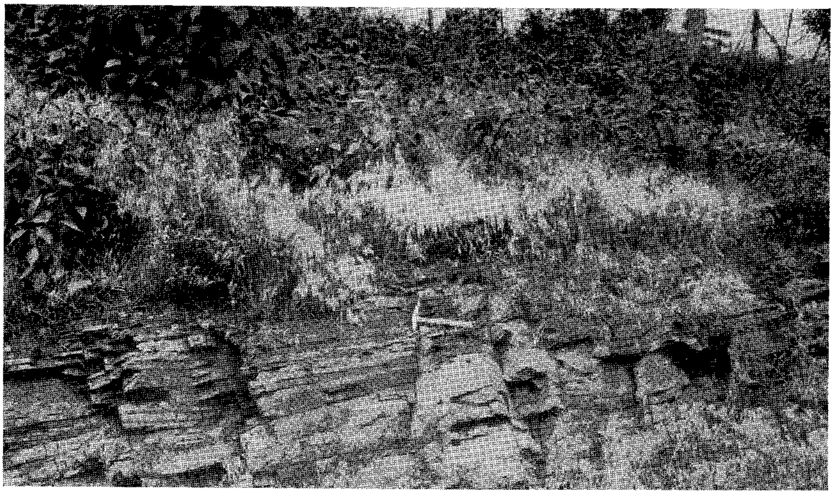


B. Hampton shale with massive beds of quartzite. On the highway in the gap through Iron Mountain south of Speedwell. Some of the quartzite beds are similar to parts of the Erwin quartzite.

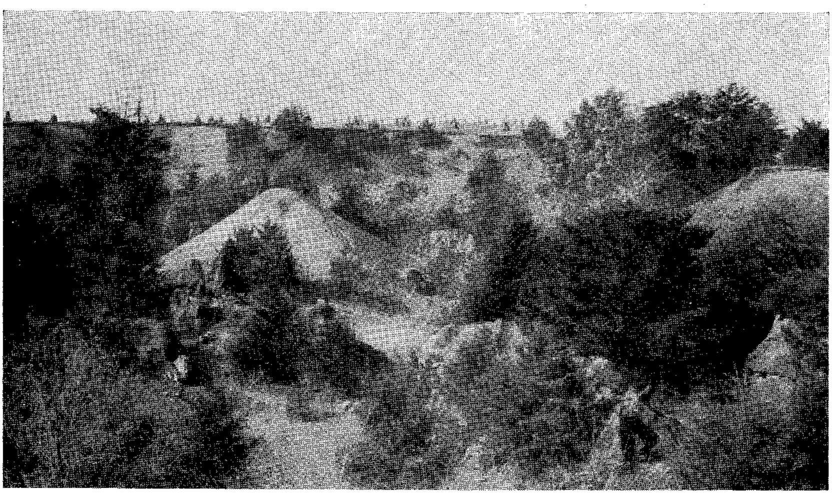


A. Gleaves Knob. The cap consists of resistant Erwin quartzite, the base of Rome beds, and the intermediate portion of the Patterson limestone member of the Shady dolomite. The abrupt change in slope near the top marks the approximate position of the higher of two thrusts that crop out in the north (right) side of the knob.

B. Hampton shale with massive beds of quartzite. On the highway in the gap through Iron Mountain south of Speedwell. Some of the quartzite beds are similar to parts of the Erwin quartzite.

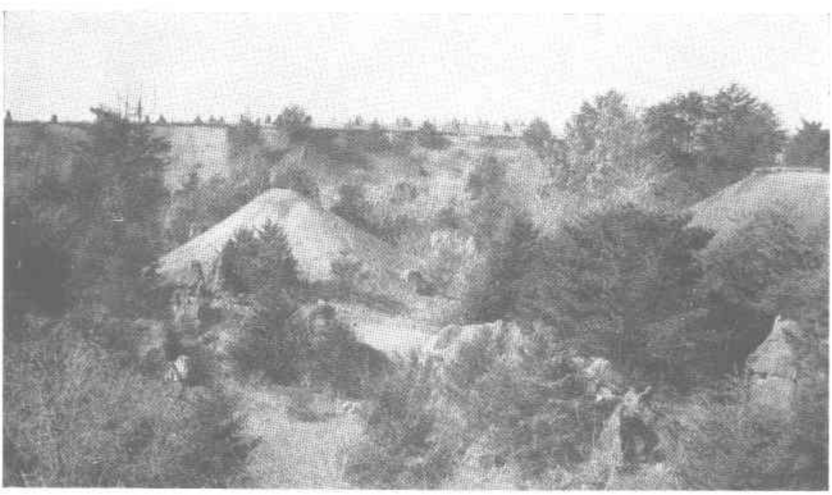


A. Erwin quartzite half a mile southeast of Galena; shaly material at the top grades into a thin blocky quartzite at the base.



B. Old iron pit half a mile south of Ivanhoe. The overburden is red clay derived from Shady dolomite. The rim level is the Valley-floor peneplain. Note the depth and degree of weathering and leaching as indicated by the sparseness of the low pinnacles.

A. Erwin quartzite half a mile southeast of Galena; shaly material at the top grades into a thin blocky quartzite at the base.



B. Old iron pit half a mile south of Ivanhoe. The overburden is red clay derived from Shady dolomite. The rim level is the Valley-floor peneplain. Note the depth and degree of weathering and leaching as indicated by the sparseness of the low pinnacles.

South of Austinville, in the area between the Austinville anticline and Poplar Camp Mountain, herein referred to as the Austinville Basin, a large part of the formation south of Buddle Branch presents unusual aspects, not comparable in most respects with the entire Shady section elsewhere. These beds are in part of somewhat doubtful correlation. Justification for their inclusion in the Shady is discussed below.

The characteristics and distribution of the several divisions of the formation are described separately in succeeding paragraphs. The formation as a whole, however, should be viewed chiefly as a dolomite unit comprising the areas of lowest relief in the valley floor. (See Pls. 4, B and 8, A).

The geologic map (Pl. 1) shows that the formation crops out in several roughly parallel strips that extend along the valley in the general direction of the regional trend, or strike, of the rocks. In places these strips converge and join, forming elongated synclinal basins or anticlinal domes. There are, however, two rather completely separated belts, each of which comprises several of the parallel strips. The northern belt has been mapped westerly or southwesterly from Swecker Mountain to the vicinity of Adwolf. The southern belt follows the entire extent of the mapped area. These two belts present different aspects of the formation, in that the Patterson and Ivanhoe members are apparently limited to the southern belt. The northern belt is composed entirely of gray and white crystalline dolomites, such as make up the saccharoidal member. It lacks, also, the clastic facies found in portions of the saccharoidal member, more particularly in the Austinville Basin. At several places west of Sugar Grove a few feet of dark "ribbony," "warty," or nodular dolomite, similar to the Patterson, appears near the base and is probably correlative with the Patterson elsewhere. On the whole, however, there is a marked difference between the northern and southern belt as regards lithologic variability.

In stratigraphic thickness, also, the two belts present contrasts. At but two places, however, could a reasonably accurate measurement of the thickness of the Shady in the northern belt be made, because for the most part one of the boundaries is a fault surface where either the Shady has been thrust over the Rome, or the Erwin has been thrust over the Shady, with a consequent reduction in thickness of the Shady outcrop. Three to four miles west by south of Teas, where a sequence from Erwin to Rome is exposed, the thickness of the Shady is close to 1,100 feet. Near Sugar Grove a less accurate measurement gives 2,000 feet. Here, however, there is a probability of some repetition by faulting or folding. It is probable that the northern belt has a stratigraphic thickness of the order of 1,000 to 1,500 feet, becoming progressively thinner toward the west.

The thickness of the Shady in the southern belt has been measured or closely estimated at several points. In the Austinville Basin a facies of the Shady appears locally that is not comparable in lithology or thickness with the formation elsewhere, and its features will be treated separately. Exclusive of this facies the measured total thickness of the formation ranges from about 1,650 feet to 2,300 feet. Between Cedar Springs and Sugar Grove the thickness is about 1,650 feet. About 2½ miles southeast of Cedar Springs, between 2,100 and 2,150 feet is probably present between the Erwin quartzite and the approximated base of the Rome. This estimate may, however, be too great by 150 to 200 feet, owing to necessary lack of precision in determining the exact locations of upper and lower contacts. In the section at Huddle about 1,700 feet of strata is exposed between the Rome normal contact at the top and the Rome fault contact at the base, where the base of the Shady is missing. From the lithologic sequence, however, it is probable that not more than 200 feet, and perhaps not more than 100 feet, of the Shady is missing here, as a result of thrust faulting; consequently the measured thickness of the Shady in this vicinity would closely approximate that stated for the section 2½ miles southeast of Cedar Springs. At Porter and at Laswell 1,660 feet and 1,550 feet, respectively, are exposed between the fault at the north ends of the sections and the normal Shady-Rome contacts at the south ends. It is believed that in these places, as in the Huddle section, not more than 100 to 200 feet of the basal Shady is missing. Consequently it would appear that the formation thickens toward the west.

Along the railroad east of Ivanhoe station the section from the top of the Ivanhoe member to a point just above the top of the Patterson member is almost entirely exposed. The Patterson is not exposed here, but its presence near water level is apparent from a study of the immediate vicinity. Exclusive of the Patterson member, the section displays 1,550 to 1,600 feet of the Shady. The Patterson member is probably close to 700 feet thick in this locality, so that the total thickness of the Shady here is believed to be not far from 2,300 feet. In this section the Ivanhoe limestone member displays its greatest thickness, amounting to 525 to 550 feet. In the previously cited sections it is of inconsiderable thickness, probably not more than 50 feet and generally much less, so that the greater local thickness of the Shady in the Ivanhoe section is to be explained by the locally thick development of the Ivanhoe limestone member.

The thickness of the Shady in the two belts differs in general by approximately the thickness of the Patterson member, which appears only in the southern belt, at least as a recognizable and mappable unit. It thus appears that the formation as a whole increases in thickness considerably toward the southeast, or, in other words, across the elongated original basin of deposition, and, moreover, that there is a very marked increase in the amount of clastic material in the same direction. Not only does the Austinville development of the Shady show a considerable clastic content, but the Patterson member itself seems to owe its rather thin-bedded, wavy "ribbon" structure to very thin argillaceous and carbonaceous partings. These conditions suggest that for a time at least the source of clastic sediments during Shady time was south or southeast of the area. The shore was of course considerably removed from the present exposed southern and southeastern border of the Shady deposits, for there has been considerable shortening by folding and thrust faulting, as well as considerable overriding of the Shady by the great southern block of Lower Cambrian quartzites.

TRANSITION BEDS

Geologic section 1 shows the transition from Erwin quartzite to Shady dolomite. The beds partake of the lithologic characters of both formations, as they contain dolomitic sandstone or sandy dolomite. A much thicker transition zone appears in the following section.

Geologic section 3.—Section 2½ miles south by west of Austinville, in the vicinity of Gray's School

	Feet
Patterson limestone member:	
Limestone, ribbon structure	300+
Transitional beds	50±
Dolomite, ribbon structure	160–210
Sandy dolomite, dark gray, fine granular	80

Erwin quartzite

South of Sugar Grove a few feet of light-gray fine crystalline dolomite, somewhat sandy, constitutes the transition zone at the base of the Patterson. It appears in an exposure about half a mile south of the village, along the railroad, where 8 feet of the dolomite rests conformably upon Erwin quartzite. This material is similar to basal beds farther west, between Quebec and Adwolf. A similar situation exists in an exposure at Eagle Cliff, about 1 mile southwest of Huddle, and also along the highway 4 miles west of Speedwell, where a few feet of light-gray crystalline dolomite, lacking ribbon structure, is interposed between the Erwin quartzite and the dark-gray ribbon dolomite of the Patterson member. Finally, at a quarry 1 mile south of Ivanhoe, 12 to 15 feet of light-gray crystalline dolomite is exposed below dark-gray Patterson limestone; the base of the dolomite is not exposed, but a regional study indicates that the exposure is probably very near the

Erwin contact. Consideration of these facts leads to the conclusion that at the base of the Patterson member or within its lower dolomite there exists a discontinuous light-gray crystalline dolomite bed of variable thickness but generally thin, which may, indeed, represent a local recrystallization of Patterson material.

The record of a diamond-drill hole in the Ivanhoe area reaching the Erwin quartzite shows a marked increase of silica in the basal dolomite, particularly through a thickness of 12 feet, the lower 4 feet of which contains more than 75 per cent of silica. Obviously the beds so recorded are the transition series, and the contact between Shady and Erwin is not sharp. Generalized columnar sections illustrating the variations in lithology and thickness of the Shady dolomite from northwest to southeast across both northern and southern belts are given in Plate 9.

PATTERSON LIMESTONE MEMBER

The Patterson limestone was named by Butts[7] from the settlement of Patterson, at the east end of the area. Here a bluff on the west side of Little Reed Island Creek displays about 100 feet of the rock. Because of generally low dips the limestone crops out through a considerable distance across the strike of the beds between this point and Reed Junction, on New River. It obviously occupies a position near the base of the Shady. Elsewhere exposures of limestone that are exactly similar in texture, structure, and stratigraphic position were correlated with that at Patterson, although there is no paleontologic evidence to support the correlation. There is, however, very little doubt as to the stratigraphic position of this member, for at several places throughout the area the Patterson member is found in conformable contact with the Erwin quartzite, and indeed the bed can be traced almost continuously over most of the area.

At first it was expected that the Patterson could be mapped as a limestone bed within the lower Shady, being separated above and below by beds of Shady dolomite. It was found, however, that the limestone showed gradational relations, above, below, and laterally, with a dark "ribbon" dolomite of similar lithologic composition. It became apparent also that the limestone had been subjected to incomplete dolomitization, without loss of its structural features, and that a large irregular body of limestone, from 200 to 400 feet thick, remained undolomitized. Consequently it was found more practicable to map the limestone and its dolomitic equivalent as a unit. This constitutes the Patterson lime-

[7] Unpublished manuscript on "Geology of the Appalachian Valley in Virginia."

stone member as recognized in this report. Locally the member is known as "ribbon rock," on account of its most persistent structure.

The Patterson member consists, in general, of a few feet of basal gray sandy dolomite, transitional from the Erwin quartzite; a dark-gray nodular dolomite showing irregular ribbon structure, generally between 50 and 200 feet thick; a dark-gray dense limestone showing ribbon structure, commonly between 200 and 400 feet thick; and, at the top, a medium- to dark-gray dolomite, also displaying ribbon structure, but less nodular and of somewhat lighter color than the lower dolomite. Together these facies comprise, on the average, about 700 feet of strata. The transition to the succeeding member of the Shady is not sharp nor stratigraphically uniform. The thickness of the transition zone is probably about 100 feet.

The ribbon appearance of the rock is due to very thin, wavy carbonaceous partings about half an inch apart, along which the rock splits readily. Surfaces of the rock broken across the bedding show a series of thin wavy bands parallel to the bedding, especially marked upon weathered exposures. (See Pls. 8, B and 10, A.) The ribbon limestone is of dark-gray color and dense texture. In a thin section the partings, though distinct, are seen to be less sharply defined. There are numerous clastic grains of quartz and feldspar which appear to be well sized but not well rounded.

Commonly in the Patterson short streaks and small lenses or "eyes" of coarsely crystalline white dolomite appear, oriented parallel to the banding. These are much more abundant in the lower 200 feet, below the limestone, and in many places they tend to obliterate the ribbon structure and give the rock a nodular or "warty" structure. Disseminated pyrite is common in both the dolomite and the limestone portions, but in places it is especially abundant in the basal or "warty" portion.

In spite of its characteristic ribbon structure the Patterson member may display massive structure in fresh or slightly weathered exposures, as shown in Plate 10, B.

At a number of places ribbon limestone is found to pass laterally into ribbon dolomite. The transition is gradational, and bands of dolomite and limestone dovetail. Moreover, the proportion of ribbon dolomite to ribbon limestone varies greatly from place to place. These conditions suggest that dolomitization of the Patterson limestone was incomplete and may have been related to a progressive process subsequent to lithification of the original sediment.

The thickness of the Patterson member, including transition beds at the base, is in general about 700 to 800 feet. Drilling records near

Ivanhoe suggest thicknesses from 850 to 950 feet, but it is probable that these figures include 100 to 150 feet of dark fine crystalline dolomites that have not elsewhere been included in the Patterson by the writer. The Huddle section exposes 690 feet, and the Porter section 585 feet, but at each locality the section is incomplete, the Patterson being faulted upon Rome shales. It is probable that 100 to 200 feet of the section is thus cut off. About 2¼ miles south by west of Austinville, west of Gray's School, a thickness of 590 feet is exposed, including 80 feet of sandy dolomite at the base; the top is not exposed in continuous section, so that the total thickness is in excess of this figure. At a point 2½ miles southeast of Cedar Springs between 750 and 800 feet of strata are assignable to the Patterson member. Farther west it becomes thinner, so that just east of Sugar Grove its thickness is between 575 and 600 feet.

SACCHAROIDAL DOLOMITE MEMBER

The main body of the Shady dolomite is characterized by light-gray to creamy-white beds of saccharoidal texture. This is the most persistent feature throughout the Great Valley from Pennsylvania to Alabama. In the southwestern Virginia zinc belt, however, associated with the light saccharoidal beds are others of dense to coarse crystalline texture and medium- to dark-gray or even black in color. Indeed, the dark beds are predominant in many places. Except in the Austinville Basin only a very slight amount of clastic material appears with these beds as interbedded shale, sandy limestone, and calcareous sandstone. Beds of relatively pure dense limestone are found in places. Together these strata are herein referred to as the saccharoidal dolomite member, the lithologic term being one of convenience for the purpose of this report. This division of the Shady is the only persistent facies of the formation throughout the area and according to Butts it is nowhere else so pronounced in its development as in southwestern Virginia and eastern Tennessee. Apparently it constitutes the entire Shady section of the northern belt. For the most part the saccharoidal beds are massive, but in many places, because of their relatively great brittleness, they have been much fractured. (See Pls. 11, A and 19, B.)

Good sections are exposed in the bluffs and railroad cuts along New River between Ivanhoe (Pl. 7, B) and Carter Ferry, and also in the highway cut south of Porter crossroads, 2 miles northwest of Ivanhoe. The variations of the beds are best described by means of typical sections. The following section at Porter exemplifies this portion of the Shady:

Geologic section 4.—Section of saccharoidal member of Shady dolomite along highway south from Porter crossroads to Cripple Creek

	Feet
Rome formation (red shale, dolomite, limestone)	
Shady dolomite:	
Ivanhoe limestone member	52
Saccharoidal dolomite member:	
Dolomite, with subordinate thin limestone beds and very thin shaly partings	36
Dolomite, very light gray to white, dense to fine crystalline	47
Dolomite, gray, in part streaky, with coarsely crystalline white dolomite	37
Limestone, dark gray, dense	14
Dolomite, gray, of variable texture	8
Chert and limestone	1
Interval	7
Limestone, dense, gray	1
Dolomite, medium to dark gray, variably crystalline	36
Dolomite, light gray to white; texture chiefly saccharoidal but somewhat variable	123
Dolomite, medium to dark bluish gray, crystalline	11
Dolomite, medium to light gray, of saccharoidal texture	21
Dolomite, light gray, dense	8
Dolomite, very light gray, of coarse saccharoidal texture	11
Dolomite, medium to very dark gray, crystalline, mottled	11
Dolomite, light gray, of saccharoidal texture	17
Dolomite, medium gray, crystalline, brecciated; streaks of coarse white dolomite	12
Dolomite, light to medium gray, dense; white streaks	33
Dolomite, nearly white, of saccharoidal texture, grading to dense at top	38
Dolomite, medium to light gray, dense to fine crystalline	44
Dolomite, medium to dark gray, fine crystalline	64
Dolomite, nearly white, dense	115
Dolomite, medium to dark gray, very fine crystalline to dense	178
Dolomite, light gray to light buff, fine saccharoidal	28
Dolomite, medium gray, dense and fine crystalline	145
Patterson limestone member	
	1,098

Along the railroad half a mile northeast of Ivanhoe station limestone and oolitic dolomite beds appear midway in the saccharoidal dolomite section, the total thickness of which is close to 1,000 feet.

Geologic section 5.—Condensed section of Shady dolomite along railroad half a mile northeast of Ivanhoe

	Feet
Ivanhoe limestone member	
Saccharoidal dolomite member:	
Dolomite, variable gray, dense to fairly coarse crystalline	140–150
Oolitic dolomite; three beds alternating with gray crystalline dolomite	25
Dolomite, gray, generally crystalline	160
Limestone, dove-gray, dense, variably dolomitized; medium thickness	45
Dolomite, as above	80
Limestone, as above	8
Dolomite, variable, in part saccharoidal, in places highly fractured and coarsely crystallized	540
Interval	100±
Patterson limestone member	

The limestone beds of the above section are partly dolomitized and may be entirely dolomitized along the bedding. The oolitic beds have not been identified elsewhere.

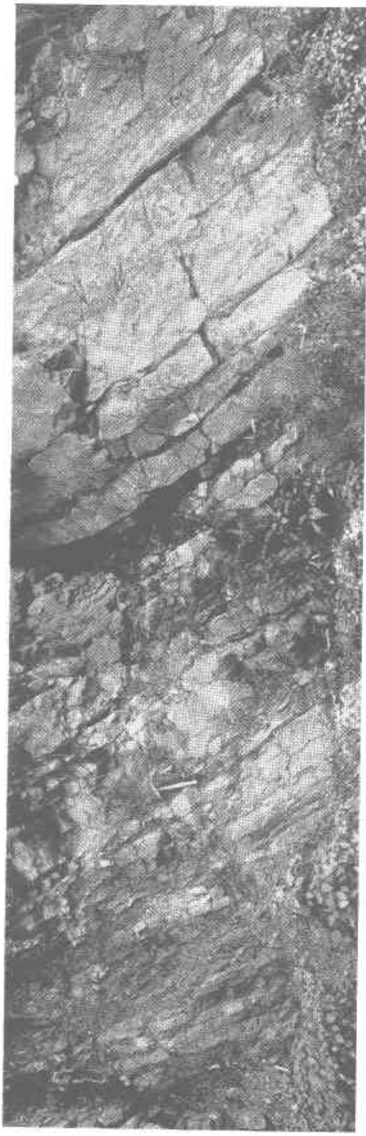
At Huddle the saccharoidal member shows some clastic material, which may represent a similar but much more greatly developed facies in the Austinville Basin.

Geologic section 6.—Section of upper part of Shady dolomite at Huddle, from "three corners" southeastward toward Catron

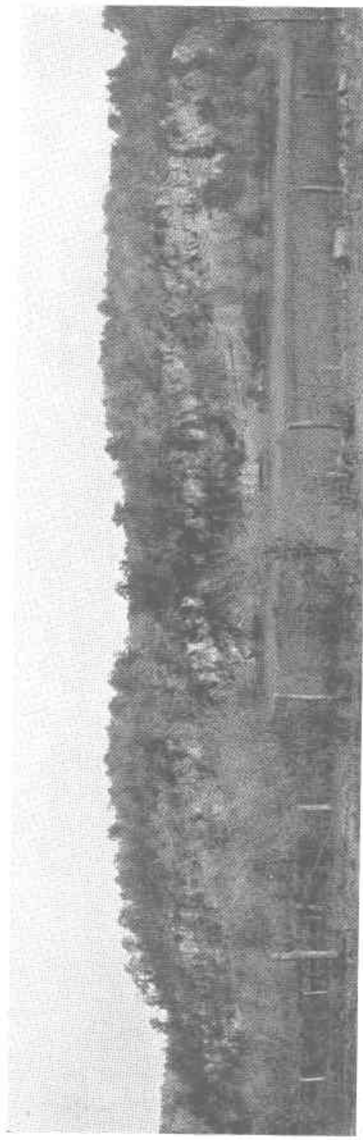
	Feet
Interval (probably Ivanhoe limestone member)	
Saccharoidal dolomite member:	
Sandy limestone, gray, thin blocky	5
Sandy shale, thin platy	2
Dolomite, light gray, fine crystalline	3
Interval	3
Dolomite, olive-green, shaly	3
Calcareous sandstone or sandy limestone, medium to dark gray, thin blocky to platy	3

A. Erwin quartzite in the gap at the west end of Henley Mountain.

B. Massive Shady saccharoidal dolomite. Along New River about 1 mile south of Ivanhoe. The beds dip slightly toward the northwest and are locally warped and displaced.

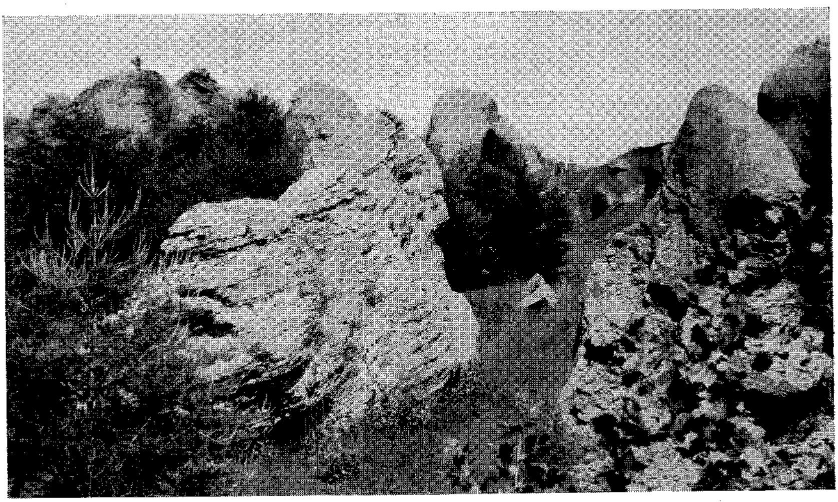


A. Erwin quartzite in the gap at the west end of Henley Mountain.



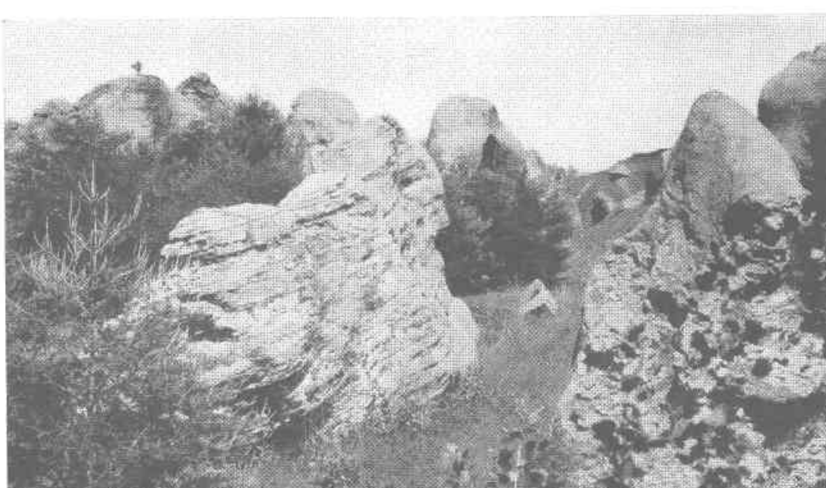
B. Massive Shady saccharoidal dolomite. Along New River about 1 mile south of Ivanhoe. The beds dip slightly toward the northwest and are locally warped and displaced.

A. Topography of area underlain by Shady dolomite. From a point near the road between Poplar Camp and Bethany. The ridge in the background, Foster Falls Mountain, is composed of the highly resistant Erwin quartzite.



B. Pinnacles of Patterson limestone, showing typical ribbon banding. In an old iron pit 1 mile southwest of Patterson, north of Periwinkle Branch.

A. Topography of area underlain by Shady dolomite. From a point near the road between Poplar Camp and Bethany. The ridge in the background, Foster Falls Mountain, is composed of the highly resistant Erwin quartzite.



B. Pinnacles of Patterson limestone, showing typical ribbon banding. In an old iron pit 1 mile southwest of Patterson, north of Periwinkle Branch.

	Feet
Shale, black	½
Dolomite, light gray to white, dense to fine crystalline, blocky to massive	16
Interval	3
Dolomite, saccharoidal	4
Dolomite, gray, finely crystalline, platy	3
Dolomite, light gray, dense to crystalline, massive	8½
Dolomite, gray to nearly white, saccharoidal to coarse crystalline, massive	10½
Dolomite, very dark gray, crystalline, blocky	4
Interval	5
Dolomite, same as above	4
Dolomite, chiefly gray to white, saccharoidal, massive	18
Dolomite, chiefly dark gray, crystalline, massive	17
Dolomite, gray, fine crystalline, laminated	4
Interval	2
Dolomite, gray, dense, massive, showing laminations	5
Interval	3
Dolomite, light bluish gray, thin platy, in part sandy	6
Dolomite, chiefly light gray, nearly white, dense massive	19
Interval	20
Dolomite, gray, dense, massive	13
Dolomite, dark gray, crystalline	2½
Interval	2
Dolomite, light gray, dense to saccharoidal, massive	17
Dolomite, variable, gray, chiefly crystalline	24
Interval	6
Dolomite, gray, platy	

The total thickness of the Shady section for this locality is about 1,900 feet, of which about 1,100 feet is assignable to the saccharoidal member. The top of the section given above is about 300 feet below the Rome contact. The interval displays scattered exposures of upper Shady dolomite and limestone (probably Ivanhoe).

Southeast of Cedar Springs the following section of the Shady above the Patterson member is exposed along the road southward from the "three corners":

Geologic section 7.—Section of Shady dolomite above the Patterson member, 2½ miles southeast of Cedar Springs

	Feet
Rome formation	
Interval	520-540
Shady dolomite:	
Saccharoidal dolomite member:	
Dolomite, saccharoidal	37
Dolomite, dark gray, crystalline	10
Dolomite, saccharoidal	2
Dolomite, medium to light gray, showing distinct ribbon structure and lenticular nodules or "eyes" of coarse white dolomite at top	17
Dolomite, light gray, saccharoidal	22
Dolomite, gray, dense	7
Dolomite, distinctly ribboned, as above	9
Dolomite, gray, fine crystalline to dense, faintly ribboned	31
Dolomite, gray, dense	27
Dolomite, light gray to white, saccharoidal	131
Dolomite, medium to light gray, dense to fine crystalline	138
Interval	375
Patterson limestone member	800±
Erwin quartzite	

The above section is of particular interest in showing the appearance of ribbon dolomite about 650 to 675 feet above the Patterson member. This material may be the approximate correlative of similar beds exposed just south of the "three corners," about half a mile south of Austinville School, and demonstrates the danger of depending upon lithologic characteristics for correlation of beds. Correlation of this ribbon rock with the Patterson member might be suggested on lithologic grounds, but the section lacks the necessary sequence of beds for such an interpretation. Moreover, closer examination discloses that the Patterson member is in general thinner bedded and much more carbonaceous, and that the bands themselves are correspondingly thinner and darker.

The probable thickening of the Shady section and the appearance of much more arenaceous material in the beds of the southern part of the Austinville Basin that are considered the time equivalent of the saccharoidal and Ivanhoe members are commented upon in the section devoted to the Austinville development of the formation (pp. 30-35). Here it will suffice to state that apparently the saccharoidal member shows increasing lithologic variability, marked by an increase in amount of clastic siliceous materials, southeastward across the valley.

Finally, it appears that, although white saccharoidal beds are characteristic of the persistent facies of the Shady throughout the region, they nevertheless constitute a subordinate percentage of the mass, except possibly in the most northern belt of outcrop. Moreover, beds of similar color and texture appear in moderate abundance in the Rome and Elbrook formations, a fact which leads to confusion when correlations of such beds by lithologic features are attempted. Again it must be stressed that sequence is of prime consideration.

Beds of the saccharoidal member contain the ore bodies at Austinville and Ivanhoe. The ores are not, however, limited to particular beds or even to this member, for drilling and other prospecting have disclosed zinc blende in the underlying Patterson member.

IVANHOE LIMESTONE MEMBER

The section of the saccharoidal dolomite member of the Shady given in geologic section 5 is succeeded by a thick body of limestone of apparently local development which increases the average Shady thickness by more than 500 feet. Above it are the Rome beds, marked by distinctive red shales. The limestone is apparently a lenticular bed traceable for not more than 9 miles east and west through the Ivanhoe exposure. In this report it is designated the Ivanhoe limestone member of the Shady dolomite. Locally it is referred to as the "carbide" limestone, or "carbide quarry" limestone, from the quarry of the National Carbide Co., located in it, half a mile northeast of the railroad station at Ivanhoe. (See Pl. 11, B.))

The Ivanhoe limestone member is composed of thick, massive beds of dense gray limestone containing a few relatively thin beds of light-gray to white dolomite, saccharoidal in part, and very thin reddish sandy and argillaceous partings. The following section was made in the vicinity of the quarry and continues the Shady column given in geologic section 5.

Geologic section 8.—Section of Ivanhoe limestone member of Shady dolomite at and above the quarry half a mile northeast of railroad station at Ivanhoe

	Feet
Rome formation	
Shady dolomite:	
Ivanhoe limestone member:	
Limestone, white to light dove-gray, dense	6
Dolomite, nearly white, fine crystalline	4
Limestone, dove-gray, dense and fine crystalline	12
Interval	8
Limestone, light gray, dense and slightly crystalline, evenly laminated; shows thin brecciated beds	6
Dolomite, light gray, fine crystalline, slightly sandy	1½
Sandstone, dolomitic, thin bedded, platy	3
Interval	3
Dolomite, saccharoidal	½
Limestone, dove-gray, dense to fine crystalline, massive	6½
Dolomite, light gray, fine grained; apparently a lens derived from limestone by dolomitization	4
Limestone, dove-gray, dense and slightly crystalline	13
Interval	5
Dolomite, very light gray, fine crystalline	2½
Interval	5
Limestone, as above	5
Interval	6
Limestone, as above	8
Interval	12
Limestone, dense, dove-gray, grading into underlying bed	5
Dolomite, very dark gray, crystalline	4
Interval	4
Dolomite, light gray, crystalline, partly calcareous	2½
Dolomite, very dark gray, fine grained	1½
Interval	6
Limestone, dove-gray, dense, massive	19
Interval	10
Limestone, as above	87
Interval	10
Limestone, nearly white, dense	40

	Feet
Interval (includes near top several feet of dark-gray brecciated dolomite, bearing streaks of coarse white dolomite and sphalerite-zinc prospect) . .	65
Dolomite, sandy and argillaceous	2
Interval	6
Limestone, dove-gray, dense to fine crystalline, massive	13
Interval	15
Dolomite, light gray, crystalline	7
Interval	9
Limestone, chiefly dove-gray and medium gray, dense, massive; includes very thin reddish sandy and shaly partings; dolomitized and streaked with coarse white dolomite at base. . . .	125–130

Saccharoidal dolomite member

The total thickness of the beds assigned to the Ivanhoe member in this section is between 525 and 550 feet. From this thickness the member becomes thinner in both directions along the strike. At a quarry in the ravine 1 mile east of Austinville Ferry and about a quarter of a mile from the road a thickness of 225 feet is exposed. Excellent exposures are to be seen within the village at Ivanhoe, crossing the railroad just east of the school. At the school the limestone is abruptly terminated by a cross fault which carries the westward extension of the outcrop about 1,100 feet to the north where it may be seen in excellent exposures along the highway. From this point it is traceable intermittently and with decreasing thickness westward for about 1½ miles, where the belt of outcrop turns north and northeast, following the bend of a pitching synclinal basin, to a point southeast of Pierce Mill, where it appears to be cut off by a thrust fault. About 2 miles west of this point, near Huddle, a similar limestone in similar stratigraphic position is exposed on the north side of the same fault and probably is the Ivanhoe member. From this point the limestone is traceable intermittently northeastward to Porter. In the Porter section it is less than 50 feet thick and appears in the roadside quarry a quarter of a mile south of Porter crossroads. East of this locality it disappears as a mappable unit and, if present, is represented only by two or three thin limestones interbedded with dolomites at the top of the Shady, as at Laswell.

The limestone is exceptionally pure and is reported to average more than 98 per cent $CaCO_3$ in the more massive beds. In quarrying, an admixture of siliceous and clayey materials, present as partings, and dolomitized portions of the limestone lower the grade. In places, especially near the base, streaks of dolomitic material extend irregularly into and along the bedding of the dense limestone beds.

South of New River at Austinville the saccharoidal member is succeeded by a series of massive, dense limestone beds and gray crystalline dolomites, the whole having a thickness of about 500 feet. In position, lithologic characteristics, and association with interbedded crystalline dolomites, these beds much resemble the beds at Ivanhoe. There is justification for a tentative correlation of these beds with the Ivanhoe limestone member on the opposite side of the anticlinal axis. At Austinville several beds have yielded fossils that indicate that they should be correlated with the Shady formation. The best exposures near Austinville are to be seen along Clear Branch from half to three quarters of a mile from its junction with New River. Exposures also appear on the hill slope west of the highway leading south from Austinville and south of the schoolhouse. At this locality excellent fossils are found in the decalcified siliceous residue ("tripoli") of the limestone, exposed in the road bank.

SHADY DOLOMITE SOUTH OF AUSTINVILLE

Near Austinville, from New River to the vicinity of the road junction 0.4 mile south of the Austinville School, the general succession of the Shady seems to conform to that elsewhere in the southern belt—that is, the three members are present with essentially the same lithologic characteristics and thickness. On this basis it is assumed that the thick fossiliferous limestone series is to be correlated with the Ivanhoe member north of the river, reasons for which are stated below. Farther south, however, the Shady presents a contrasting lithology, unlike that of the formation at any other locality. Fossils indicate a correlation with the Tomstown dolomite of Pennsylvania, hence the interpretation that this facies represents the Shady. As the dips are homoclinal throughout and to the south, the situation can be satisfactorily explained only by thrust faulting, which brought the more clastic southern development of the saccharoidal member upon the limestones of the uppermost Shady. One prominent fault of considerable stratigraphic displacement is clearly traceable southeast of the highway leading from the above-mentioned road junction to Sheeptown, where basal Patterson has been thrust upon upper Shady. In this overriding block the succession is exemplified by section 5 of Plate 9, in which the major part of the saccharoidal member and the Ivanhoe member are replaced by sandy dolomite or limestone, shale, and limestone breccia.

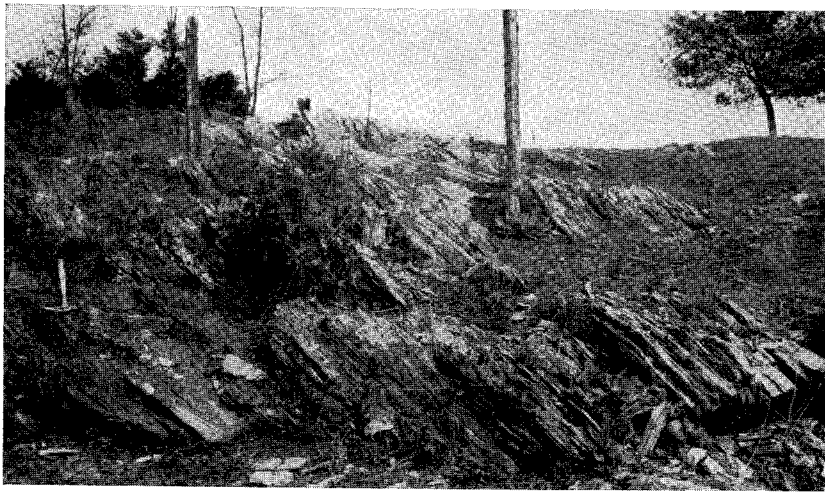
A detailed study of the beds in the southernmost block—the Austinville development—discloses from 1,350 to 1,400 feet of strata from the top of the sandy dolomite in the section just cited. In this series the homoclinal attitude with southeasterly dip is continued throughout. The lithology is varied, and no repetition by thrust faulting can be certainly determined, as distinctive beds or sequences can not be identified with assurance. At least 39 beds, which show successive differences in lithology, make up the series. Continued in the line of strike, as given by scattered exposure along the line, the top of the series should appear just north of exposures of similar material at Poplar Camp, in a position occupied by highly fractured, nonarenaceous crystalline dolomites of entirely different lithologic aspect and indeed similar in general to the more common types of the saccharoidal member. Consequently there is probability of repetition by faulting, though the positions and characteristics of the faults are not disclosed by the sparse exposures, which are not discriminative as to different beds.

Certain beds within this series are worthy of record because they present aspects so far unrecorded for the Shady formation elsewhere in the Great Valley region. The following column is a composite section from a plane-table traverse covering the many small scattered exposures from a point about three-quarters of a mile southeast of Austinville schoolhouse nearly to Bethany:

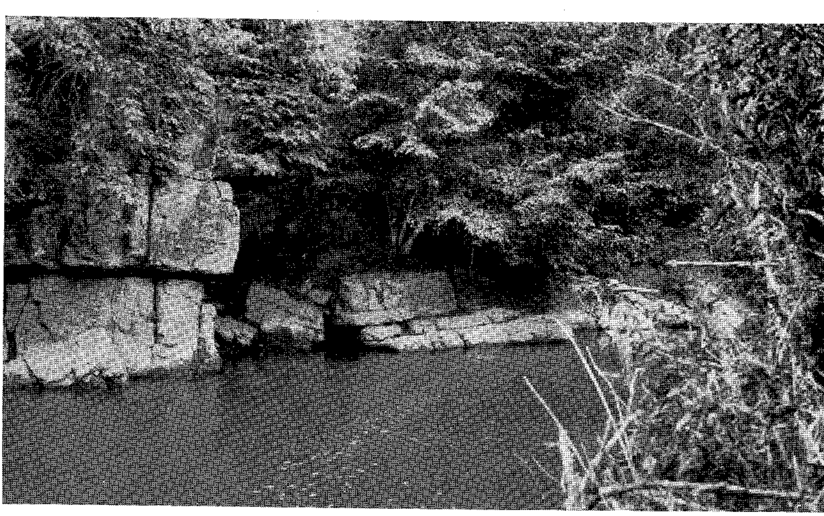
Geologic section 9.—Composite section of Shady dolomite above the sandy dolomite, between Austinville and Bethany

	Feet
Limestone breccia	
Interval	15±
Dolomite breccia, gray	4±
Calcareous sandstone	2+
Oolitic limestone	3+
Interval	175±
Dolomite, gray, massive, fine crystalline	1
Limestone, largely oolitic	20
Interval	75
Limestone breccia (maximum)	5
Dolomite, light gray, fine crystalline	30–35
Interval (probably includes 8 feet of oolitic limestone)	30–35
Dolomite, gray, crystalline, brecciated	7–8
Limestone and dolomite, interbedded	1–2
Dolomite, light gray, somewhat clastic	5–6
Interval	45±
Dolomite, gray, brecciated	5
Sandstone, calcareous	3±
Interval	20±
Dolomite, gray, brecciated	3
Dolomite, medium and light gray, fine crystalline and somewhat clastic	6±

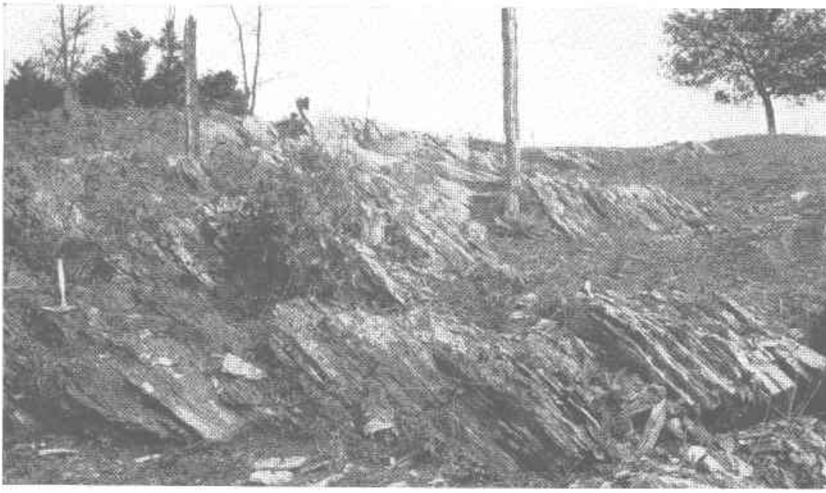
	Feet
Interval	20–30
Dolomite, as preceding	10
Dolomite, light gray, crystalline	10
Interval	50±
Dolomite, as preceding	5
Interval	90–100
Dolomite, gray, thin-bedded	1
Dolomite breccia, massive	4
Interval	1
Dolomite, light gray, platy	1
Interval	4
Dolomite, light gray, dense, massive	3
Interval	25±
Limestone breccia	12+
Dolomite, light gray, crystalline	25
Interval	25
Limestone and dolomite, interbanded	1
Dolomite, gray, crystalline	15±
Interval	15±
Interval (estimated)	90–100
Dolomite, gray, somewhat clastic	1
Interval	50
Limestone	2
Dolomite, somewhat clastic	30
Interval	5
Dolomite and limestone, interbanded	5
Dolomite, light gray, coarse crystalline	1
Interval	25–30
Limestone breccia	3+
Dolomite, gray, crystalline, somewhat clastic and brecciated	65–70
Sandstone, calcareous, light gray	10±
Interval	35–40
Dolomite, gray, crystalline, platy	4
Interval	15
Dolomite, gray, crystalline, in part brecciated and oolitic	120–125
Limestone breccia, containing fossiliferous bed	25–30
Shale, olive-green	10
Limestone and limestone breccia, fossiliferous	10
Dolomite, platy	10–12
Sandstone, calcareous, very dark	120–125
Dolomite, gray, crystalline	5
Dolomite, sandy	



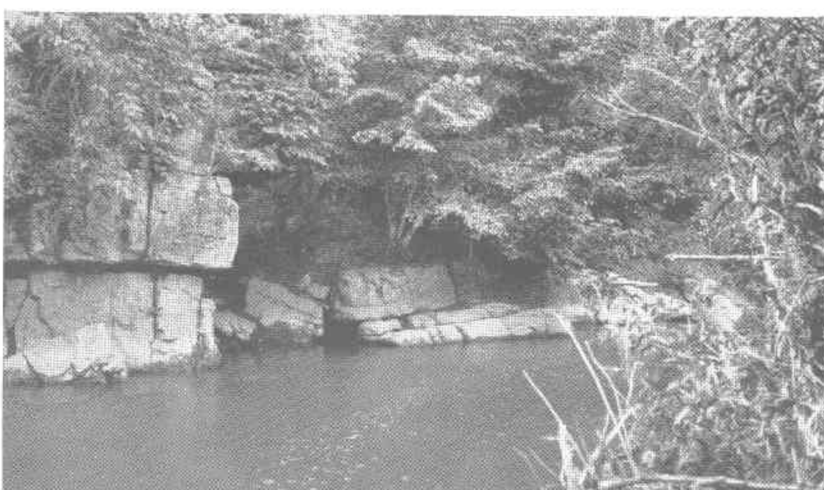
A. Weathered exposure of Patterson limestone showing characteristic ribbon structure. About 1 mile east by north of Olive Branch Church.



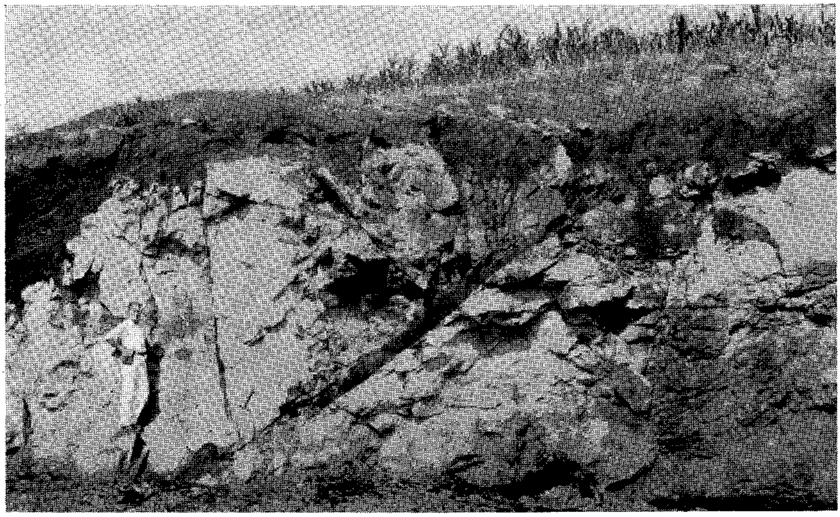
B. Massive structure in the Patterson member on Little Reed Island Creek. About three-fourths of a mile south by west of Kayoulah, at a meander where the stream leaves the surface channel.



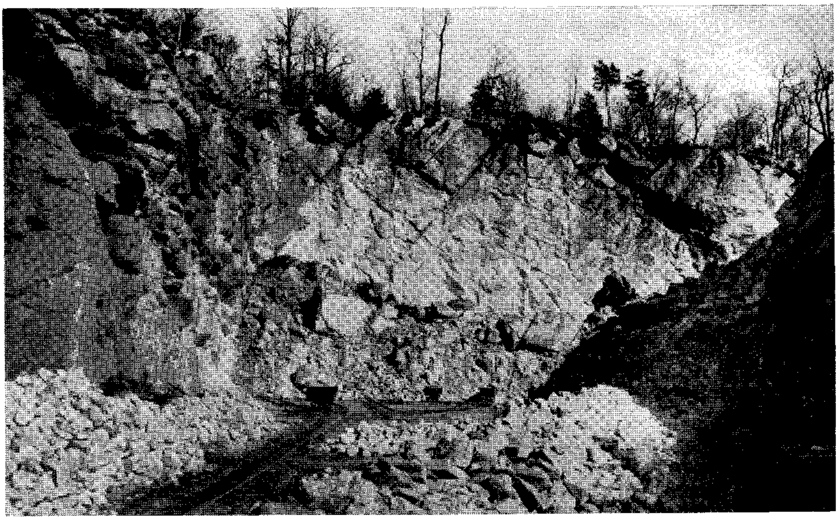
A. Weathered exposure of Patterson limestone showing characteristic ribbon structure. About 1 mile east by north of Olive Branch Church.



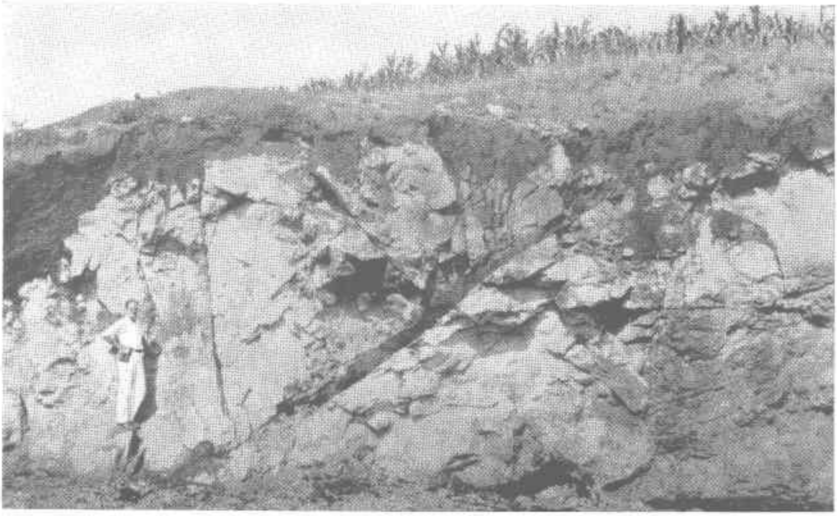
B. Massive structure in the Patterson member on Little Reed Island Creek. About three-fourths of a mile south by west of Kayoulah, at a meander where the stream leaves the surface channel.



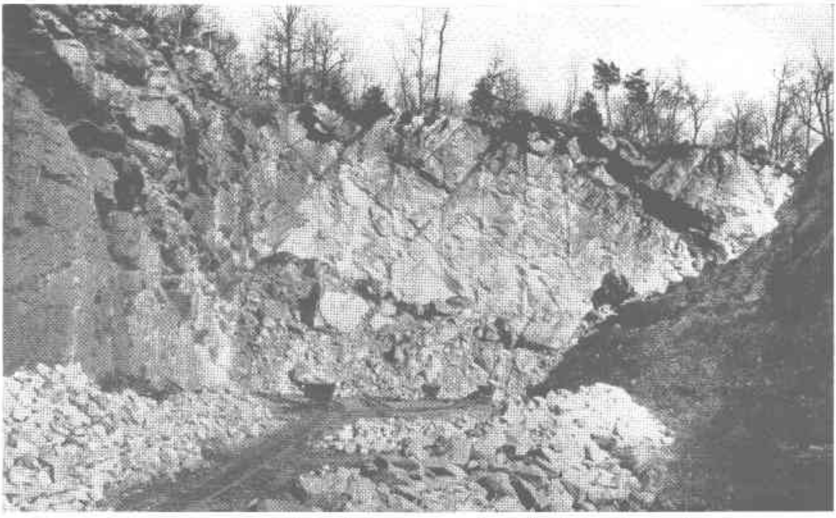
A. Shady dolomite in a road exposure between Jackson Ferry and Poplar Camp, showing characteristic massiveness. The dip is toward the southeast (left); a clay-filled bedding slip plane appears centrally in the view. Below this plane the dolomite is a compactly cemented breccia. (See Pl. 19, B.)



B. Face of Ivanhoe member in quarry of the National Carbide Corporation half a mile northeast of Ivanhoe station. About 125 feet of the lower part of the Ivanhoe limestone is exposed, dipping 50° NW. This view shows a dip section at the widest portion.



A. Shady dolomite in a road exposure between Jackson Ferry and Poplar Camp, showing characteristic massiveness. The dip is toward the southeast (left); a clay-filled bedding slip plane appears centrally in the view. Below this plane the dolomite is a compactly cemented breccia. (See Pl. 19, B.)



B. Face of Ivanhoe member in quarry of the National Carbide Corporation half a mile northeast of Ivanhoe station. About 125 feet of the lower part of the Ivanhoe limestone is exposed, dipping 50°NW. This view shows a dip section at the widest portion.

The foregoing section demonstrates the presence of abundant clastic beds, in part calcareous, in part arenaceous, and in part dolomitic. Noteworthy also are the several nonclastic and fossiliferous limestones, in part oolitic. The members of the column may be readily grouped as follows:

	Feet
4. Chiefly calcareous beds, partly oolitic limestone and limestone breccia	300±
3. Chiefly more or less crystalline dolomite, in part clastic	400±
2. Dolomites, partly clastic, and calcareous beds, in part clastic, interbedded	580–600
1. Chiefly calcareous beds, partly limestone and limestone breccia, and partly calcareous sandstone	190–200
	1,470–1,500

The fossiliferous beds appear in the lower 200 feet. The dolomites of groups 2 and 3 are lithologically closely similar to some beds of the saccharoidal member and are not distinctive. The sequence involved in groups 3 and 4 is in general similar to that shown by the beds at Poplar Camp, east of the State highway and south of the highway leading eastward to Rackettown, where the following section was measured.

Geologic section 10.—Section of Shady dolomite east of Shorts Creek at Poplar Camp

	Feet
Fault contact with Lower Cambrian quartzite series	
Interval	
Calcareous sandstone and sandy limestone	50–60
Interval	12
Dolomite, somewhat clastic	3
Interval	75
Limestone, gray, brecciated	15
Limestone, gray, dense, massive	14
Interval	25–30
Limestone, crystalline and oolitic	2
Limestone breccia	12
Interval	2
Limestone, dense, massive, light gray	12
Interval	15
Limestone breccia	2

	Feet
Limestone, dense, massive, dove-gray	8
Interval	8
Limestone breccia	15
Interval	12–15
Sandstone, calcareous, containing a lens of limestone breccia.	15–20
Interval	12
Sandstone, calcareous, somewhat slaty	10
Limestone breccia	3
Limestone, gray, massive	3
Dolomite and limestone, interbanded	6
Limestone	3
Interval	20
Dolomite beds, variable, gray, fine crystalline, in part somewhat clastic and brecciated	140–150

This sequence obviously constitutes a group of dolomites (140-150 feet) succeeded by a group of limestones and calcareous clastic rocks (350-360 feet), the latter lithologically similar to the calcareous beds of the Austinville-Bethany section.

The local lithologic peculiarities of the Shady beds in the Austinville Basin about halfway between Austinville and Bethany and at Poplar Camp are worthy of further consideration. Stratigraphic details are given in geologic section 9. Of particular interest are the sandy dolomite, calcareous sandstone, sandy limestone, and limestone breccia beds, which appear chiefly at the base of the Austinville-Bethany section.

The limestone breccia beds, which apparently occur at several horizons, consist of fragments and blocks of rather pure limestone, some of which are oolitic, in a matrix of rather fine-textured and somewhat porous dolomite. The limestone fragments show great range in size and shape. Of angular outline in large part, they consist of variously shaped blocks and elongated slabs without orderly arrangement. The texture is shown in Plate 12. Their variations in texture and lithologic composition indicate their derivation from different beds. The mode of occurrence suggests intraformational breccia beds resulting from a local accumulation of limestone blocks in a dolomitic mud. At one locality a fairly dense unbrecciated limestone bed interstratified with breccia beds yielded fossils.

The calcareous sandstone and sandy limestone are thin bedded, evenly laminated, and generally very dark colored, though the limestone is, as a rule, lighter than the sandstone. Hand specimens indicate an obviously high but variable content of clastic quartz sand grains.

Under the microscope thin sections show a prominent content of quartz and feldspar grains, subrounded and uniformly sized. Sand grains are dominant in some of the laminations, nonclastic calcareous matter in others. Organic matter is present. The material is in places interbedded with thin bands of dolomite, likewise apparently of sandy character. By weathering the calcareous matter is leached from the rock, leaving a soft yellow sandy residue, well laminated and of somewhat shaly appearance.

Below these calcareous beds is a considerable thickness of rather thin bedded sandy and argillaceous dolomite. This is tentatively correlated with the upper part of the saccharoidal member of the Shady, as shown in columnar section 5, Plate 9. The dolomite weathers to a yellow soft gritty mass of somewhat shaly appearance.

Beds similar in character to the sandy beds described above are found at a few other points but in very subordinate amount. The most noteworthy occurrence of such beds is found at about the middle of the saccharoidal member at Huddle. (See geologic section 6.)

The increase in content of clastic material in the Austinville Basin, the breccia beds, and the heterogeneity of the section suggest near-shore conditions of sedimentation. It may be that these beds constitute a block of sediments belonging to an area of deposition nearer shore and at some distance from their present position, and that they were brought over the more common Shady beds into their present position by thrust faulting from the south or southeast. They may, indeed, have been closely allied to a connecting waterway between the Shady trough of southwestern Virginia and the York-Lancaster Basin of Pennsylvania, whence came the fauna now found in the Shady of the Austinville Basin.

CORRELATION

In early reports the limestone-dolomite formation of the Great Valley was designated Shenandoah limestone, a name first proposed by Darton[8] for the limestone underlying the Shenandoah Valley of northern Virginia. Apparently similar formations in southwestern Virginia and eastern Tennessee were included in the Shenandoah by later writers, but it was subsequently discovered that some of the beds so included belonged to the Lower Cambrian, some probably to the Middle Cambrian, and some to the Upper Cambrian and Ordovician. The formations thus included in the Shenandoah have been separated as follows:

[8] Darton, N. H., Notes on the stratigraphy of a portion of central Appalachian Virginia: American Geologist, vol. 10, no. 1, p. 13, 1892.

TABLE 1.—*Formations represented in the Shenandoah limestone of earlier reports*

<table>
<tr><td>Lower Ordovician
and
Upper Cambrian</td><td>Knox dolomite</td><td colspan="2">Post-Nittany strata
Nittany dolomite
Copper Ridge dolomite and Conococheague limestone</td></tr>
<tr><td rowspan="2">Upper Cambrian</td><td colspan="2">Nolichucky shale</td><td rowspan="4">Elbrook limestone</td></tr>
<tr><td>Maryville limestone</td><td rowspan="3">Honaker limestone</td></tr>
<tr><td rowspan="2">Middle Cambrian</td><td>Rogersville shale</td></tr>
<tr><td>Rutledge limestone</td></tr>
<tr><td rowspan="2">Lower Cambrian</td><td colspan="3">Rome formation (†Russell; †Watauga)</td></tr>
<tr><td colspan="3">Shady dolomite</td></tr>
</table>

The Shady dolomite has been identified and traced as a distinct formation at intervals from Alabama into Virginia, where it occurs along the Shenandoah River, and on paleontologic evidence it is correlated with the Tomstown dolomite of Pennsylvania. The term Shady was first proposed by Arthur Keith for exposures at Shady Valley, northeastern Tennessee.[9]

Fossils of the Austinville Basin.—The thick limestone member at the top of the Shady south and east of Austinville and limestone beds associated with the sandy limestone and limestone breccia between Austinville and Bethany have yielded fossils at several localities. The presence of fossils was first discovered by W. H. Brown, geologist of the Bertha Mineral Co. A preliminary examination of the collections in comparison with faunas from the Tomstown of Pennsylvania has been made by C. E. Resser, of the United States National Museum. He reports that the fauna of the Austinville area is closely similar to those of L'Anse au Loup, Labrador; Bic Harbor, Quebec; the "sand rock" above the "*Olenellus* shale," Georgia, Vermont; east of Troy, New York; and the York and Lancaster basins, Pennsylvania, where the fauna is referred by Stose and Jonas[10] to the middle member of the Tomstown dolomite, which is correlated with the Tomstown at the type locality in Pennsylvania. According to Charles Butts, the Tomstown is continuous with the Shady. Mr. Resser further states that the "forms are similar, if not identical" with these fossils:

[9] Keith, Arthur, U. S. Geol. Survey Geol. Atlas, Cranberry folio (No. 90), p. 5, 1903.

[10] Jonas, A. I., and Stose, G. W., Lancaster quadrangle: Top. and Geol. Atlas of Pennsylvania No. 168, Pennsylvania Geol. Survey, p. 32, 1930; and Middletown quadrangle, U. S. Geol. Survey Bull. 840, pp. 25-26, 1933.

Kutorgina singulata (Billings)
Nisusia festinatus (Billings)
Paterina bella (Billings)
Bonnia senectus (Billings)
Olenellus logani (Walcott)
Botsfordia caelata (Hall)
Dorypyge ellsi (Walcott)
Dorypyge marcoui (Whitfield)
Wanneria sp.
Zacanthoides eatoni (Walcott)
Stenotheca sp.

The chief localities at which fossils were found in the Austinville area include (*a*) several points in the limestone exposure along Clear Creek, near the junction with its largest tributary, about 1 mile east of Austinville station; (*b*) the south wall of a ravine tributary to Clear Creek, about 1¼ miles east (slightly north) of Austinville station; (*c*) limestone exposures about a quarter of a mile south of Austinville School, especially in the leached exposure along the highway; (*d*) limestone exposures in ravines on the west side of the road to Sheeptown, about one-quarter and three-quarters of a mile from "three corners," south of Austinville School; (*e*) exposures near spring house on Jackson farm, near head of Clear Creek, about 1 mile west of Bethany, and (*f*) in limestone breccia on the south side of the highway at this locality. Fossils were also found in limestone exposed in the low escarpment about half a mile east of Jackson Ferry. All the collections indicate a correlation with the equivalent to the middle Tomstown Kinzers fauna of Pennsylvania, according to the preliminary report of Mr. Resser.

Fossils west of Sugar Grove.—Specimens collected in 1917 by G. W. Stose, of the United States Geological Survey, from an exposure of the saccharoidal dolomite member 1 mile west of Teas, yielded *Archeocyathus,* a sponge somewhat resembling a cup coral. According to Mr. Resser this form marks the horizon below the Kinzers formation of Pennsylvania, and the rock is therefore to be correlated with the Shady dolomite.

ROME (†WATAUGA) FORMATION (LOWER AND MIDDLE CAMBRIAN)

The Rome formation (†Watauga shale of previous reports) overlies the Shady dolomite conformably and is extensively exposed in the area.

The Rome is a heterogeneous formation consisting of shale, sandstone, limestone, and dolomite. (See Pl. 13, B.) The most characteristic feature is an abundance of red shales and, subordinately, red sandstones, which in places have a quartzitic texture. These red beds serve, indeed, as a mark of distinction, for no other formation of the region contains such beds in even moderate abundance. Wherever found, they establish the local identity of the formation. On the other hand, although the red shales are the most outstanding lithologic feature of the formation, there are many exposures of Rome beds that contain no red shales and that can be recognized only from their sequential relation to the Shady formation. Because of the sharp contrast between the red beds and the associated strata, extensive exposures of the Rome may appear at first to consist predominantly of red or reddish shale and sandstone. Closer examination reveals, however, that the red beds probably constitute much less than 50 per cent of the formation and that dolomite beds are, in many places, much more abundant. Yellowish-green shale, in part of sericitic appearance, is common in the formation. In many places the Rome shales show prominent sun cracks and ripple marks (Pl. 13, A).

The dolomite beds of the Rome formation display no characteristic features by which they can be certainly distinguished from commonly occurring similar beds in the Shady and Elbrook formations. Very light colored beds of saccharoidal character are present in the Rome in places and, unless interbedded with typical red shales, are easily confused with similar dolomites in the Shady. Probably the most abundant dolomite beds in the Rome, however, are of two varieties that are present in greater abundance than in the lower formation. These are a thin-bedded, shaly to thin-platy gray fine-crystalline variety, weathering buff, and a somewhat more massive medium-gray fine to medium crystalline variety. Commonly a Rome area will display scattered exposures of such beds, apparently without associated red shales, the latter being less resistant and easily covered by mantle rock. The presence of shale beds is generally indicated by the appearance of red shale fragments in the soil. Plate 14, A shows platy and blocky dolomite beds in the Rome.

Limestone beds in the Rome are somewhat numerous but comparatively thin. These beds are commonly dense textured, rather massive, and of medium to dark-gray color. The formation also includes thin beds of argillaceous limestone which weather to soft yellowish siliceous material by leaching of the lime content.

It is difficult to obtain an accurate measure of the thickness of the Rome as exposed in this area, because of close and overturned folding and local minor faulting. The formation is relatively very weak and is the most incompetent formation of the region. The overlying (Elbrook) and underlying (Shady) formations are not in general deformed by very close folding, but the Rome exposures commonly display steep dips, close folds, and slight overturning of beds. The most satisfactory measure of thickness was obtained south of Porter crossroads, where about 2,150 feet of strata are exposed between the top of the Shady formation, about 1,000 feet north of Cripple Creek, and the base of the dolomite beds on Cripple Creek assigned to the Elbrook formation. Throughout this exposure the dip of the Rome beds appears to be uniformly south, with no indication of repetition by folding. Probably the most uncertain factor in this determination of thickness is the Rome-Elbrook contact. The details of the lower part of this exposure are given in the following section:

Geologic section 11.—Section of lower part of Rome formation along highway south of Porter crossroads, north of Cripple Creek bridge

	Feet
Rome formation:	
Dolomite, variable, red partings (top of section in Figure 18)	15
Sandstone, chiefly massive, red, in part dolomitic and shaly	30
Dolomite, gray, chiefly platy and blocky	18
Shale, dolomitic; weathers reddish	2
Dolomite, gray, blocky	5
Limestone, dark gray, dense	2
Interval	3
Dolomite, gray, shaly	2
Limestone and dolomite beds alternating, each 2 to 4 feet thick	16
Sandstone, red	2
Limestone, light gray, dense	5–6
Dolomite, light gray	4
Limestone, gray, platy	2
Dolomite, gray, fine crystalline and dense	9
Limestone, gray, dense, massive	4–5
Dolomite, gray, platy	5
Limestone, dark bluish gray, dense, grading to underlying bed	10
Dolomite, gray, platy	2
Interval	10
Dolomite	5
Interval	125
Dolomite, gray, dense, platy to blocky	26
Shale, red, sandy	3
Sandstone, red	4–5

	Feet
Dolomite	10–11
Shale, red, with shaly sandstone and dolomite partings	20
Dolomite	2
Shale, red, sandy	2–3
Dolomite	10
Shale, red	3
Limestone, gray, dense	2
Shale, red; subordinate red sandstone and sandy dolomite	8
Dolomite	3–4
Limestone, dark gray, dense, chiefly massive	15
Sandstone, dolomitic, thin platy	7
Dolomite, variable, partly sandy	4
Shale, red	3
Dolomite	3
Shale, red	2–3
Dolomite, gray, dense, chiefly massive	8
Limestone, dark gray, dense	2–3
Dolomite, variable; contains 6 inch bed of limestone near top	17
Sandstone and shale; weathers red	4
Limestone, dark gray, dense, massive	7
Dolomite, sandy, and dolomitic sandstone, thin platy; weathers red	5
Dolomite, gray, dense, massive; red partings	7
Shady dolomite (Ivanhoe limestone member)	
	470

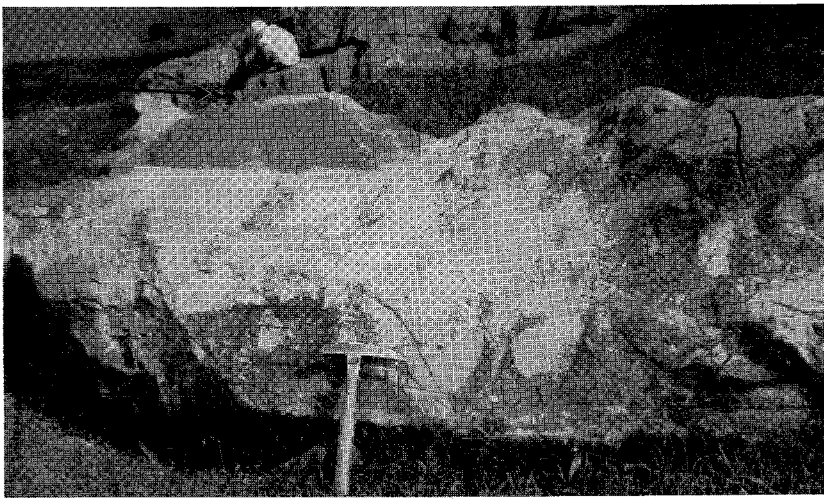
This section is described in detail to show the characteristic heterogeneity of the formation and the thinness of the individual lithologic units. There is, of course, no constancy to the sequence and thickness of the beds.

In some exposures beds of dolomite more than 100 feet thick are found without intercalated red beds. Such beds are in part massive and of saccharoidal texture. Excellent exposures of thick dolomites in the Rome can be seen along the railroad about a quarter of a mile west of Pierce Mill and in the vicinity of Bertha railroad station.

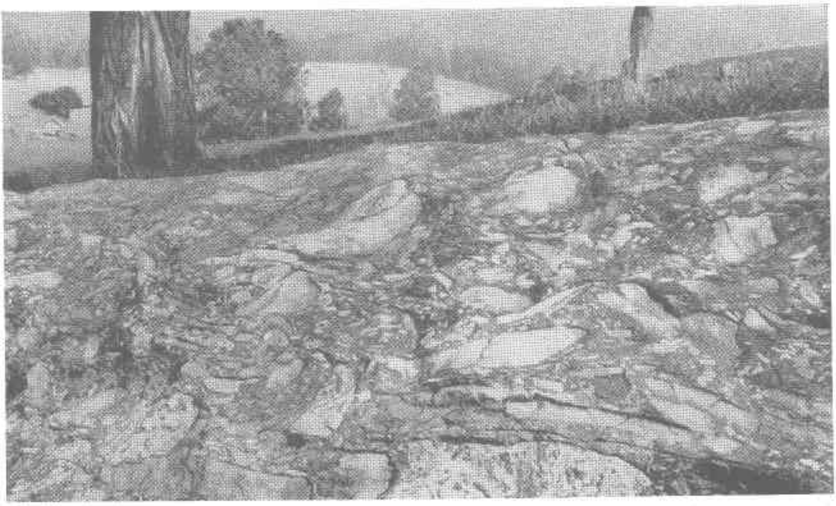
Charles Butts,[11] of the United States Geological Survey, reports ptychoparian trilobites and a species (probably new) of *Olenellus* from the Rome shales of this region.

[11] Oral communication.

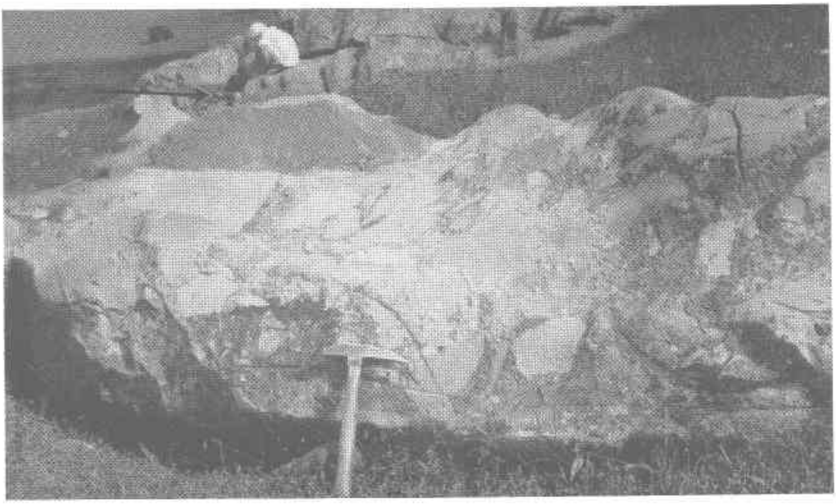
A. Limestone breccia in the upper part of the Shady dolomite in the Austinville Basin. About 1 mile west of Bethany, just south of the highway.



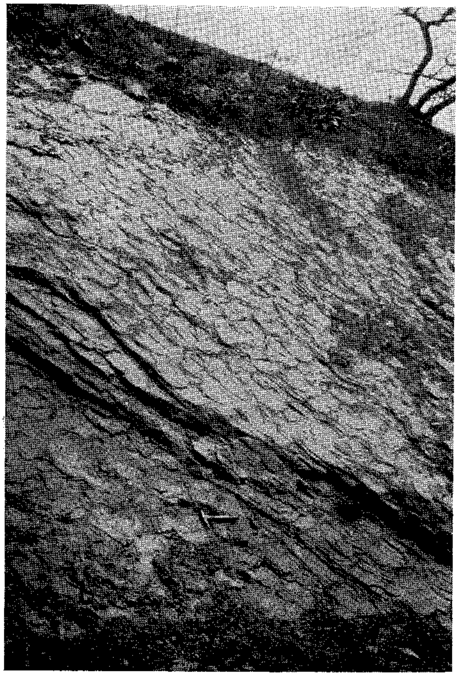
B. Detail of limestone breccia in the upper part of the Shady dolomite, just below exposure shown in A. The arrow indicates an interbedded fossiliferous limestone.



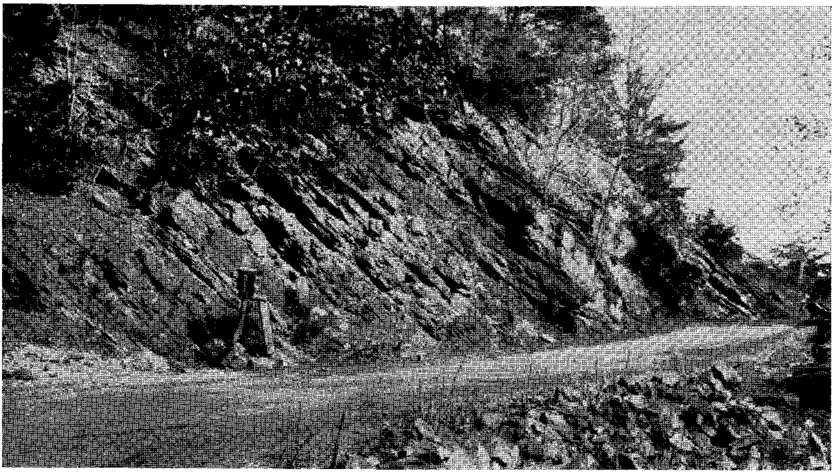
A. Limestone breccia in the upper part of the Shady dolomite in the Austinville Basin. About 1 mile west of Bethany, just south of the highway.



B. Detail of limestone breccia in the upper part of the Shady dolomite, just below exposure shown in A. The arrow indicates an interbedded fossiliferous limestone.

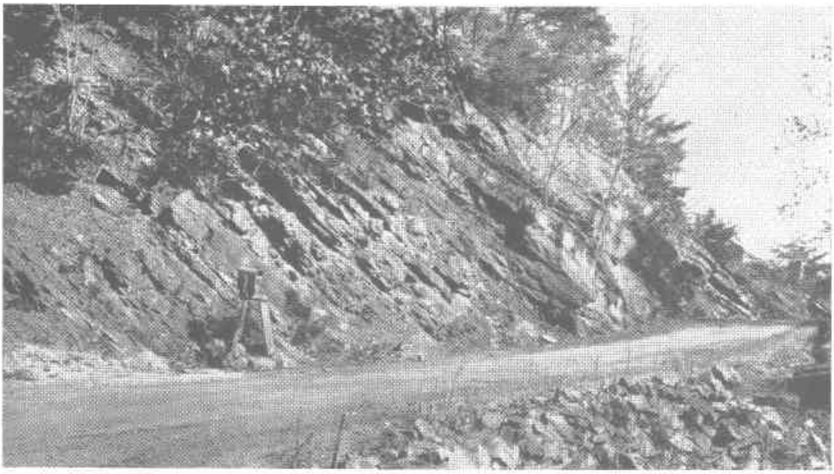


A. Red shales of the Rome formation showing characteristic ripple marks and sun cracks. Along the highway at Slade Spring School.



B. Rome beds exposed at the top of the Porter section. Along the highway half a mile south of Porter crossroads.

A. Red shales of the Rome formation showing characteristic ripple marks and sun cracks. Along the highway at Slade Spring School.



B. Rome beds exposed at the top of the Porter section. Along the highway half a mile south of Porter crossroads.

ELBROOK DOLOMITE (MIDDLE AND UPPER ? CAMBRIAN)

In this area the only beds that can be interpreted as belonging to the Elbrook crop out along a strip about 9 miles long and from one-fifth to one-half mile wide, extending from a point between Ivanhoe and Porter crossroads northeastward to a point about half a mile west of Bertha railroad station. Along this belt of outcrop appears a thick series of dolomites in conformable succession with beds of undoubted Rome age. Subordinate white limestone beds are present, especially near the base. A quarry beside the highway at Galena and another near the highway between Austinville Ferry and Porter crossroads are believed to be in the base of this formation. Just below the beds of these quarries red shales of the Rome are exposed prominently, but above them there appears to be a succession of dolomites lacking red beds, except for a thin reddish shale or shaly parting here and there near the base. At the Galena quarry the basal beds are characteristically dark even-bedded platy dolomites, breaking in smooth-surfaced thin slabs. Above the quarry are several thin beds of dolomite and of white limestone, the latter of rather distinctive Elbrook type.

The base of the quarry between Austinville Ferry and Porter, 2 miles due east of Porter crossroads, is about 100 feet stratigraphically above Rome red beds. The Rome-Elbrook contact has been drawn between the quarry beds and the nearest exposed red shale. The quarry cut shows the following section of Elbrook dolomites:

Geologic section 12.—Section of Elbrook dolomite exposed in quarry east side of highway, 2 miles east of Porter crossroads

	Feet
Dolomite, shaly, even bedded; weathers buff	6
Dolomite, massive, white, very fine crystalline to dense	10
Dolomite, white, massive but showing even laminations	7
Dolomite, thick platy to massive, very dark gray, very fine crystalline	5
Dolomite, blocky, dense, light gray grading to dark gray	3
Dolomite, blocky and thick platy, rather even bedded, light gray, dense	7
Same, darker gray	4
Dolomite, thin platy, gray	10

The outstanding structural characteristics of these beds are their smooth even-bedded character, leading to platy or blocky development.

The correlation of these beds with the Elbrook is somewhat uncertain because paleontologic evidence is lacking, and the beds are not traceable from exposures of established Elbrook identity. The fact that the section exposes about 1,200 feet of dolomite and limestone beds, without clastic argillaceous and siliceous beds such as are elsewhere so prominent in the Rome, reasonably leads to their tentative correlation with the Elbrook. Undoubted Elbrook beds in part of the same general lithologic character, are exposed just outside the area mapped, in the vicinity of Wytheville and along U. S. Highway 11 east of Fort Chiswell. (See Pl. 15, A.)

The Elbrook section at Wytheville, just southwest of the corporate limits and between the railroad and Reed Creek, shows a continuous exposure of about 1,800 feet. The total thickness between probable positions of upper and lower contacts is estimated to be close to 2,000 feet. Hence the Elbrook exposures in the Ivanhoe-Bertha belt are probably in the lower half or two-thirds of the formation and for this reason may lack the rather abundant limestones that appear in the upper third of the Wytheville section. Certainly it appears that the Elbrook of this belt is essentially a dolomite formation throughout, with very subordinate thin limestones. The dolomite displays varied textural characteristics, but rather dense or finely crystalline light-gray to white, fairly massive beds seem to be most abundant. Some saccharoidal beds are also present, as well as coarser dark dolomites resembling certain beds of the Rome, so that, in the lack of evidence of a conformable and sequential relation to Rome beds, exposures might easily be confused with lower formations.

STRUCTURAL GEOLOGY

The area covered by this report lies within the portion of the Appalachian Valley that is characterized structurally by a series of pronounced folds and associated overthrusts. The general trend of these major structural features is about N. 70°E., but there are local departures from this direction. Although the area is within Willis's "district of close folding,"[12] the observable variation in degree of folding and the presence of a considerable number of prominent thrust faults suggest that the term "district of close folding" is a misnomer as applied to this particular area. Commonly the Rome shales show compressed and even slightly overturned small folds, whereas the Shady and Elbrook formations show broad, open structures. All the formations have been considerably faulted.

Most of the dips seen in exposures are toward the southeast, but there are many exceptions, chiefly where more locally circumscribed structural features occur, or where weaker beds, such as the Rome shales, have been more severely deformed into a series of narrow folds.

MAJOR STRUCTURAL FEATURES

GENERAL SUMMARY

The major structural features of the mapped area are shown in Plate 2, which is a reduced-scale map of the faults and axes of folds that are shown in greater detail on the geologic map, Plate 1.

In its broadest structural aspect the larger part of the area comprises the frontal portions of large blocks overthrust from the south or southeast. The edges of the blocks are now represented by the traces of the Sugar Grove and Laswell overthrusts. These overthrusts were probably parts of a single extensive thrust, later divided by erosion in the area of the Cripple Creek anticline. From the south and southeast other great blocks or slabs have been thrust upon the Sugar Grove-Laswell slab, and the quartzite beds of these blocks stand out in strong relief as the Poplar Camp Mountain and Iron Mountain ridge systems.

North of the Laswell and Sugar Grove faults lie Lick and Brushy mountains. These quartzite masses are probably erosional outliers (klippen) of the Poplar Camp and Iron Mountain overthrust sheets, respectively. The lower and narrower ridges south and southwest of Lick Mountain (Sand, Henley, and Swecker mountains), and those at the southwest end of the Brushy Mountain range (Barton

[12] Willis, Bailey, The mechanics of Appalachian structure: U. S. Geol. Survey Thirteenth Ann. Rept., pt. 2, pp. 224, 229, 1893. In this paper Willis divides the Appalachian province into four structural districts,—(1) district of open folding (Allegheny region of Pennsylvania and West Virginia), (2) district of close folding (Appalachian Valley), (3) district of folding and faulting (southern Appalachian region of Virginia, Tennessee, and Georgia), and (4) district of folding and schistosity (Great Smoky Mountain region).

Mountain, Long Ridge, and Short Mountain) are not included in the klippe masses, since they are not bounded on their south side by fault contacts. These minor ridges, on the other hand, comprise local anticlines whose northwest limits only are cut by relatively steep thrust faults.

The Sugar Grove and Laswell blocks are themselves deformed by folding and faulting. Deformation of the Laswell block is particularly great, and within its area are the Austinville-Ivanhoe and Bertha mining districts, as well as several outlying prospects and mineral exposures. Indeed, the only profitable mining has been done within this area.

Both the Laswell and the Sugar Grove fault traces indicate a subsequent broad synclinal warping of the fault surfaces. The distribution of the strata within these blocks indicates a series of broad synclinal basins. These prominent basins are modified by thrusts and by local folds and warpings.

The northern belt of Shady dolomite, as defined on page 17, lies entirely outside the Sugar Grove and Laswell overthrust blocks, that is, within the footwall block of these faults. This belt is also deformed by folding and faulting. The structural features of the area surrounding and including the west end of Lick Mountain constitute an anticlinorium cut by two prominent thrusts. In the vicinity of Cedar Springs there is local and close folding with minor faulting, and in the area between Teas and Adwolf several anticlines are exposed whose northwest limbs have been truncated by thrusts.

LASWELL OVERTHRUST BLOCK

The chief structural features within the Laswell overthrust block are the Hematite Mountain overthrust, the Gray's School thrust and minor thrusts in the Austinville area, the Ivanhoe cross fault (flaw?) and the Austinville anticline. Minor features include the cross faults (possibly flaws) at Carter Ferry and Sayer School and the New Castleton fault. The Periwinkle and Dry Pond Mountain, Poplar Camp Mountain, and Ewing Mountain overthrust blocks have overridden the south and east sides of the Laswell block. Their genetic relation to the Laswell thrust is not clear, although the Laswell thrust may be in the nature of a sole with respect to the subordinate Hematite Mountain, Gray's School, and Austinville thrusts. The pattern of thrusts in the Austinville Basin, however, does not conform closely to the general regional trend of the strata. Here the beds are locally distorted, with strike directions averaging more northerly than the general strike of N. 55°-65° E. Moreover, the axis of the Austinville anticline shows, besides minor local deflections in trend, a marked bend at Foster Falls and is here bounded by the Hematite Mountain thrust, which is apparently pivoted at some point between this locality and Patterson. These conditions suggest subordinate blocks within the Hematite Mountain overthrust block but related to a more locally concentrated force. This local adjustment was attended not only by considerable thrust faulting but also by cross shearing and local distortion of the beds, all of which contributed to the intense shattering and brecciation of the beds in the Austinville Basin.

SUGAR GROVE OVERTHRUST BLOCK

The Sugar Grove overthrust block shows little deformation as compared with the Laswell block. There has been broad synclinal warping of the thrust surface, as in the Laswell overthrust. Although there was also local minor thrust and cross faulting within the block, as indicated south of Sugar Grove and between Cedar Springs and Speedwell, as well as local slight distortion of the strata, on the whole deformation was generally slight, and comparatively little shattering and brecciation of the strata were accomplished. Within the Sugar Grove block there appears to have been no focus of strong local adjustments. This may indeed be a significant fact in relation to mineralization. Prospects within the Sugar Grove and Speedwell synclinal basins, which occupy the Sugar Grove overthrust block, are very few and apparently unimportant.

SYNCLINAL BASINS

Three distinctly defined elongated synclinal basins, each largely outlined by the traces of a synclinal fault surface, occupy a large tract that extends from the east end of the mapped area nearly to Sugar Grove. The axes of these basins practically constitute a single synclinal axis, the basins being separated only by low anticlinal arches. In the central portions of these basins Rome and Elbrook beds are exposed. The peripheral formation is the lower Shady, or Patterson member, and in a few places fragments of the Erwin quartzite. Although the synclinal character of these areas is obvious, this basic structure has been modified in various ways by thrust faulting. All these synclines are within the southern belt of Shady exposures, as defined on pages 17-18. Broadly considered, these basins are the dominating structural features of the southern belt.

For convenience, the easternmost is called the Galena basin, from the settlement of Galena, centrally located within it; the next westerly is called the Speedwell basin, from the village near its east end through which the synclinal axis passes; the westernmost is called the Sugar Grove basin, from the near-by village.

Galena basin.—The Galena synclinal area extends from the vicinity of Reed Junction, on the east, to Gleaves Knob, near Huddle, on the west. The basin as a whole is part of a block thrust over the Rome shales along the north boundary of the mapped area. The northwest limb of the syncline has a nearly constant trend of N. 65° E. for a distance of about 10 miles, between Huddle and Carter Ferry. At these points the attitudes of the beds change to form the west and east closures of the basin.

The southeast limb shows less regularity. For most of its length it forms the marginal belt of a subordinate overthrust block, the thrust having variably shortened the transverse dimension of the basin structure. The southeastern limb of the syncline constitutes the northwestern limit of the prominent anticline extending from Ivanhoe through Austinville and Foster Falls to Patterson. Further account of the dislocation of the Galena synclinal basin is given in the section devoted to faults.

The east end of the Galena basin broadens into a wide area of very low dips, at some points nearly horizontal. In this area the widths of outcrop of the Patterson and saccharoidal members of the Shady are much greater than at any other part of the mapped area, except where there has been repetition by faulting. This area of low dip is believed to be nearly free of such duplication of strata. On the other hand, it is very largely covered by surface mantle, so that critical horizons are difficult to trace, and only a generalized interpretation of the areal distribution of formations and members is possible. It is significant in this connection that, in contrast with conditions elsewhere, the exposures here show a very slight amount of fracturing of the type that is apparently common to areas near faulted zones. It is also significant that, although a large amount of oxidized zinc ore was mined from the vicinity of Glenwood (Bertha and other mines), the pillars of Shady dolomite exposed in the open cuts show a remarkable lack of mineralization, whereas similar pillars in open cuts in the Ivanhoe-Austinville area display considerable mineralization by sphalerite, galena, and pyrite.

The west end of the Galena synclinal basin, though distinctly marked by the peripheral dips, is largely overridden by the Hematite Mountain thrust block, the fault trace passing nearly through the nose of the syncline, which pitches northeastward at this locality. The geologic map (Pl. 1) clearly shows the stratigraphic disclocation.

Speedwell basin.—Like the Galena basin, the Speedwell syncline lies in an overthrust block overlying the Rome belt to the north. The rocks within this syncline include those from the top of the Erwin, which appears in a few places along the northern border, into Rome shales, which occupy the central belt. This basin also is well defined by dips, but the base of the fault block in which it lies is at a shallower depth than that of the Galena basin, as can be inferred from the fault trace which nearly circumscribes the syncline. Within this basin there are no marked dislocations by thrust faulting. The axis as traced by the dips of the strata is almost centrally located in the east end, indicating a nearly symmetrical fold in this portion, but toward the west end the axis is nearer the southern border, where the syncline becomes asymmetric by steepening of the south limb.

The Shady belt along the north limb of this syncline is rather easily divisible into the Patterson and saccharoidal members, but along the south limb exposures are sparse, especially toward the base of the bordering quartzite ridge, so that although the Patterson is probably present beneath the extensive apron of talus and slope wash from the ridge, it has not been seen here, and the formation is accordingly mapped as undifferentiated Shady.

The Speedwell synclinal basin is separated from the Galena basin by a low anticline, which exposes a central area of the saccharoidal dolomite member of the Shady.

Sugar Grove basin.—The Sugar Grove basin is separated from the Speedwell syncline by a low anticlinal area of Shady dolomites, about half a mile wide. This intervening area, however, does not display a distinctly marked structural pattern, but shows a variety of low dips, which indicate undulatory warping passing into the broader synclinal areas on each side. In reality the Sugar Grove and Speedwell basins constitute portions of the same general synclinal area, the axis of which is locally deflected and warped in the intervening area.

Structurally the Sugar Grove synclinal area is a broad, shallow basin, which shows local undulation, so that at least two subordinate axes, probably divergent from the western part of the basin, may be interpreted. Throughout the basin the dips are low. At the west, south of Sugar Grove, the structure dies out in a broadly exposed area of lower Shady, where dips are low and variable and indicate an area without simple structural distinction.

At the west end the basin is slightly disturbed by faulting.

AUSTINVILLE ANTICLINE

The Austinville anticline lies along the southern and southeastern border of the Galena synclinal basin. The crest appears well exposed in section as a bluff on the east side of New River at a bend about three-quarters of a mile west by south of Austinville (Pl. 15, B). It can be traced from New River in the vicinity of Ivanhoe northeastward through Austinville to and including Hematite Mountain near Jackson Ferry, and thence eastward to the vicinity of Patterson.

The west end of the anticline, at Ivanhoe, is indistinct, good rock exposures being few, but in the river bluff at Ivanhoe Ferry the low anticlinal character may be readily determined by obvious dips of the beds on both limbs. Indeed the west end of the fold flattens south of Ivanhoe, in part as the effect of the southwesterly pitch of the anticlinal axis, but also because of the general fading out of the anticlinal structure and the swinging of strikes of the formation in conformity with the closure of the Galena synclinal basin.

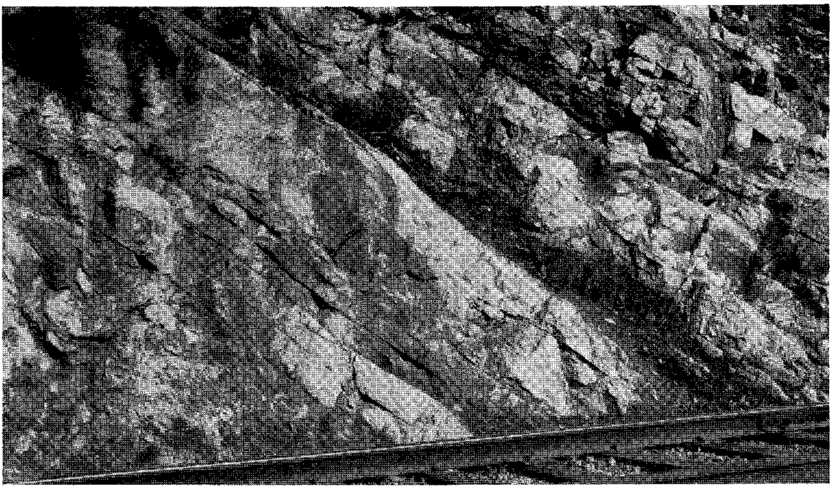
From the ferry at Ivanhoe the anticlinal axis extends in an average direction of N. 55° E., except for local deflections of 5° to 10°, across the New River meanders, through Austinville, thence in general along the south side of the river and in the south wall of the valley to the river bend about 1 mile west of Jackson Ferry. At this point it crosses New River and with a course of N. 60°-65° E. follows Hematite Mountain to the bend of the river just north of Foster Falls. In the bluffs at this locality, where the river crosses the anticline, the structure is obvious in a well-exposed section of the Erwin quartzite. From the crest of Hematite Mountain the course of the axis changes rather abruptly and continues in an easterly direction, following Foster Falls Mountain, to the vicinity of Patterson, where, by apparently much increased pitch of its axis through the last mile of its course, it loses its identity as a marked and simple anticline. Conditions at the gap are obscured by local distortions and overthrusting from the southeast, but at or near the end of the anticline, in the vicinity of the gap, a flexure on the south flank forms a synclinal nose pitching in a southwesterly direction. This is displayed clearly by the attitude of the Patterson limestone at several exposures just southwest of the gap, in the vicinity of Periwinkle Branch. It is believed, however, that most of the quartzite mass forming the ridge on the southeast side of this branch is a block thrust over the basal Patterson and uppermost Erwin of this local pitching synclinal fold.

In general, the Austinville anticline is nearly symmetrical, the north or northwest limb dipping but a few degrees more than the southeast limb, except at places where local pronounced distortion, in part brought about by local thrusting, has produced steep dips, as along the railroad three-quarters of a mile northeast of Austinville station.

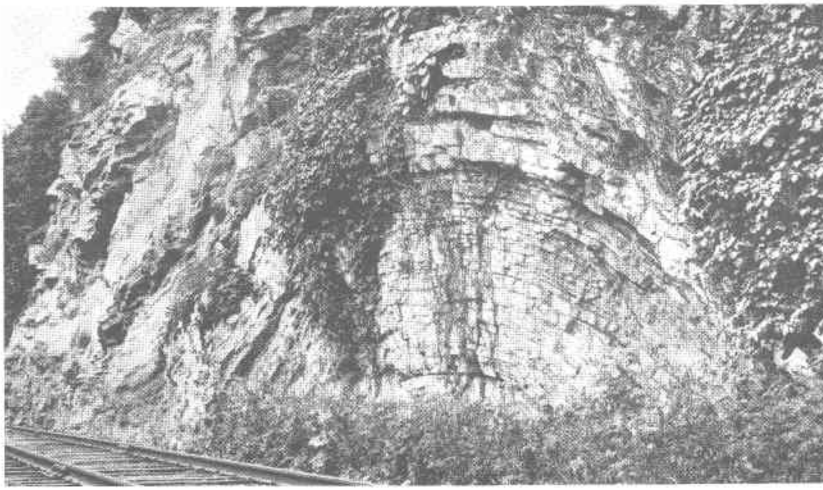
MINOR FOLDS SOUTH AND SOUTHWEST OF AUSTINVILLE

The short ridge of Erwin quartzite just west of Sheeptown constitutes an anticline with steep northeast pitch. The northwest limb appears to be cut off by a thrust fault, for which the anticline forms the border of the overriding block. On the east and southeast sides basal Patterson and transition beds are apparently in normal sequence

A. Local fold in blocky dolomite beds of the upper part of the Rome formation. Along the railroad west of Reed Junction.



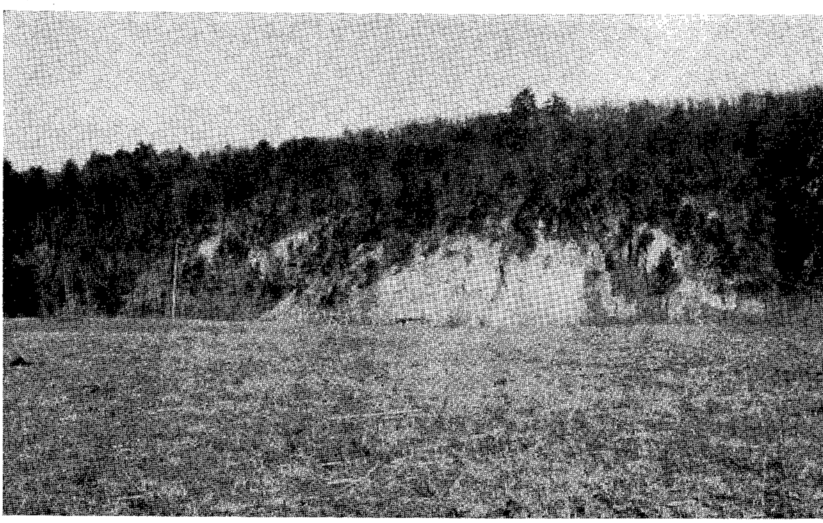
B. Blocky and massive dolomite beds of the Elbrook formation. Along the railroad north of Foster Falls. These beds are similar in appearance to beds of the lower formations.



A. Local fold in blocky dolomite beds of the upper part of the Rome formation. Along the railroad west of Reed Junction.

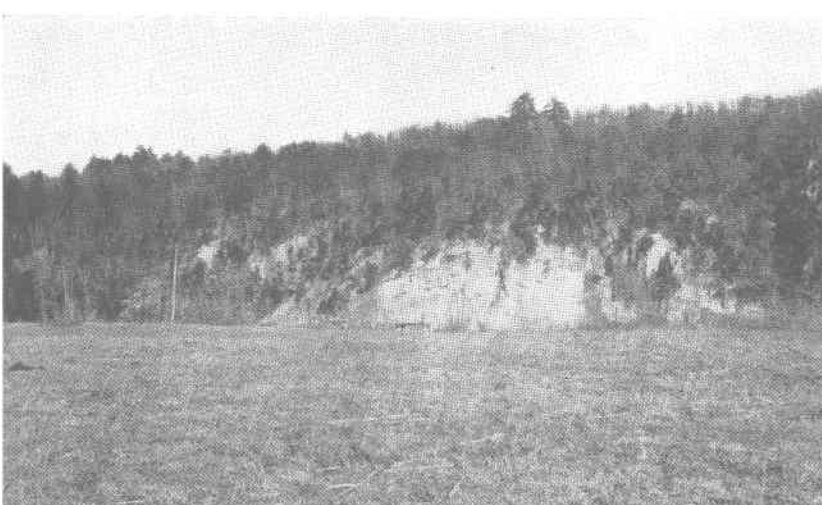
B. Blocky and massive dolomite beds of the Elbrook formation. Along the railroad north of Foster Falls. These beds are similar in appearance to beds of the lower formations.

A. Elbrook formation along highway at southwest corner of Wytheville corporate limits. Displays typical evenly bedded, platy to blocky character of the formation.



B. The Austinville anticline where crossed by New River between Austinville and Ivanhoe. The section shows the crest of the fold and its open character. In this bluff, a few feet above the river, is "Chiswell's Hole," the point of original discovery of lead ores.

A. Elbrook formation along highway at southwest corner of Wytheville corporate limits. Displays typical evenly bedded, platy to blocky character of the formation.



B. The Austinville anticline where crossed by New River between Austinville and Ivanhoe. The section shows the crest of the fold and its open character. In this bluff, a few feet above the river, is "Chiswell's Hole," the point of original discovery of lead ores.

with the Erwin quartzite, as indicated by the dips at several points. The scattered exposures, scarcer toward the south and southwest, are insufficient to determine whether or not the wedge-shaped area of Shady between the short quartzite ridge and Poplar Camp Mountain forms a similarly pitching synclinal nose, though such might be the natural inference.

Three-fourths of a mile west of Gray's School a high knob of quartzite forms the central portion of a sharp anticline which pitches steeply in a direction slightly east of north. On the northwest side of this fold, along an old roadway well up the face of the bluff, the basal Patterson and Erwin beds are apparently in conformable contact, though with an almost vertical attitude. Around the north side of the anticlinal nose the dips are found to accord in direction with the structure as interpreted. This accordance is continued southward along the east side, where the amount of dip becomes moderate, to the highway, south of which the structure is lost below the thrust block of Erwin quartzite that carries the pitching anticline previously described.

MINOR FOLDS AT CRIPPLE CREEK

At and south of Cripple Creek several minor folds are exposed in succession through a distance of 1½ miles. At Cripple Creek a narrow low anticline exposes the saccharoidal member of the Shady for about a quarter of a mile across the strike. Successively to the south appear a closely folded syncline in the Rome, an anticline in the Shady with steep north limb, a shallow syncline in the Shady, and an anticline exposing a central area of Erwin quartzite, the south limb exposing Patterson beds overridden by a thrust block of quartzite. (See geologic section E-E, Pl. 1.)

FOLDS OF THE LICK MOUNTAIN AREA

The area of Shady dolomite and Erwin quartzite exposures around the west ends of the ridges of the Lick Mountain range, which includes Sand and Henley mountains, shows a succession of several roughly parallel anticlines and synclines. The general course of these folds is slightly north of east. As shown by the map (Pl. 1), their axes pitch moderately toward the west, where the folds become lost in the extensive area of Rome shales. The dominant structural feature of this belt is anticlinal, and the succession of subordinate folds composing it gives it the structural characteristics of an anticlinorium, though the mass is scarcely large enough to be designated technically by that term. The area is nevertheless one of strong local upwarping and includes a number of subordinate folds. The major structure is cut by at least two strike-thrust faults, which are described on page 59. The mapping was extended northward to include this area because of local mineralization displayed by prospects near Mount Ephraim Church and Mountain View School. The main mass of Lick Mountain, however, appears to be a klippe which overlies the eastern parts of the Henley-Sand Mountain anticlinorium.

Warping South and West of Sugar Grove

The area of Shady dolomite just south of Sugar Grove and another extending from a point about 1 mile west of the village nearly to the quartzite ridge 3½ miles west show minor anticlinal and synclinal warpings. In the area south of the village the dips are low for the most part, and the warpings are not of uniform trend, though in general the attitudes of the beds conform to the west end of the Sugar Grove synclinal basin, of which this local area is the flattened and undulatory border portion. Dips in the warped area west of the village, however, are steeper, and the folds, though of only local extent, are more pronounced anticlines and synclines which conform in general trend to the regional structure.

Anticlines Between Teas and Adwolf

The Sugar Grove-Adwolf highway crosses three prominent ridges of quartzite, including the ridge about 1 mile west of Teas, mentioned in the preceding paragraph. Distinct anticlinal structure is shown by that nearest Teas, especially at its southwest end, at Barton Branch, and where dips in the conformable Shady dolomite and Erwin beds, south of the fault that transects the northern limit of the structure, clearly display a southwest pitch of the anticlinal axis. The other anticlines are probably part of the larger anticlinal structure of Barton Mountain and its associated ridges. Thrust faults bound these anticlines on the northwest sides. Intervening Shady areas show homoclinal southeasterly attitudes. The broad Shady area between Barton Mountain and Adwolf shows a definite asymmetrical anticline, comparatively low, with axis approximately as mapped. No evidence of faulting within this Shady area was seen, but to the east, the Shady dolomite is overlain by the lower quartzite beds of Pond and Rich mountains, which either comprise the western end of the Brushy Mountain klippe, or a series of overturned folds resting upon the dolomites. Structural details of the entire Brushy Mountain complex have not been worked out.

THRUST FAULTS

Reverse faults of the overthrust type are prominent structural features of the mapped area. They are genetically connected with the period of regional folding and apparently differ in no way from the general Appalachian features of deformation and sequence. In general, the result of overthrust faulting has been to eliminate the surface expression of some of the synclinal axes, and to preserve the southeast anticlinal limbs, thus causing a great predominance of southeasterly dips to appear in the exposures.

The common homoclinal attitude over extensive areas, the lack of thin key beds in the Shady formation, and the paucity of exposures in many places make it difficult or impossible to determine accurately the positions or amounts of displacement of some of the faults. It is probable, too, that some minor faults have escaped detection for these reasons. Further detailed stratigraphic study of the Shady formation will facilitate the recognition of more structural data, but the time available for this preliminary investigation was necessarily too short to permit an exhaustive study. Especially it is felt that more detailed work in the Austinville Basin will be fruitful.

The exact dip of a fault plane is rarely determinable from surface exposures. Exceptionally the position and site of a fault outcrop may be inferred within close limits for a short distance along a slope, and the attitude evaluated accordingly. For the most part the actual fault surfaces are hidden from view beneath talus or soil, and only the presence of the fault is determinable. At Laswell the fault dips approximately 40° SE. At Porter the same fault probably dips between 35° and 40° SE. This fault plane has been folded, however, and the localities cited are on the steepened limb of the synclinal fold. At Poplar Camp the dip of the thrust surface is believed to be of the order of 20°. South of Patterson the dip of the Alum Hollow fault seems to be about 35°.

The trend of most of the overthrusts is parallel to the strike of the beds, but local departures from this trend are found in places along the major faults, and some of the subordinate thrusts show marked differences. There is generally a closer accordance of fault strike with that of the beds in the overriding block than in the overridden block. This indicates that, although the original break was controlled by the trend of the strata, relative rotation of the overriding block ensued during the movement. It is a striking fact, however, that the average trend of the two major faults of the area, the Laswell and Sugar Grove overthrusts (which may be portions of a single overthrust), is closely similar to the average strikes of the strata in both fault blocks. On the other hand, the subordinate thrusts within the overriding block of the Laswell-Sugar Grove overthrust show in several places a marked discordance between the strike of the beds in the overriding block and trend of the fault, on the one hand, and the attitudes of the overridden beds, on the other hand. These conditions suggest that the compressive stress which produced the major fault, possibly the sole, was uniformly distributed and normal to the trend of the regional structure, but that in the later stages of deformation, when the subordinate imbricate faults were formed, shearing stresses were not uniformly distributed and locally produced rotational effects.

Laswell fault.—The Laswell overthrust has been named for the settlement near which it is well exposed along the roadside. (See Pl. 16, A.) This overthrust has been traced continuously from the vicinity of Reed Junction, at the east end of the mapped area, southwestward to Gleaves Knob. Except for the stretch from Allison to Reed Junction the strike is rather impressively uniform and averages about N. 65° E. From the vicinity of Allison to Reed Junction the trend becomes more easterly, and at Reed Junction it is approximately due east.

At Sayer School, near Allison, the fault may be offset by cross faulting. A quarter of a mile east of the road bend the fault trace apparently crosses to the south side of the road and follows the river channel and leads into the bluff on the east side of the road, where exposures show the Patterson member above Rome shale. From this point, after crossing the peninsula of Patterson beds, the fault trace probably follows more closely the south bank of New River and rises into the south bluff near Reed Junction. Along this stretch of bluff, however, the fault consists of at least two associated thrust shears, constituting a zone rather than a simple break. In this vicinity minor thrusts are found in the Rome formation (Pls. 16, B and 17, A).

Along the Laswell overthrust from Reed Junction to Gleaves Knob, basal Patterson rests upon Rome beds. It is probable that nearly the entire Shady column appears in the overthrust block. On the other hand, the particular horizon of the Rome is not determinable; hence the stratigraphic displacement along this fault can not be stated. Gleaves Knob is capped by Erwin quartzite, which at this locality is thrust upon the Patterson member, and the Patterson itself is thrust over Rome beds. Lack of satisfactory exposures in and around the knob causes confusion as to whether the quartzite of this peak belongs partly in the overriding block of the Laswell fault or entirely in that of another fault (the Hematite Mountain overthrust), the trace of which converges toward the Laswell fault at this point. The latter interpretation seems more probable from the stratigraphy of the Gleaves area. Though somewhat obscure, the structural relations of the Patterson and saccharoidal members of the Shady south of Cove Branch School lend some support to this view. The suggested fault shown along Cove Branch may be a continuation of the Laswell fault, which, between this locality and Gleaves Knob, lies beneath the overthrust block of the Hematite Mountain fault. In either case it would appear that the trace of the Laswell fault turns southward and southeastward between Gleaves Knob and Cove Branch and forms a synclinal fault trough, indicating a slight synclinal folding of the Laswell fault.

Hematite Mountain overthrust.—The Hematite Mountain thrust fault borders the north side of the mountain, just north of Jackson Ferry, and shows its maximum stratigraphic displacement at this locality.

Starting at Gleaves Knob, the thrust may be traced east by north to Baker Island, north of Foster Falls, thence along the north side of Foster Falls Mountain to a point about halfway between Foster Falls and Patterson. The broad slope extending from 1 to 2¼ miles west of Patterson on the north side of the ridge suggests an apron of quartzite debris, but from its extent, sharp soil changes along its borders, and iron pits it is interpreted as an area underlain by Erwin quartzite. Somewhere along the border of this shelf the Hematite Mountain thrust either dies out or takes a more northerly course, for the gap at Patterson shows Patterson beds conformable upon the Erwin quartzite of the ridge. No evidence is at hand to suggest its continuation into the Shady area north of Patterson.

From Patterson west to the New River gap successively higher formations appear in contact with the Erwin quartzite of Foster Falls Mountain. In a distance of about 3 miles along the fault, therefore, the stratigraphic displacement probably increases from practically nothing to 3,000 or 4,000 feet. At the east end of Hematite Mountain beds of dolomite correlated with the Elbrook dip beneath the Erwin quartzite. At this point the fault has its greatest stratigraphic displacement, for the Erwin quartzite has been thrust over Elbrook dolomite. From this locality to Cripple Creek Valley north of Ivanhoe, Elbrook beds are exposed on the northwest side, and successively younger beds, from Erwin to Rome, inclusive, are exposed on the southeast side. The fault thus follows in average trend the strike of the beds in the overridden block but sharply bevels the beds in the overriding block. Near Ivanhoe the fault may be cut and displaced by the Ivanhoe flaw (transverse thrust). This interpretation, however, is not satisfactorily demonstrated, as good exposures are lacking on the west side of the cross fault.

The continuation of the Hematite Mountain overthrust westward to Catron is satisfactorily indicated by the stratigraphy, although the exact position of the fault trace is not everywhere determinable. From Catron to Gleaves Knob there is little difficulty in tracing the break. At Eagle Cliff the top of the Erwin has been faulted upon the upper Shady. On Gleaves Knob the fault either merges with or overlaps the Laswell overthrust, as discussed above.

Dry Pond Mountain and Periwinkle Branch overthrusts.—The blocks of Cambrian quartzites that form the high ridges east of Little Reed Island Creek and southeast of Periwinkle Branch are believed to be overthrust upon the upper Erwin and basal Shady sequence. It is probable that several related breaks are involved in the displacement. Along the fronts of these blocks exposures are unsatisfactory and do not reveal the nature of the Shady contact. Interpretation must be made largely on the basis of attitude and projected position of beds. At a few points, in the vicinity of Alum Hollow, a normal contact between the Patterson member and Erwin quartzite can be reasonably assumed at the base of the ridge, although the attitude of the beds above and their distribution east of Kayoulah indicate that Dry Pond Mountain probably constitutes an overthrust block. The geologic map (Pl. 1) thus shows in places a normal Erwin-Shady sequence overlain by Cambrian quartzites of the thrust block. A fault exposure at Alum Hollow is shown in Plate 17, B.

The ridge on the southeast side of Periwinkle Branch is believed here to reflect similar structural conditions. In the gap and along the northwest side of the branch there can be no question whatever that the relations between Erwin quartzite and Shady formation are conformable. The anticlinal character of Foster Falls Mountain is clearly shown by structural attitude and stratigraphic distribution, as well as the local conformability of beds. Along the southeast side of the road, and eastward around the northeast end of the ridge toward the High Rocks mill, the attitude of the beds indicates that the Cambrian quartzites in part are thrust upon Erwin beds and in part upon the Patterson member. This overthrust mass, however, is probably overlain at the south by the main Poplar Camp overthrust slab.

Poplar Camp overthrust.—Conditions in the gap at Poplar Camp clearly indicate that the quartzites of Poplar Camp Mountain are thrust upon younger beds to the north. The approximate position of the fault is indicated in Plate 18, A.

Except at Poplar Camp, where Shorts Creek has cut a gap through the quartzite ridge, there are no good exposures along the contact between the quartzite and the Shady of the mountain front. Numerous scattered exposures between Sheeptown and the area south of Rackettown show a general homoclinal uniformity of dips in the Shady formation, as the beds dip southeast beneath the broad talus and wash slope at the base of the ridge. Moreover, the beds belong relatively high in the stratigraphic section. No lower Shady beds were found in this belt. Dips in the Shady formation along this strip are generally between 20° and 40° SE.

The excellent exposures on the east side of Shorts Creek at Poplar Camp clearly display quartzite beds overlying sandy anad calcareous beds of the upper Shady, such as those southeast of Austinville. Dips in the Shady beds are fairly low to the southeast; dips in the quartzite beds are variable but in part steep to the northwest.

The Poplar Camp thrust may be readily traced southwestward to the vicinity of Sheeptown, where, in the reentrant formed between Poplar Camp Mountain and the short Gray's School ridge, Shady exposures are wanting, although the deep-red soil indicates their presence. It is probable that the fault trace continues southwestward along the ravine, crossing New River at or near the sharp bend west of Buck, possibly Big Branch, where an overthrust has been reported.[13]

The amount of displacement along the Poplar Camp overthrust can not be stated, but it is believed to be great, perhaps of the order of several miles. Structural conditions and areal distribution of formations in the Laswell and Hematite Mountain overthrust blocks as compared with the area south of the village of Cripple Creek suggest that these blocks may have moved northwestward at least 2 or 3 miles, and the Poplar Camp overthrust represents an additional fault of considerable displacement over the Hematite Mountain block. There has also been some shortening by folding.

New Castleton faults.—Exposures of green and yellow, reddish-weathering shales, in part slightly sericitic, in the vicinity of New Castleton School are believed to be Hampton shale. The sequence from Erwin quartzite in Foster Falls Mountain to the shales is probably unbroken, so that the intervening area includes nearly the entire Shady formation. Patterson beds of east-west strike and south dip are present in places along the flank of Foster Falls Mountain, and scattered exposures of saccharoidal dolomite are present in the central part of the belt. Exposures are few, however, and necessarily only the most general structural relations can be interpreted.

The gentle slope east of the school is covered with an abundance of quartzite blocks. This mantle continues northeastward for 2 miles, crossing the road at two points. The local concentration of quartzite blocks is great enough to suggest a quartzite bedrock beneath, but from the disposal of material and topography to the east it seems probable that this area is largely a talus and wash slope from the ridges. The material probably covers Shady and Erwin beds.

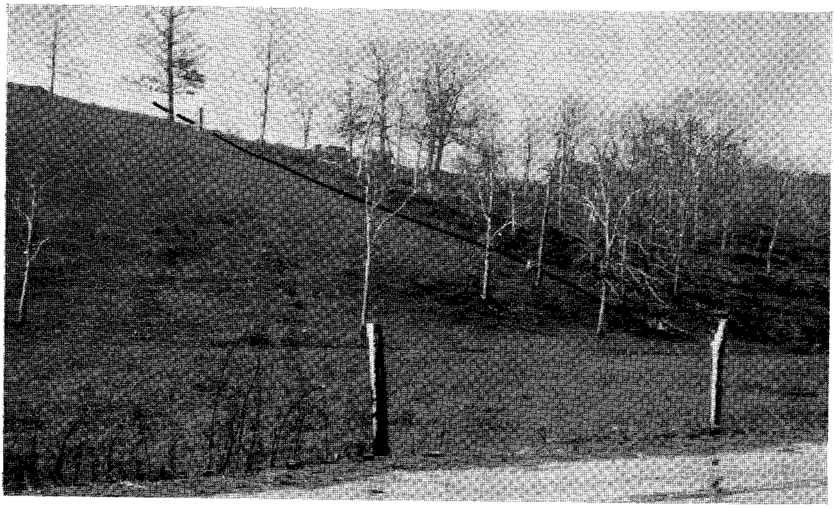
If, therefore, the stratigraphic interpretation for the vicinity of New Castleton School is correct, the Hampton shales have been thrust over Shady beds, and the shales in turn underlie the main overthrust mass of Poplar Camp Mountain. The structure of the shales is not determinable, but is probably to be interpreted as a recumbent overturned mass, the roots of which are beneath Poplar Camp Mountain.

[13] Jonas, A. I., oral communication.

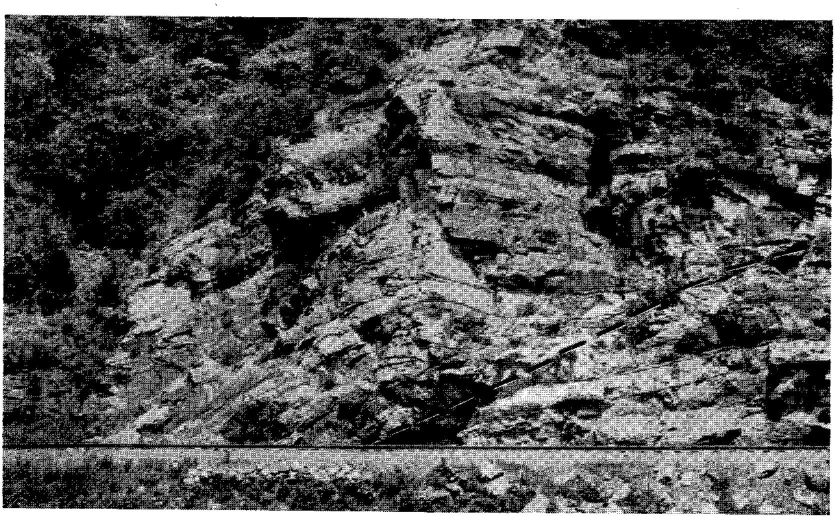
From New Castleton School to Jackson Ferry a straight, low, uniform escarpment suggests a steeply inclined minor thrust fault. The probability is strengthened by the highly fractured condition of the Shady dolomite beds along the escarpment and the strike of the beds at a few points. At New Castleton School this fault trace would pass beneath the Hampton shales. It is incidentally of interest to note that zinc minerals are present in the brecciated dolomite at the west end of the escarpment. Prospecting by diamond drill has been done a short distance east, but the results have not been divulged.

Thrust faulting between Austinville and Poplar Camp Mountain.—The presence of thrust faults and associated fractures in the Austinville Basin can be readily demonstrated. The details of this deformation, however, have not been revealed satisfactorily by this investigation. The stratigraphy presents aspects that differ from those of other known outcrops of the Shady formation. Complete elucidation of the structural problems of this locality can be attempted only after much detailed field work, necessarily augmented by facts of stratigraphy that can be obtained from careful study of the mine openings and drill records. Such information is probably in possession of the New Jersey Zinc Co., but has been withheld. At best, only the broad structural conditions can be suggested.

Exposures of the Patterson limestone member on the property of the New Jersey Zinc Co. indicate clearly an overthrust of considerable magnitude; probably the stratigraphic displacement nearly equals the thickness of the Shady formation. The local dips at the surface are about 40°, probably not greatly different from the dip of the fault surface, though this can not be determined satisfactorily from surface observation. The fault trace appears to pass north of the main shaft collar and trends northeastward, crossing the highway near the top of the hill. It probably continues to New River and is involved in the highly fractured zone in the bluffs half a mile east of Austinville station. Projected across the river, this line would continue to the area half a mile south of Galena and west of the highway, where there is marked reduction in the width of exposure of the saccharoidal member between the Ivanhoe and Patterson members. The relation of this condition to the Austinville fault may, of course, be only apparent. Southwest of the mine shaft the fault appears to bifurcate or to intersect another at a sharp angle, one branch continuing southwestward toward the peak west of Gray's School, where it dies out in a steep asymmetric fold, the other branch continuing to the bluffs of New River. Locally along the bluff exposure small breaks appear; one that lies nearly half a mile south of Ivanhoe Ferry appears to dip to the northwest and to represent very local subsidiary overthrusting from that direction.

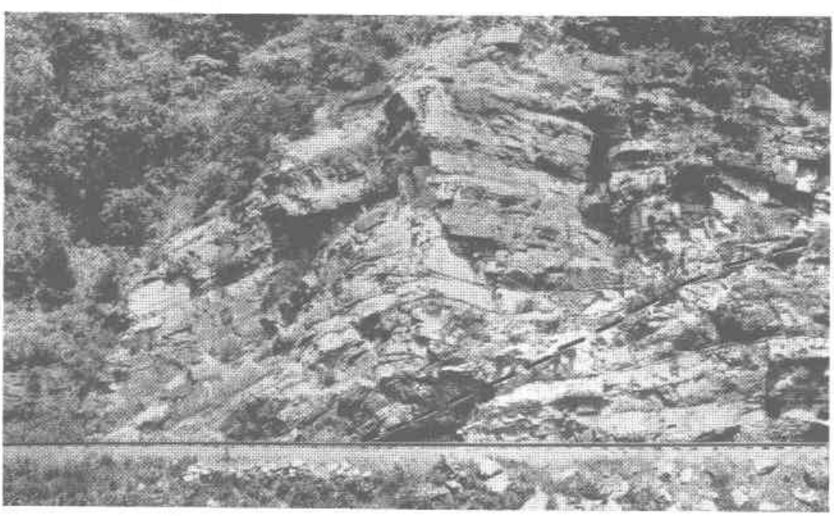


A. Exposure of the Laswell overthrust on the east side of the highway at Laswell. The fault is approximately in the position of the black line. On the east side of the road, looking east. Shady dolomite (right) thrust over Rome formation.

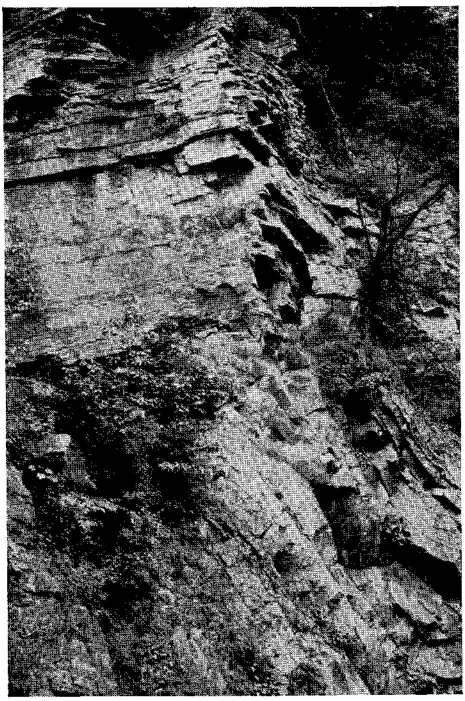


B. Local minor overthrust in Rome formation near Reed Junction.

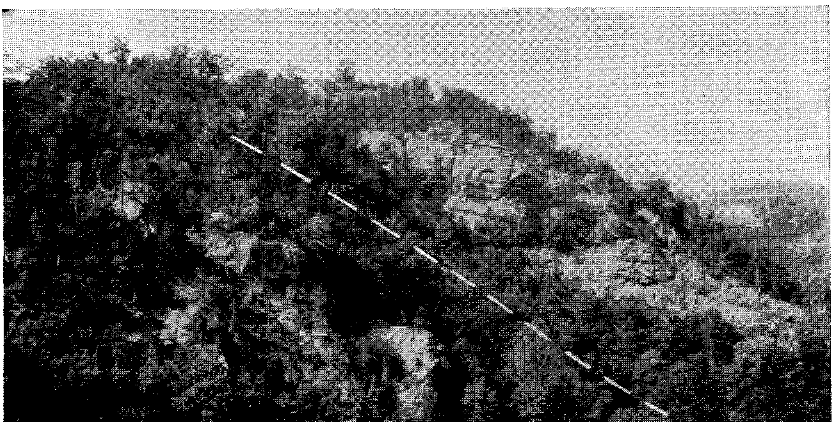
A. Exposure of the Laswell overthrust on the east side of the highway at Laswell. The fault is approximately in the position of the black line. On the east side of the road, looking east. Shady dolomite (right) thrust over Rome formation.



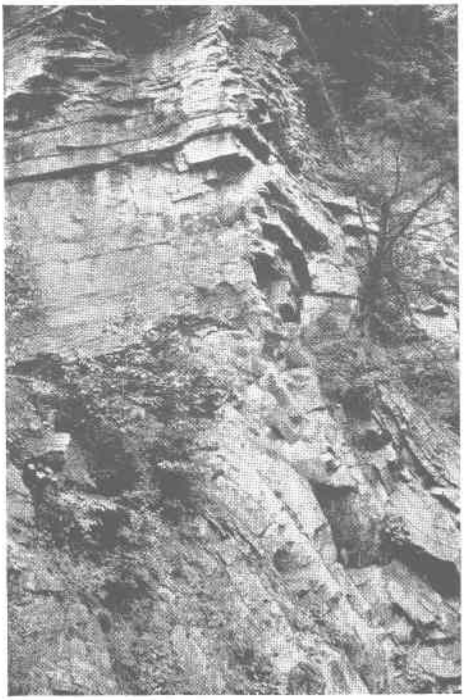
B. Local minor overthrust in Rome formation near Reed Junction.



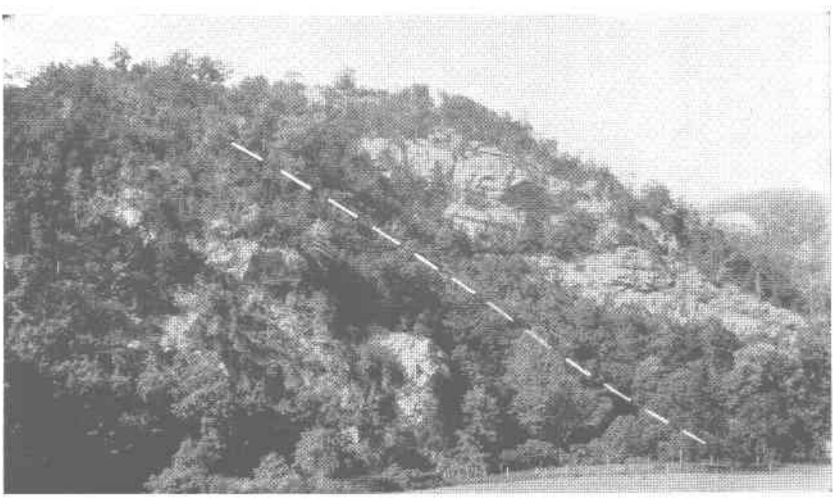
A. Prominent overthrust in the Rome formation; associated with the Laswell fault zone at Reed Junction. Looking east.



B. Lower Cambrian quartzite beds thrust over higher beds (Erwin quartzite). The fault is associated with the Dry Pond Mountain overthrust zone. At Alum Hollow, three-quarters of a mile east of Patterson. Looking east.



A. Prominent overthrust in the Rome formation; associated with the Laswell fault zone at Reed Junction. Looking east.



B. Lower Cambrian quartzite beds thrust over higher beds (Erwin quartzite). The fault is associated with the Dry Pond Mountain overthrust zone. At Alum Hollow, three-quarters of a mile east of Patterson. Looking east.

Gray's School thrust.—In the vicinity of Gray's School the quartzite ridge between the school and Sheeptown is thrust upon Erwin quartzite, Patterson member, and saccharoidal member successively northwestward from New River. The overriding block displays the same sequence but with a stratigraphic displacement probably of the order of 1,000 to 1,500 feet. The actual displacement[14] must be considerably greater, however, for the break is essentially a strike fault and, for a considerable distance northeast of the point of the quartzite ridge, the beds are homoclinal on both sides, dipping generally between 30° and 40° SE. There is no measure of the dip of the fault plane, but the angle it makes with the bedding must be comparatively small.

The fault trace has an average trend of about N. 45° E. and may be followed fairly well to the Jackson farm, three-quarters of a mile south of Austinville School. Here, though the relations are not very clear, it may be offset a short distance to the southeast by a minor flaw. East of the farm house it apparently continues northeastward through the low saddle, crosses the Austinville-Poplar Camp highway, and follows the southeast slope of a prominent ridge across Clear Branch. In the vicinity of Clear Branch the displacement is apparently smaller, for the lower Shady beds are absent and the fault is entirely within the upper Shady assemblage. A locally associated minor fracture appears to repeat a few feet of the calcareous sandstone beds in the upper block.

Other thrust features in the Austinville area.—A minor associated thrust is believed to exist about a quarter of a mile northwest of the one just described, along Clear Branch, bringing dolomite beds upon limestone and limestone breccia. The dolomite beds are in part "ribbony," strongly suggesting the Patterson member, but their position and associations indicate that they probably belong in the upper Shady sequence, together with somewhat similar beds to the southwest, near the highway bridge, and 1,000 feet farther southwest, on the east side of the tailings pond. The fault probably crosses the Austinville-Poplar Camp highway within 1,000 feet east of the highway bridge over Buddle Branch. Structural conditions along this strip are complex, several minor breaks being indicated by the confused folding and attitude and the possible repetition of sandy calcareous beds. It is possible that there is here a zone of minor associated fractures which in general trends southwest to join with the Gray's School thrust.

Along Clear Branch south of its junction with Buddle Branch several fossiliferous limestones with alternating dolomite beds are exposed for a distance of a few hundred feet. These are considered to represent the Ivanhoe limestone member. All these beds dip to the

[14] "Slip" as defined by the committee on nomenclature of faults (Geol. Soc. America Bull., vol. 24, p. 168, 1913).

southeast. The lowest limestone bed is exposed on the west side of Clear Branch at or just north of the junction with Buddle Branch. On the east side, however, though exposures are practically continuous across the strike, the limestone does not appear, its projected position being occupied by crystalline dolomites, apparently of the saccharoidal member. The conditions suggest that the lower limestone bed has been repeated by diagonal faulting, the fault conforming in general trend and position to the valley of Buddle Branch. The fault thus interpreted would cross the bedding at a sharp angle. Analysis of the movement can not be made from the scant surface evidence at hand.

At the New River bluffs along the railroad about three-quarters of a mile northeast of Austinville station locally distorted and nearly vertical beds of the Patterson member are overlain by younger beds of the Shady, with marked discordance of attitude. Some of the dislocation may be due to the Austinville fault. Other fractures are present, however, and there are distinct evidences of displacement along a zone nearly parallel to the bedding. In particular, at one point, it is believed that there has been nearly horizontal displacement along a fault plane striking N. 50°-55° E., the movement being southeast at a pitch of about 10°, making it nearly a strike-slip fault. Regardless of local details, as suggested by definite planes of fracture in this locality, however, there seems to have been a shift of several hundred feet horizontally in a general east by north direction, the northern block having moved relatively eastward, offsetting the area of outcrop of the Patterson member to the east. The time available for this investigation did not allow stratigraphic study in sufficient detail to solve all of the structural problems involved in this area.

Exposures along the railroad both east and west of Austinville station give evidence of many slight dislocations that can reasonably be assigned to the epoch of thrust faulting. Some of these breaks are definitely of low-angle thrust type; others are apparently of nearly strike-slip type. From the bluff west of Clear Branch to a point about three-quarters of a mile west of the station, the section displays a series of highly fractured zones, of varied width and intensity, marked by these features as well as a general shattering of the Shady formation. In places variations of attitude in the highly fractured beds testify to strong local deformation attended by strong brecciation. At some places, as about a quarter to half a mile west and three-quarters of a mile east of the railroad station, thrusting has apparently deformed the anticlinal crest by shearing and shattering, and a common feature of the entire section is the presence of very low angle fracture planes and cross "slicing," the latter probably representing the response of the massive, brittle dolomite beds to stresses of the transverse thrust, or "flaw" type. Common also are curved low-angle "spoon-shaped" shear surfaces, commonly with a lower angle of dip than the bedding but inclined in the same direction. They are essentially strike fractures. These "spoon" fractures can most satisfactorily be explained as one of the results of thrust faulting.

Ewing Mountain overthrust.—The broad northward projecting spur of Ewing Mountain, west of Ivanhoe, is believed to be an overthrust block of Erwin quartzite upon the basal (Patterson) member of the Shady. On the west side of the peak three-quarters of a mile west of Gray's School basal Shady (Patterson) beds are in conformity with Erwin quartzite. The beds stand practically vertical and strike northeast. The same condition is found along the line of strike to the southwest, in the bluffs on the west side of New River about 1½ miles south of Ivanhoe, where an excellent exposure shows the same contact in the same attitude. Northwest of this point marked discordances of attitude between the two formations are to be noted at several places. West of Powder Mill Branch, however, exposures are very few and inadequate, the contact being covered by a wide apron of talus and wash. In the Patterson area along this belt, dips are very low—of the order of 15° N.—so that it becomes evident that the maximum allowable width of outcrop is insufficient to accommodate the entire Shady formation. In view of the conditions described above, it is believed that Ewing Mountain constitutes a block thrust northward upon a fault surface which dips at a relatively low angle to the south, that the movement was northerly to northeasterly, and that the amount of displacement increases from zero in the vicinity of New River to a maximum 2½ miles west of Ivanhoe. The fault is thus conceived to be pivoted in the vicinity of New River. Farther west the fault trace must necessarily turn southwestward and continue or die out in the quartzite area of the Ewing Mountain range, for in the Cove Branch-Gleaves Knob area only the normal sequence of the Erwin and Shady formations can be interpreted.

Along the Ewing Mountain overthrust the maximum displacement can not be great. Stratigraphically it must be of the order of a few hundred feet—probably 500 to 600—and the minimum actual displacement may well be of the order of 3,000 to 5,000 feet.

Sand Mountain and Henley Mountain overthrusts.—The north sides of Sand and Henley mountains are bounded by thrust faults of moderate magnitude, which dip to the south. The mountains have thus been thrust over saccharoidal dolomite of the Shady, and the underlying fault surfaces thus represent the major expression of structural failure in this portion of the Lick Mountain anticlinorium. The displacement is probably not great in either locality. Stratigraphically, the Sand Mountain overthrust has an apparent displacement about equal to the thickness of the Shady formation, for on the north side the outcrop of this unit is reduced nearly to disappearance.

Lick Mountain klippe.—Work done by Messrs. Laurence and Gildersleeve during a brief period in the spring of 1934 indicates that the main Lick Mountain mass constitutes a klippe of the Lower Cambrian quartzites resting upon beds of Shady dolomite and Rome formation. The relations along the north side of Matney flat are obscured by heavy residual clays and talus, but the distribution of formations at the east and southeast sides of the mountain clearly indicates a fault contact. As mapped Henley and Swecker mountains are not included in the klippe slab for the structures of these mountains seem to be clearly indicated by the condition at the west and east ends of the range, and the gaps at either end of Henley Mountain.

Sugar Grove overthrust.—The Sugar Grove overthrust may be traced from a point 3 miles southwest of Sugar Grove for 20 miles in an east by north direction to a point 1 mile north of Simmerman, thence southeast, south, and southwest into the area south of Speedwell. It partly outlines and limits the Speedwell synclinal basin. Except at the west end, where Erwin quartzite overlies Shady beds, the fault brings the lower Shady and, in places, the top of the Erwin upon Rome beds. The trace of the fault and the topography of the involved area indicate a broad synclinal folding of the fault surface.

Like the Laswell-Galena fault block, the Sugar Grove block must have been moved northward at least 2 or 3 miles if the Shady beds within it may be correlated with the southernmost unfaulted exposure of this formation south of the town of Cripple Creek. The front of the Iron Mountain Range, including Bowling Green Ridge, along the entire length of the area west of Speedwell, represents the edge of another extensive overthrust block from the south, overlying the Sugar Grove fault block. According to this interpretation, the Sugar Grove-Laswell thrusting antedated the Poplar Camp-Iron Mountain thrusting, and the forces that developed the latter may well have caused synclinal warping of the Sugar Grove-Laswell blocks.

Brushy Mountain overthrust and klippe.—From a point about half a mile west of Cedar Springs to a point half a mile north of Teas, a distance of 8½ miles, much of the northern belt of Shady outcrop is overlain by an overthrust sheet of the Erwin quartzite and Hampton shale. This mass constitutes a klippe, a frontal portion of an overthrust block subsequently separated entirely from the main mass by erosion. Such structural relation is well indicated by the distribution of outcrops of Shady dolomite and Rome shale with respect to the quartzite beds and by the observed dips of the dolomite beds. The data are shown on Plate 1.

It is clear that the belt of Shady seen in continuous exposures along the highway just north of the Cedar Springs crossroad passes beneath the quartzite block comprising Buchanan and White Rock

Mountains and probably continues beneath this mass in a west by south direction, becoming exposed again in a wide belt along the highway that follows Slemp Creek. Contacts between the quartzite and the higher beds are obscured by a wide apron of quartzite debris along the south front of Buchanan Mountain, but the distribution of abundant fragments of Rome shale in the soils far up this slope indicates that for some distance the quartzite probably rests upon the Rome formation

Structural relations between the Erwin quartzite and Shady dolomite along the north side of Sheep Ridge and Hickory Ridge are not clear due to the lack of diagnostic exposures, but as a fault relation along the south side of these ridges is reasonably certain, the interpretation is inevitable that such relation continues around the west end of Sheep Ridge and along the north side of both ridges.

The Shady dolomite that underlies the relatively narrow valley between Sheep and Hickory ridges and Brushy Mountain, to the north, may be in conformable contact with the quartzite of Brushy Mountain. Here also scarcity of exposures and a wide frontal slope of soil and quartzite blocks makes the interpretation uncertain, but in the vicinity of the west end of Brushy Mountain, several miles to the southwest, the interpretation appears to be substantiated.

In May, 1934, a fault contact was traced by Benjamin Gildersleeve and Robert A. Laurence from the southwest end of Rich Mountain around the west, north, and east sides of the Brushy Mountain range to the previously mapped fault at the east end of White Rock Mountain (west of Cedar Springs). The klippe thus outlined would appear, therefore, to rest upon and north of the anticlinal ridge of Barton Mountain. The southern limit of the klippe mass from the southwest side of Rich Mountain to the region north of Teas has not been established. Possibly the klippe slab here rests upon Erwin quartzite, so that the fault trace would appear at some distance up the slope, above the interpreted normal Shady-Erwin contact. The anticlinal quartzite ridges immediately south of South Fork of Holston River would not be included in the Brushy Mountain klippe, and were probably overridden by the overthrust slab. It is possible that small remnants of the slab rest upon these ridges. According to this interpretation folding of the anticlinal ridges antedated the overthrusting of the Brushy Mountain mass, although the faulting along the north sides of these ridges may have been coincident with the overthrusting. As southerly dips appear to prevail in the Brushy Mountain mass, it seems likely that the folds in this ridge are, in many places, overturned with axial planes dipping to the south or southeast.

A subordinate feature of the Brushy Mountain klippe is the presence of Shady dolomite within the valley of White Rock Creek, near the east end of the klippe. The very few and small exposures are on the north side of the creek at the base of the valley wall and are apparently overlain by quartzite. It is possible that much of the alluvium that covers the broad, flat valley is directly underlain by Shady dolomite. As quartzite exposures cross the valley at its narrow constriction at the east end of the flat, the area of Shady dolomite exposures within the valley constitutes a small fenster within the klippe.

Iron Mountain overthrust.—The high ridges of the Iron Mountain range, from the southwest corner of the area mapped to the gap 2 miles south by west of Speedwell, appear to have been thrust over the southern part of the Sugar Grove thrust block. The exact determination of this fact is lacking in so far as shown by formation contacts, but the attitudes and larger relation of the strata involved lead to this conclusion as the only satisfactory explanation. In general the width of the Shady belt of exposures adjacent to these ridges is greatly inadequate to allow for a normal sequence of formations, as the observed dips in the Shady formation along this strip are all very low. Moreover, at several points the strike directions of both quartzite and dolomite are not in accordance with a normal transition between them. The distribution of Rome beds and the trace of the Sugar Grove overthrust 2 miles southwest of Sugar Grove also indicate an overthrust relation of the quartzite. However, at several points in ravines along the quartzite front the Erwin beds have a very low northerly dip, roughly conformable with the Shady beds, and at a railroad cut along the highway 1 mile south by west of Sugar Grove an exposure displays a normal contact between the formations. The accumulated evidence suggests, therefore, that the Iron Mountain block of quartzite has been thrust over both Shady and Erwin beds and therefore that some of the lower-lying beds of quartzite of low northerly dip are part of the overridden block,—that is, of the Sugar Grove thrust block. Unfortunately the slopes along the front of the Iron Mountain range are exceptionally obscured by a wide apron of quartzite slope wash and talus, so that diagnostic exposures are lacking. For this reason much of the interpreted fault trace is shown with some question on the geologic map.

South of Speedwell the Iron Mountain fault is interpreted as continuing southeastward into the quartzite area, and between this point (Henley Hollow) and a point about 1½ miles south of Cripple Creek a normal contact between quartzite and dolomite is indicated. Again, the exact relations of this strip of quartzite are obscured by heavy slope wash and talus, but such dips of the strata as are observable along the line of contact suggest the relations shown on the map, and the larger areal features do not demand overthrusting in this area. Moreover, the narrow "peninsula" of quartzite south of Cripple Creek certainly shows structural conformability with the basal Patterson beds, as indicated, and the structure is clearly anticlinal. Accordingly the Iron Mountain thrust trace, if present, is somewhat south of the contact.

Roberts Mill thrust (?).—A minor thrust, probably of small displacement, brings saccharoidal beds of the Shady upon Rome shale at Roberts Mill, slightly less than a mile east of Teas. The beds above the contact are much distorted. The local change in strike of the Shady beds from northeast to north by west may be due to drag, and if so, the movement along this fault was not a simple thrust but had an appreciable horizontal component. Whether or not this fault is the same that is reported to exist at the abandoned mine of the Rye Valley Mining Co., 1 mile northeast of Roberts Mill, remains a matter of conjecture, as it can not be traced because of the absence of rock exposures along the intervening slopes.

Teas thrust.—The short ridge west and southwest of Teas coincides with an anticline in the Erwin quartzite which, on its northwest side, is thrust over Shady dolomite. The displacement is moderate, probably less than the thickness of the Shady formation for this region. The fault trace has a northeasterly strike and passes into a wide area of Shady outcrop north and northwest of Teas. Northeast of this settlement the fault may continue, to form again the northwest limit of an anticline in the quartzite series. On both sides of the fault small anticlinal folds are found in the Shady. The anticlinal axis apparently pitches slightly at both ends of the short ridge.

Quebec fault.—At Quebec a short fault of slight displacement is indicated by homoclinal dips in Shady beds on both sides of a thin remnant of Rome red beds. This fault can not be traced far in either direction, as the fault trace passes into areas of Shady outcrop characterized by sparse exposures.

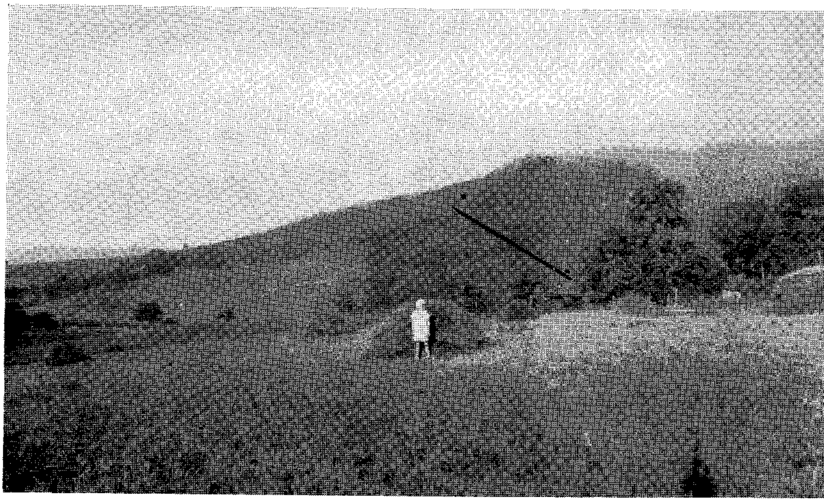
Barton Mountain thrusts.—The ridges southeast of Adwolf known as Barton Mountain, Short Mountain, and Long Ridge consist of Erwin quartzite, for the most part with southerly and southeasterly dips. On the south side of Barton Mountain and Long Ridge the contact with Shady dolomite is apparently normal. The north side of the Long Ridge-Barton Mountain anticline is thrust upon southeastward-dipping lower Shady dolomite beds, which are in normal contact with the quartzite of Short Mountain and its low continuation east of the highways. At this place, in the base of the dolomite, zinc mineralization has occurred (Martin prospect). The north side of Short Mountain and Barton Mountain is bordered by a thrust fault that probably represents an overturning, infolding (Pl. 18, B), and shearing of the north limb of the general anticlinal mass that involves the main anticline of Barton Mountain and its associated subordinate fault of Long Ridge and minor folds. It is perhaps noteworthy here that the Van Hoy zinc prospect is situated in the dolomite of the narrow valley on the north side of Barton Mountain, probably not much below the fault surface.

CROSS FAULTS

Ivanhoe fault.—The Ivanhoe limestone can be followed southwestward along its strike, without interruption, from the quarry east of the town to Ivanhoe schoolhouse, where it is abruptly terminated by a cross fault. At a point on the highway 1,000 to 1,200 feet northwest of the schoolhouse, the limestone is again exposed, whence it may be traced westward along its strike for some distance, as shown by the mapped band of outcrop. (See Pl. 1.) The cross fault that causes this horizontal separation has a trend N. 35°-40° W., which is approximately normal to the regional strike of the formations for this vicinity. Other evidences of this fault appear in the highly fractured and contorted condition of the strata along the railroad cut northwest of the town, in the apparent displacement of the Patterson member south of the town, and in the records of several drill holes on the property of the Ivanhoe Milling & Smelting Corporation.

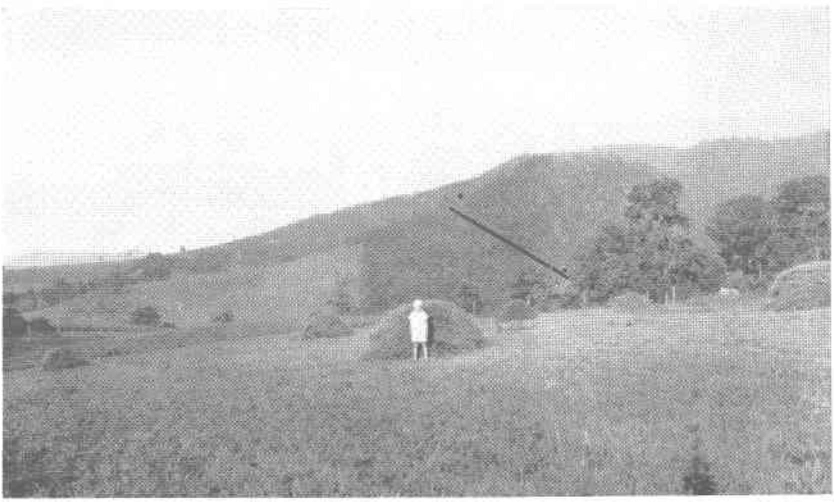
The fault disappears in the broad valley of Cripple Creek, for the exposures along the north bank of this stream and in the area west of Porter give no evidence of a break of comparable magnitude in the expected position. Likewise the fault apparently dies out also to the southeast along its strike, as there is no displacement of the Erwin-Shady normal contact south of the town on either side of New River. Unfortunately, there are too few exposures in the Shady plain south of Ivanhoe to allow tracing of the fault to its point of disappearance. The writer had no access to underground workings, as the shaft on the property of the Ivanhoe Mining & Smelting Corporation was not in operation.

There is no conclusive evidence as to the direction of movement along the fault plane, as the available subsurface information does not give a satisfactory measurement of the displacement of a key bed. If the movement were vertical, the east block being the downthrown side, the apparent horizontal displacement of 1,200 feet northwest of Ivanhoe would require a vertical movement of nearly the same amount, as the dips in the limestone average about 40°. However, the scant data on the surface of the Ivanhoe Mining & Smelting Corporation's property indicate a probably very much smaller horizontal separation of the beds, and correlation of limestone beds in holes drilled at the same place on opposite sides of the fault indicates proportionately smaller vertical separation at a lower limestone horizon. These conditions, together with the possible limitation of the fault to the south side of the Hematite Mountain overthrust, inasmuch as strata on the north side of Cripple



A. Erwin quartzite thrust over Shady dolomite at Poplar Camp Mountain. East side of the gap. The black line indicates approximately the trace of the fault. Shady beds are exposed north (left) of the fault.

B. Infolded Erwin quartzite beds at an exposure of an overthrust. Along the highway 2 miles west of Quebec. Looking east.



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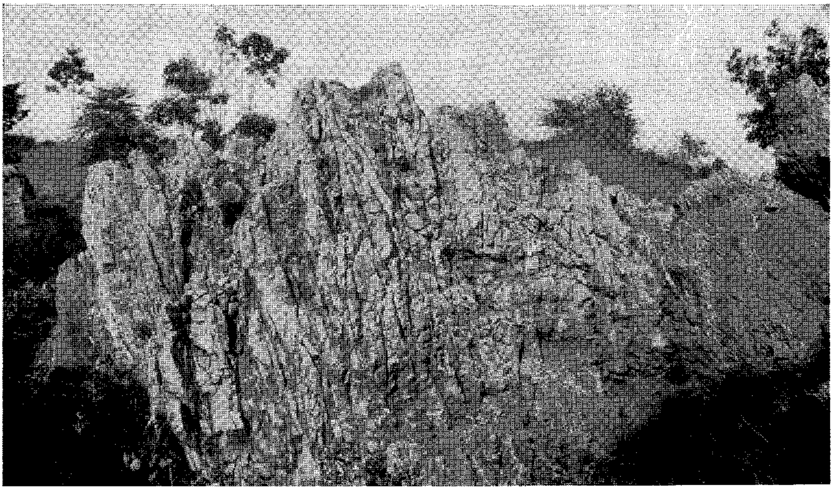
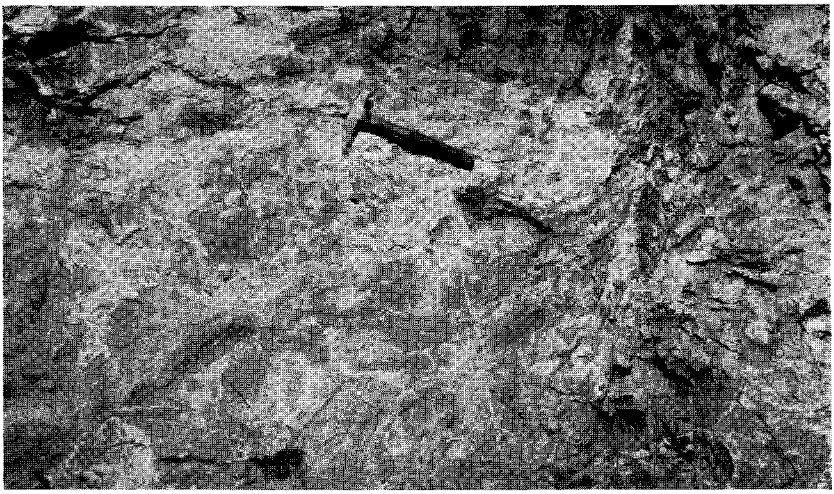
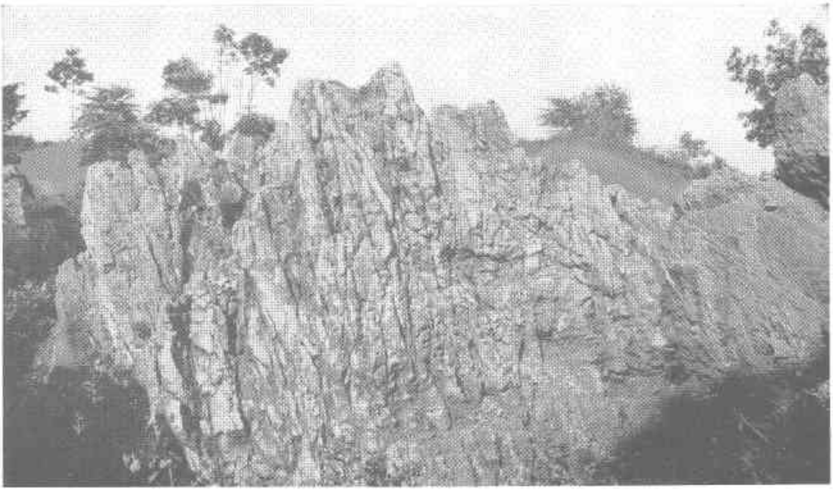


A. Sheeting effect produced by closely spaced fractures. In the Bertha pits, west of Glenwood School. The phenomenon is more common in the Austinville-Ivanhoe district.



B. Breccia zone along the highway between Jackson Ferry and Poplar Camp. This zone, partly rubble, appears beneath the local bedding slip shown in Plate 11, A.



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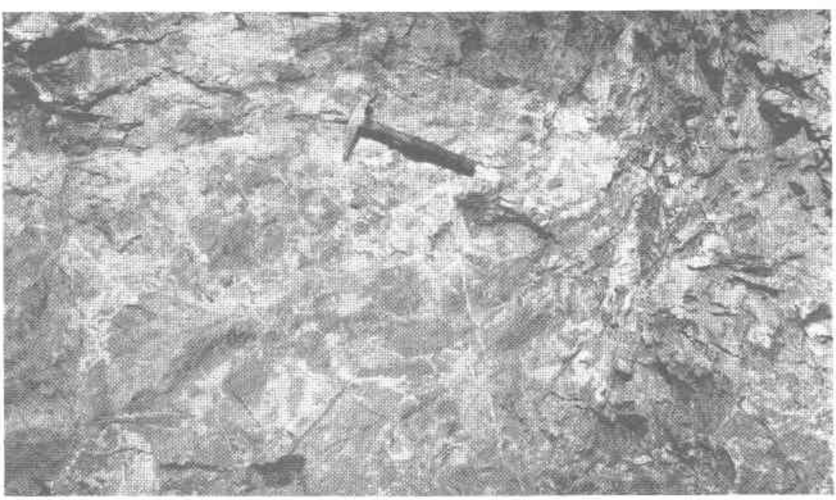


B. Breccia zone along the highway between Jackson Ferry and Poplar Camp. This zone, partly rubble, appears beneath the local bedding slip shown in Plate 11, A.

Creek show no comparable displacement, and the great decrease in horizontal separation southeastward through Ivanhoe, suggest that the movement was largely horizontal with some vertical component, the west block riding upward on the footwall of the Hematite Mountain thrust. This hypothesis reconciles the rather abrupt disappearance of the fault along the line of strike south of Ivanhoe with the great horizontal displacement of the Ivanhoe limestone. If this is the correct interpretation of the Ivanhoe fault, it has the nature of a transverse thrust, or flaw,[15] in which the displacement is chiefly horizontal. This conforms also to the "tear" fault as defined by Collet.[16] Genetically, the flaw or tear fault is a feature directly connected with folding and thrust faulting, representing shear in a direction transverse to the fold axes. Such structural failure may be occasioned by either local lithologic weakness or unequally distributed force. These transverse breaks are consequently features that characterize regions of folding and thrust faulting and are practically contemporaneous with the major deformation, following it very slightly in point of time and in essential continuity.

Carter Ferry fault.—About a quarter of a mile west of New River at Carter Ferry exposures along a ravine show Rome beds opposite the upper Shady—probably the Ivanhoe horizon—with fracturing and distortion of the beds. To the northwest abrupt soil changes mark the continuation of this break. At one point also the Patterson member is along the line of strike, opposite beds of the saccharoidal member. Finally, east of Red Hill, although exposures are poor or lacking, soil changes suggest a break in the trace of the Laswell thrust. The average trend of the fault trace is about N. 40° W., at an angle of approximately 70° with the strike of the beds. No information is available as to the dip of the fault plane. The horizontal displacement is apparently of the order of 500 feet or less. It is noteworthy that mineralization with sphalerite has occurred in the vicinity of the fault, though the prospect at Carter Ferry appears to be somewhat east of the fault.

Nearly half a mile west by south of Sayer School, abrupt soil changes across the regional trend of the strata suggest another break of similar character, possibly divergent from the Carter Ferry fault, but definite stratigraphic evidence is lacking.

Sayer School fault.—Just south of Sayer School the trace of the Laswell fault appears to be offset several hundred feet. Although there is a reasonable possibility that this offset may represent merely a sharp bend in the Laswell fault plane, there is some additional evidence of a cross fault on the south side of New River three-quarters of a mile southeast of Sayer School, where Patterson and saccharoidal beds are

[15] Reid, H. F., and others, Report of the committee [of the Geological Society of America] on nomenclature of faults: Geol. Soc. America Bull., vol. 24, p. 179, 1913.

[16] Collet, L. W., The structure of the Alps, p. 15, London, Arnold and Co., 1927.

apparently in juxtaposition along the line of strike. These conditions have led to the suggestion that a cross fault of northwest trend may pass from the vicinity of Sayer School into the Shady area of Barren Springs Ferry.

Cross faulting between Cedar Springs and Speedwell.—Four miles west of Speedwell the Erwin quartzite and Patterson dolomite, with intervening transition beds, may be found in normal succession at a broad bend in the highway. The transition beds consist of several feet of coarse-grained light-gray to white dolomite, similar to beds of like position elsewhere (p. 19) that grade into siliceous dolomite and dolomitic quartzite toward the true Erwin beds. At the west end of the exposure cross faulting has displaced the Patterson beds in relation to the quartzitic beds, so that the two are in contact along the line of strike. Apparently the western block has moved northwest relatively. The displacement here may be less than 25 feet, or it may be much greater, because the exact horizon of the Patterson beds is indeterminate. Within a half mile along the strike to the west, however, there is evidence of more transverse displacement, possibly due to stresses of the tear type, with which the break described above is probably associated in a zone of cross shearing or even tear faulting. There is, for instance, some uncertain evidence of displacement along the ravine a quarter of a mile west of the exposure, and still farther west local sharp distortion of the strata, with sharp bending of the bands of Rome soil to the north that indicates either sharp folding or actual faulting, probably of the tear type. Finally, about a quarter of a mile south of the highway, along the road leading to Camp, a definite zone of sheeting indicates cross shearing, and a third of a mile east the distribution of Rome soil suggests an offset zone in continuation of those directly north. It is probable, therefore, that in this vicinity there is a zone of cross faulting, perhaps in part minor cross faults, in part sheeting, and in part sharp transverse folding.

Although no mineral deposits have been reported in this zone, prospecting has shown the presence of galena and sphalerite on the Buchanan property, one-eighth to one-quarter of a mile east of the exposures in the bend of the highway.

MINOR STRUCTURAL FEATURES

JOINTING AND SHEETING

Jointing is a conspicuous feature of the rocks of the area, but the relation of mineralization to joints or sets of joints can not be ascertained without a detailed study of underground conditions. That some of the joint fissures are mineralized can be readily demonstrated. So far as can be judged from surface exposures, the development of joints as well as fractures of distinct displacement was an important factor in the brecciation of the dolomites. There is in general some difficulty in discriminating between simple stress joints and other fractures of more or less displacement that might be related to torsional or other undistributed forces. Many of the fractures are doubtless of the types commonly induced by folding and subsequent settling. Others seem to bear a more specific relation to deformative forces of the transverse or flaw type. There is probably no practical discrimination between the minor fractures along which there has been no movement and those along which slight movement of different degrees has occurred. Usually the surfaces show no slickensides, but as the fissures have commonly been widened and their walls modified by subsequent weathering and solution, slickensides may have been destroyed. This modification has been facilitated by the somewhat ferruginous dolomitic character of the rocks.

A system of fractures showing in part fluted surfaces, due probably to movement, makes a sharp angle (10° to 20°) with the strike of the beds. These fractures have dips that are variable in amount and direction. Some of those of low south to southeast dip seem to be due to nearly horizontal shearing. The strike of most of these fractures is between N. 70° E. and N. 85° E. Other fractures, also of approximately strike character, are of the nature of thrusts. Some of these are flatter than the bedding, in part nearly horizontal. In places mineralization has occurred in the strike-joint zones.

Fractures have also been formed at various attitudes bluntly transverse to the strike of the beds. Measurements of the strike of these fractures show a wide range, but those of northwest trend are particularly prominent. With intermediate dips of 40° to 65°, both southwest and northeast, these fractures appear in places to constitute conjugate joints.

Sheeting of the rocks by closely spaced parallel fractures is observable at several points in the Austinville and Ivanhoe mineralized areas. The fractures were probably formed by shearing with small, generally indiscernible displacement and are believed to represent deformation of the flaw or transverse thrust type, though not developed as simple fault fissures. Most commonly these fractures are practically vertical and have a strike approximately normal to that of the beds. The fractures are only a few inches apart. Though generally parallel, in places the planes converge and join at sharp angles. The phenomenon is illustrated by Plate 19, A. Deformation of this type is usually characteristic of a zone crossing the regional strike of the beds and as much as 75 feet or even more in width. Notably these sheeted zones are closely associated with mineralized areas.

In the Austinville pits a prominent system of vertical fractures having a strike of N. 50°-65° W. displays some vertical slickensides. Generally, however, such evidence of direction of movement is lacking in surface exposures, and the true nature of the sheeting effect is obscure. In view of the fact that they occur in local areas wherein the strikes of the beds depart materially from the general regional strike and indicate transverse warping of the anticlinal structure, these fractures may indeed be the strain effects of flaw stresses.

Whatever details of stress the minor fractures may suggest, the general inference that they are the accumulated and locally distributed results of regional folding, thrust faulting, and torsion appears entirely reasonable.

BRECCIATION

The deformation of the brittle Shady dolomite beds by folding, faulting, sheeting, and jointing has resulted in a high degree of brecciation of the rocks. The tectonic breccias so formed can be satisfactorily classified on a textural basis as rubble breccias and crush breccias. The distinction is rather arbitrary, and all gradations between the two can be found. In general the breccias have been cemented with coarse white dolomite of interlocking crystalline texture, which to a large extent fills open spaces but partly may also represent a recrystallization of fragments of the original rock material. This "gangue" dolomite is everywhere a characteristic feature of the tectonically brecciated zones.

Rubble breccia.—In places the dolomite breccia displays rounded to subangular fragments of the rock in an abundant matrix of recrystallized or coarsely crystallized white "gangue" dolomite. The texture strongly suggests movement and displacement of the fragments, with attendant rounding of the corners and edges. As fault surfaces are inadequately exposed on the surface, and as no underground studies could be made, the definite relation of such breccias to faults can only be inferred. However, intense brecciation of the rocks is a characteristic feature of exposures in close proximity to known fault traces, and accordingly brecciation of the formation was associated with the faulting. It would be difficult to conceive that extensive movement along such brecciated zones could have taken place without considerable rotation and attrition of fragments, at least within a narrow zone.

Subsequent crystallization of coarse white dolomite around and penetrating the borders of fragments leads to uncertainty as to the original texture of the breccia and the exact significance of the apparent rounding of fragments or their spatial relations.

Crush breccia.—The crush breccia is essentially a mosaic showing very little relative displacement and rotation and little or no rounding of the edges of the rock fragments. The usual coarse white dolomite is present as a cementing material. This is the most extensively developed breccia of the deformed zones. The fragments commonly show relative displacements of only a fraction of an inch. Much of the crush breccia is composed of relatively small blocks and fragments except where it merges into the shatter or crackle facies described below. The fragments are sharply angular, except where replacement by coarse white dolomite has occurred, and are derived from the enclosing beds.

The crush breccias are distributed abundantly in the more greatly deformed parts of the area, where faulting, shearing, and strong local folding are prominent. They are interpreted as representing a somewhat less localized strain effect of the compressive forces of folding and faulting upon the thick, brittle, competent beds of the Shady dolomite.

As a limiting facies of the crush breccias are the crackle or shatter features whereby the rock mass shows excessive unsystematic jointing effects with no rotation of fragments and but very slight displacement. The fractures are filled as usual with coarse white "gangue" dolomite. The blocks are of course sharply angular and more variably sized than in the typical crush breccia. The crackle or shatter breccia of this type, however, in its broader aspects is not distinctive from the crush breccias but rather represents a less pronounced crushing than is indicated by the more typical crush breccias. The crackle beds are accordingly marked by irregular networks of thin seams and veinlets of white dolomite.

In general, the limestone beds show very little or no crushing effects such as described above, even where closely associated with dolomite beds that have been so greatly modified by crushing as to have the bedding completely obscured. In places it is possible to ascertain the attitude of such dolomites satisfactorily only by observations upon the comparatively unfractured limestones. This seems to be explained by the well-known fact that dolomite is particularly brittle under deformative stresses. The dolomite and limestone beds of the Shady formation were evidently deformed under a great superincumbent load—probably as great as 20,000 to 30,000 feet and possibly much more, considering the thickness of the Paleozoic section in this part of the Appalachian Valley region. The exact measure is immaterial, but the general order of magnitude is significant. With such a load it is readily conceivable that limestone would react somewhat plastically with only slight brecciation under compression stresses that would greatly fracture dolomite. Indeed, such difference in behavior of interbedded limestone and dolomite is strikingly demonstrated, according to Keith,[17] by exposures in certain marble quarries in Vermont.

[17] Keith, Arthur, Oral communication; also photographs by him in U. S. Geological Survey files.

It is pertinent to note the remarks of Cornelius, [18] whose studies of Alpine dolomites led him to a consideration of tectonic breccias. He says in part: "In the first place a breccia can develop through any sort of stress—for example, flexing of a homogeneous brittle rock above the elastic limit, a rock brittle under the conditions prevailing during deformation. In this manner the rock is broken into the most angular fragments; these become cemented into a breccia, either loosely by the products of grinding, or more firmly by precipitation of dissolved rock materials. Such endogenetic formation of breccia is, indeed, a very common phenomenon in many limestones and especially in dolomites."

It should not be construed that the types of breccia described in the foregoing paragraphs are separate and distinct features. The distinction of types is made rather for convenience of analysis. The writer's interpretation of the origin of the breccias is that the deformative processes that caused folding, thrust faulting, and to a lesser extent cross faulting were the sole cause of the intense brecciation of the Shady dolomite. Compressive forces acting upon the thick, brittle, rigidly inclosed Shady strata produced a crackle or shatter breccia in the dolomite beds, perhaps even before the stage of maximum folding was attained. The usual slipping of beds during competent folding was doubtless somewhat less readily accomplished along bedding planes in the thick, massive dolomite series than it would have been had numerous easy zones of slipping or weak bedding planes existed. The more uniform the strength of the rock mass in all directions, the more difficult it would be for bedding to control the site of fracturing; nevertheless even small differences between successive beds might operate in the direction of approximate stratigraphic control of tectonic brecciation, particularly in the earlier stages of deformation. When thereafter the culminating phase of the thrust epoch arrived there would be an initial partial restriction of faulting to the zones already weakened by fracturing. Ultimately, of course, thrust faulting must necessarily cross the bedding at certain points. Parts of the previously formed crackle and crush breccias would then become modified into a fault breccia of rubble type. Crush breccias would also continue to form during the process of overthrusting. The preparation of the terrane for mineralization was thus initiated early in the deformation period, and strongly developed in the major thrust epoch.

[18] Cornelius, H. P., Ueber tektonische Breccien, tektonische Rauhwacken, und verwandte Erscheinungen: Centralbl. Mineralogie, 1927, B, p. 121.

ECONOMIC GEOLOGY

GENERAL FEATURES

Zinc and lead ores constitute the chief mineral products of the southwestern Virginia area discussed in this report. Until recent years iron ores were largely produced, and manganese ores were mined at several places and prospected at many more. No other mineral resources of more than local importance have been developed or prospected.

In part the ores of zinc, lead, iron, and manganese are associated in deposits; in part they present distinctive features in mode of occurrence and distribution. The resources of iron and managanese are here mentioned only briefly and with emphasis on their relations to occurrence of zinc and lead minerals.

IRON ORES

The several thousand acres of abandoned iron-ore pits and the numerous smelting furnaces scattered over the area testify to the former importance of this region in the iron industry. The history of the industry in southwestern Virginia practically ceases with the year 1926, when the production of iron ore dropped 97 per cent. In 1928 the Porter mine, near Cripple Creek, produced 4,615 gross tons; in 1929 no production was reported for the State; and in 1930 the Porter mine resumed activities for a brief time and was the sole producer reported.[19]

The iron ores of the area belong to the classes known as "valley ores" and "mountain ores." Both classes are residual limonites—the former within the Shady dolomite, the latter at or near the contact of the Shady with the Lower Cambrian quartzites. In places little distinction between the two is possible. Holden[20] describes the iron ores as "limestone limonites," and according to him they have their greatest development in the New River-Cripple Creek area.

The iron ores of this area occur (1) at the normal contact between the Erwin quartzite and the Shady dolomite; (2) within the Shady formation but at no definite horizon; (3) at fault contacts between the Lower Cambrian quartzite series (Erwin quartzite, Hampton shale, and possibly the Unicoi formation) and the Shady dolomite; and (4) at fault contacts between the lower or Patterson limestone member of the Shady and the Rome formation. The ores seem to be by far most abundantly developed in the Patterson member, both at fault contacts with the Rome beds and at normal contacts with the Erwin. Almost continuous workings are found along the Laswell fault between Walton

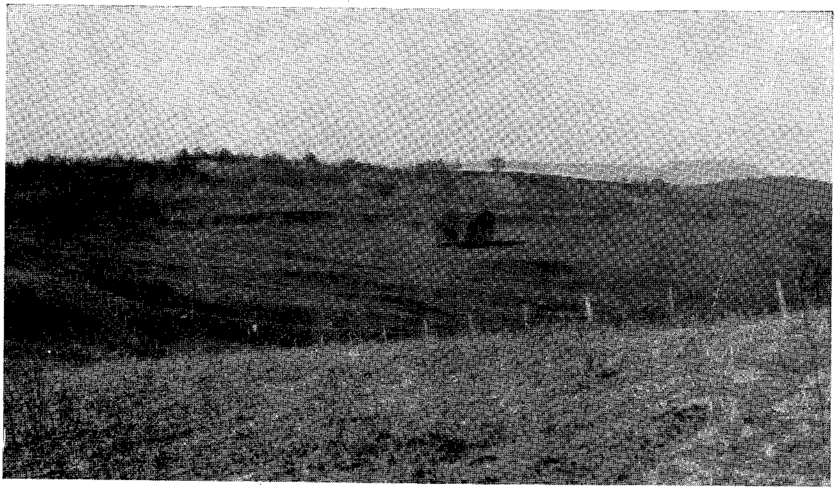
[19] U. S. Bur. Mines, Mineral Resources, 1930, pt. 1, p. 77, 1933.

[20] Holden, R. J., *in* Watson, T. L., Mineral resources of Virginia, Virginia-Jamestown Exposition Commission, p. 410, 1907.

School and Red Hill. (See Pl. 20, A.) Large pits are located about a quarter of a mile south of New River, three-quarters of a mile west of Reed Junction. (See Pl. 21, A.) Numerous pits are distributed along both sides of Foster Falls Mountain and along the north flank of Poplar Camp Mountain from New Castleton School to Sheeptown. Some pits appear also on the west side of Dry Pond Mountain. The crest of Hematite Mountain has furnished considerable ore. Contact ores have also been mined on the high bluffs of the steeply pitching anticline southeast of Ivanhoe, south of Cripple Creek, southwest of Speedwell, and at several places in the Cedar Springs-Sugar Grove district, especially west of Cedar Springs near White Rock Furnace. Chief among the pits not at formational contacts but within the Shady formation are those in the broad Barren Springs-Bertha region, at Austinville (zinc-lead workings), in the extensively mined area at and west of Ivanhoe, and in the Porter banks on the divide between Cripple Creek and the South Fork of Holston River, between Cedar Springs and Sugar Grove. There are many more pits, however, scattered over the area.

It was a common experience in the mining of these iron ores to encounter associated oxidized zinc and lead minerals, especially calamine, hydrozincite, and smithsonite in complex relations. Indeed, some pits, as in the Bertha-Barren Springs area, were worked in part for iron ores and in part for "soft" zinc ores. The presence of iron ores is therefore of interest to zinc prospectors, in so far as there is a possible association of oxidized zinc and iron minerals. At several places it is clearly apparent that the basal Shady (Patterson member) is pyritiferous. Locally the concentration of pyrite is impressive, as in the road exposures at the west end of Hematite Mountain, where the contact with Erwin quartzite is disclosed. Above on the ridge is the line of iron-ore pits, and the soil and weathering products of both the Patterson limestone member and the Erwin quartzite are unusually strongly colored by iron oxides. There is suggestion of a definite relation between the concentration of iron ore and the presence of abundant pyrite in the undecomposed rock.

Although many of the iron pits are located just within the Shady formation, along the traces of thrust faults where the Shady is brought upon Rome beds, or in Shady dolomite or Lower Cambrian quartzitic shales (Hampton?) where the shales are thrust upon the Shady, there are also many pits either within the Shady formation or at its normal lower contact. It is possible, therefore, that fault zones, contacts, or highly brecciated beds in the Shady were individual and separately determining factors in the localization of the deposits. Probably the brecciation of the dolomite along fault zones greatly facilitated the oxidation of iron content and leaching of the carbonate rock. The orig-



A. East end of Sanders iron-ore pits in lower Patterson beds. The fault outcrop is near the crest on the northwest slope. Looking northwest.

B. Rubble breccia below a thrust zone in the saccharoidal member of the Shady dolomite. Note the characteristic small size of fragments and the fair degree of uniformity in size.

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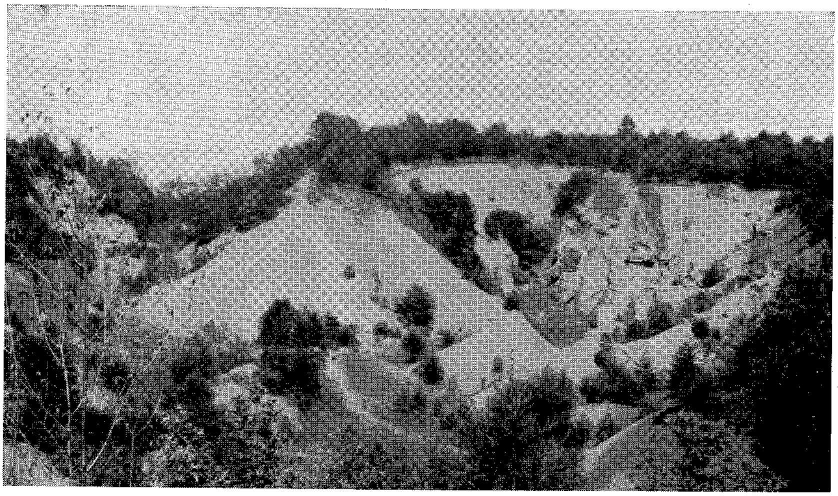
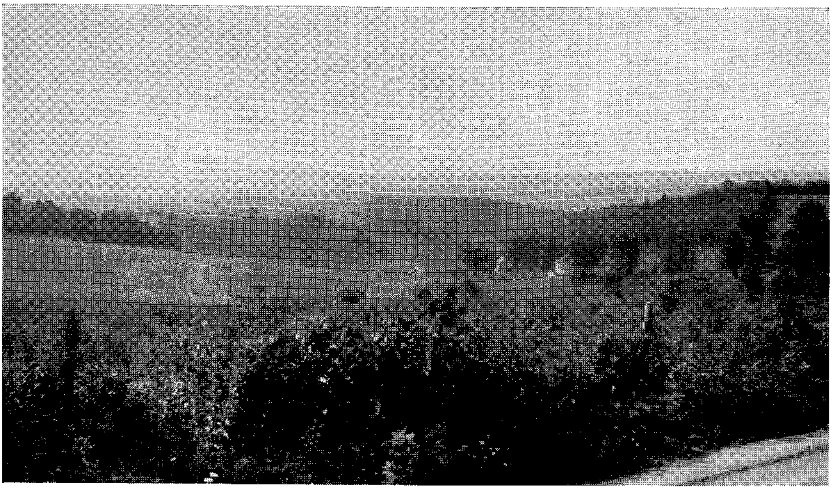
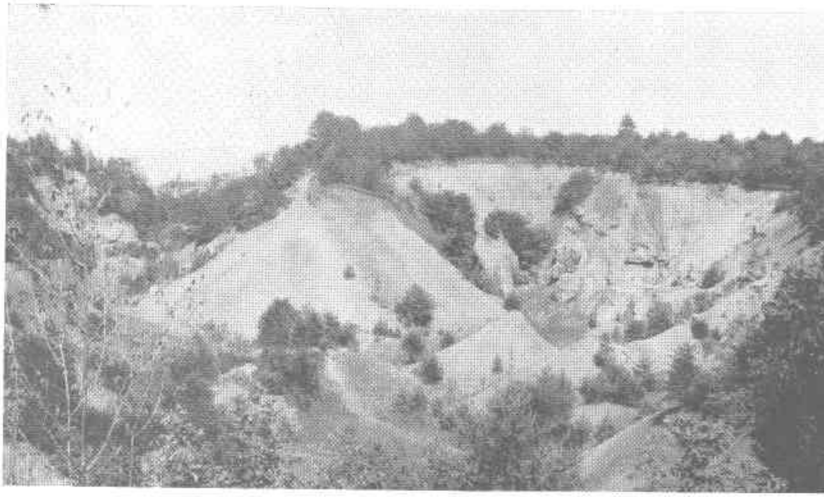


A. Westernmost iron-ore pit of the old Rich Hill mines. Half a mile southwest of Reed Junction. About 100 feet deep. The lower Shady is here faulted over Rome beds. Note the sparseness of pinnacles. Looking northeast.



B. The even upper surface of the Bertha basin which represents the Valley-floor peneplain. In this area it is 250 to 300 feet above New River. Looking northwest from a point near Barren Springs.



A. Westernmost iron-ore pit of the old Rich Hill mines. Half a mile southwest of Reed Junction. About 100 feet deep. The lower Shady is here faulted over Rome beds. Note the sparseness of pinnacles. Looking northeast.

B. The even upper surface of the Bertha basin which represents the Valley-floor peneplain. In this area it is 250 to 300 feet above New River. Looking northwest from a point near Barren Springs.

inal material, or protore, may have been largely the pyrite so commonly found in these zones, disseminated in the Shady dolomite.

MANGANESE ORES

Manganese ores have been produced along the northwest side of the Blue Ridge for many years, and although the total production has not been exceptionally great, up to 1917 the Blue Ridge ores outside the district gave Virginia first rank as a manganese-producing State. The World War greatly stimulated production and the search for more deposits, but at present the industry is almost inactive.

The geologic features of the manganese deposits of Virginia have been adequately described in publications of the Virginia Geological Survey,[21] so that only a brief statement regarding the manganese ores of the zinc-lead district need be made here.

The minerals of the manganese deposits include pyrolusite, psilomelane, manganite, and the less definite species known as "wad." The black and brownish-black oxides and hydrous oxides are associated with secondary iron minerals, chiefly limonite. In fact, the manganese ores for the most part are subordinate to the iron-ore minerals of the "limonite" and "brown hematite" types. In this area, then, the distribution of iron-ore minerals likewise indicates, in a general way, the distribution of the manganese ore minerals.

Like the iron minerals, the manganese ores are largely more or less nodular masses occurring in clays derived chiefly from the lower part of the Shady formation at or near normal or fault contacts. The minerals occur also as narrow veinlets extending to a very shallow depth into much fractured Lower Cambrian shales and quartzites. In a few places the manganiferous shale belongs to the Rome formation at or close to positions where Shady dolomite has been thrust over the shales. Structurally, synclinal and monoclinal areas have seemed to favor the concentration of manganese minerals. "It will be noted that the number of deposits in synclines is only slightly larger than that of the monoclinal type. The synclinal group includes the most productive deposits in the valley region, and . . . they appear from other reasons to offer the most favorable areas for the accumulation of manganese ores."[22] The manganese now mined as oxides is believed to have existed largely as manganese carbonate originally disseminated in the Lower Cambrian strata, chiefly the basal part of the Shady formation, although some manganese silicates in near-by beds may have contributed. Weathering, leaching, and oxidation by the

[21] Stose, G. W., Miser, H. D., Katz, F. J., and Hewett, D. F., Manganese deposits of the west foot of the Blue Ridge, Virginia: Virginia Geol. Survey Bull. 17, 1919. Stose, G. W., and Miser, H. D., Manganese deposits of western Virginia: Virginia Geol. Survey Bull. 23, 1922.

[22] Stose, G. W., and others, op. cit., pp. 53-54.

atmosphere and ground water were more specifically the agents of transportation and concentration.

ZINC AND LEAD DEPOSITS

Exposures of rocks bearing zinc and lead minerals are to be seen at numerous places within the mapped area. Some of the showings have been prospected, but as yet with unsatisfactory results. Only at Austinville has persistent mining of sulphide ores been done. At Ivanhoe a number of shallow shafts and pits have yielded a moderate quantity of sulphide or oxidized ores through recent periods of intermittent mining, but a definite program of exploration and development has never been attempted.

MINERALS OF THE DEPOSITS

The mineralogy of the zinc-lead deposits is simple. In the sulphide ores the following minerals have been recognized:

Metallic minerals:
- Sphalerite, ZnS (zinc sulphide)
- Galena, PbS (lead sulphide)
- Pyrite, FeS_2 (iron sulphide)
- Chalcopyrite, $CuFeS_2$ (copper-iron sulphide)
- Bornite (trace), Cu_5FeS_4 (copper-iron sulphide)

Nonmetallic minerals:
- Dolomite, $CaMg(CO_2)_2$ (calcium and magnesium carbonate)
- Calcite, $CaCO_3$ (calcium carbonate)
- Barite, $BaSO_4$ (barium sulphate)
- Quartz, SiO_2 (silica; silicon dioxide)
- Fluorite (fluorspar), CaF_2 (calcium fluoride)

The secondary metallic minerals occurring in the oxidized ores include the following:

- Calamine, $Zn(OH)_2SiO_3$ (hydrous silicate of zinc)
- Smithsonite, $ZnCO_3$ (zinc carbonate)
- Hydrozincite, $ZnCO_3.2Zn(OH)_2$ (hydrous zinc carbonate)
- Cerussite, $PbCO_3$ (lead carbonate)
- Limonite ("brown hematite"), $2Fe_2O_3.3H_2O$ approximately (hydrous oxide of iron). Probably mixed in part with goethite, $Fe_2O_3.H_2O$, and turgite, app. $2Fe_2O_3.H_2O$.

Manganese oxides, including
- Manganite, $Mn_2O_3.H_2O$ (hydrous manganese oxide)
- Pyrolusite, MnO_2 (manganic oxide)
- Psilomelane (hydrous manganese manganate, exact composition in doubt)
- Wad (impure manganese oxides, of indefinite composition)

METALLIC MINERALS

Sphalerite ("blende").—Sphalerite is by far the most abundant ore mineral of the region, judged from mineral discoveries to date. Its color ranges from light yellow to green and somewhat brownish green, but with fairly light shades predominant, and denotes a comparatively high degree of purity. Exceptionally, as at Allisonia, very dark-gray or steel-gray sphalerite is found. At several places where pyrite and galena are abundant, as in the Austinville area, the darker shades are prevalent; in other localities, as at Cedar Springs, where other sulphides are lacking, the lighter shades seem to prevail. In other words, there appears to be a general relation between shades of color and simplicity of the ore.

The sphalerite appears as fracture fillings between angular fragments of the dolomite breccia; "rosettes" or apparent incrustations around fragments, in part at least replacing both wall-rock material and coarse white "gangue" dolomite; and disseminated grains impregnating rock fragments, recrystallized dolomite, and the "gangue" dolomite. The replacement relation is clearly apparent in thin sections.

Galena.—The lead ore mineral, galena, is apparently less widely distributed than sphalerite, with which it is always associated. At very few localities has any appreciable concentration of this mineral been found. At only two places, Austinville and Rye Valley, has it had economic importance, though its presence has been noted at several other points.

In parts at least of the Austinville mining area galena is abundant and constitutes a valuable commercial product. It is notably rare in the Ivanhoe area. At Laswell, about 4 miles north of Austinville, there are rather numerous veinlets in dolomite beds of the Patterson limestone member, just above the Laswell fault in the iron pits, a quarter of a mile east of the highways. A showing of galena is also to be found, in association with sphalerite, in a highly brecciated cross-shear zone on the south side of New River and on the east side of Shorts Creek a few hundred feet east of Jackson Ferry station. The prospects on the north side of New River at Allisonia, about a mile east of the eastern border of the mapped area, show galena associated with sphalerite, pyrite, and quartz. At the abandoned mine of the Rye Valley Mining Co., Sugar Grove, a vein carrying galena as the chief economic mineral was exploited. Fragments left in the dump pile show that here the mineral is associated with sphalerite, fluorite, and pyrite. Galena has been reported from several other places in the vicinity of Sugar Grove. However, galena is apparently more restricted in occurrence than sphalerite, as most of the prospects and exposures show sphalerite without associated galena.

According to statements made to the writer, the galena at Austinville carries only very small amounts or traces of silver. Ball and Thompson[23] report analyses of galena from the district that range from a trace to 12.5 ounces of silver to the ton, with an average slightly less than 3 ounces to the ton for pure galena concentrate. No assays were made in connection with the present investigation. From the recorded data cited above it is obvious that although the average silver content is small, the range of silver content is marked.

Pyrite.—Pyrite is universally present in the exposed mineralized zones and appears in great amount in several places, as at Austinville. Its paragenetic relations are not consistent in the material available for study; in some places it appears to be clearly earlier than sphalerite, in others definitely later. It occurs abundantly as minute grains widely disseminated in the rock, especially in the lower Shady (Patterson limestone member). It is also closely associated with sphalerite as larger grains replacing recrystallized wall rock and "gangue" dolomite. In some ore specimens from the second level of the Austinville mines it forms a replacement border around remnants of dolomite rock fragments, especially between the fragments and an encircling rim of sphalerite. (See Pl. 24, A.) Here the sphalerite would appear to be later than the pyrite, but close study discloses places where pyrite is clearly crosscutting and replacing sphalerite, although the chief site of development of the pyrite may indeed be between the rock fragments and their aureoles of sphalerite.

Pyrite is abundantly found in some places where iron ores have developed through oxidation of dolomite in the lower Shady (Patterson member). Commonly exposures of the ribbon rock show much disseminated pyrite as minute grains. It is found also in the ribbon ores near Ivanhoe.

Chalcopyrite and bornite.—The copper minerals chalcopyrite and bornite are exceedingly rare in the zinc-lead area. The deposits at Austinville are said to be practically copper free. No copper minerals were found in the few available specimens from the 200- and 350-foot levels of the mine nor in the surface workings.

At the Riggles prospect, 2¼ miles nearly due east of Crockett, chalcopyrite and bornite were both found associated with galena, sphalerite, pyrite, and crystalline quartz, in the usual shatter breccia of dolomite cemented by coarse white dolomite.

Copper minerals have been reported from several places in the valley adjoining the mapped area but not in important quantity.

Calamine and smithsonite.—The alteration of sphalerite by oxidation at and above ground-water level has produced the secondary min-

[23] Ball, S. H., and Thompson, L. H., The southwest Virginia lead-zinc deposits: Eng. and Min. Jour., vol. 102, p. 735, October 21, 1916.

erals calamine and smithsonite, which in places have constituted valuable ore deposits and, indeed, were the only ores of zinc mined during the earlier decades of the industry in Virginia. These minerals are commonly associated with iron ores (limonite) and in several places the two metals have been economically produced from the same pits. The "soft ores" of the Bertha district were justly famous for the purity of the zinc product obtained from them. On the other hand, some iron ores from several parts of the zinc belt contained a sufficient quantity of zinc, as carbonate or silicate, intimately intergrown with the limonite, to give trouble in smelting. Some pits were exploited at times for zinc, at other times for iron.

Calamine appears as finely crystalline incrustations, large, irregular, more or less porous masses and layers, crystalline druses, coating of sheaf-like forms, stringers of fine crystalline material, and loose powdery material. Incrustations and layers showing botryoidal, mammillary, and even stalactitic forms have been found, as well as the more common structureless masses. To a large extent the mineral masses, whatever their form, are colored yellowish or brownish by iron oxides, but generally some portions display the characteristic fine glistening colorless crystals of calamine.

Smithsonite in the deposits is generally not well crystallized but is inclined to be finely granular and earthy, mostly yellow to brown, and, in contradistinction to calamine, reacts readily with dilute hydrochloric acid. Commonly smithsonite and calamine are intermixed, as a rule so intimately that discrimination is impossible. Although either may be locally prominent, calamine is by far the dominant secondary ore of the district.

These secondary ores, originally the only zinc ores mined in the area, are very slightly exploited at present. At Ivanhoe they are being mined in desultory fashion on the properties of the Ivanhoe Mining & Smelting Corporation.

The calamine-smithsonite ore occurs as masses and sheet-like bodies in the residual clays derived from Shady dolomite and as incrustations upon or secondary seams slightly penetrating the dolomite pinnacles or "chimneys." (See Pl. 23, B.) It is perhaps most abundant in the bottom portions of the clay close to or upon the underlying dolomite surface. As in places the clay over-burden is very thick—100 feet or more, though generally much less—mining is accomplished by sinking shallow shafts and developing short sinuous drifts as well as by surface stripping of the clay. The ores are mostly soft, requiring only pick and shovel for removal.

Although the oxidized zinc ores are widely distributed, production has been confined chiefly to the Bertha, Austinville, and Ivanhoe localities.

Cerussite.—The carbonate of lead, cerussite, is present as a secondary mineral where deposits carrying galena have been subjected to weathering. It is not abundant, however, and has no commercial importance. Some crystalline aggregates have been found, but it generally has earthy texture. It is most commonly associated with galena, on which it forms coatings. It occurs with galena in the dolomite pinnacles in the pits at Austinville.

NONMETALLIC MINERALS

Dolomite.—Besides composing the country rock, either as originally deposited or as recrystallized, dolomite is doubtless the most common and widespread mineral of the area. It occurs as a white, coarsely crystalline material, filling fractures in the country rock and cementing the breccias, and is consequently the most prominent associated or gangue mineral of the zinc ores. It is invariably present in the ores. It is not always possible to make a satisfactory discrimination between "gangue" or "vein" dolomite and coarsely recrystallized country rock, as a gradation seems to exist in places, but much of the coarse white material is definitely of later origin than the brecciation and recrystallization and obviously fills spaces of various sorts besides replacing country rock.

Study of thin sections shows that at least part of the "vein" dolomite is of earlier deposition than the sphalerite, for the sphalerite shows a definite replacement pattern toward the dolomite.

No analyses of the coarse white dolomite were made, but analyses of material from two localities given by Watson[24] indicate exceptional purity and a composition conforming almost exactly with the analysis of the theoretical mineral.

Calcite.—Except as the chief component of limestone, calcite is not a prominent mineral in this area, especially as an associate of the ores. In places it is found as white, coarsely crystallized material somewhat resembling coarse white dolomite. Coarse calcite was also noted in specimens from the lower levels of the mines at Austinville.

Barite.—Barite is found with sphalerite and dolomite at several places in the Austinville-Ivanhoe district. It occurs at Austinville and may be seen in the exposure of the anticlinal crest on the east side of New River between Austinville and Ivanhoe, where it is associated with lead and zinc sulphides. On the west side of the river at this locality prospecting by means of shafts has disclosed a mineralized portion as the base of the saccharoidal member of the Shady and extending into the top of the Patterson member. Specimens of ore from the Patterson horizon show a characteristic wavy ribbon structure,

[24] Watson, T. L., Lead and zinc deposits of Virginia: Virginia Geol. Survey Bull. 1, p. 42, 1905.

fractured and mineralized by pyrite, sphalerite, dolomite, and barite. Exposures in Ivanhoe show barite, sphalerite, galena, and dolomite in highly brecciated light-colored dolomite of the upper Shady. The barite replaces coarse white crystalline dolomite. It is coarsely crystalline, shows prominent tabular structure, and is white with a slight bluish tint, somewhat translucent.

Fluorite.—Fluorite is found at a number of places in the zinc belt. It is reported at several places in the lower levels of the mine at Austinville, and occurs in exposures at prospects on the "Simmerman property," about half a mile east of the Ivanhoe ferry. Here purple fluorite appears rather abundantly with sphalerite and pyrite in a dolomite breccia of the saccharoidal member. A little of the mineral was seen also in the specimens from the dumps at the Cedar Springs prospects. Again, it was found in material at the mine of the Rye Valley Mining Co., Sugar Grove, associated with galena, sphalerite, and pyrite.

Quartz.—Clear, colorless crystalline quartz was found in the material at Allisonia and at the Riggles prospect, east of Crockett. The mineral is also occasionally found elsewhere in the dolomite breccias but is distinctly of rare occurrence. At the Riggles prospect it is associated with sphalerite, galena, pyrite, chalcopyrite, and bornite.

Cherty quartz appears in specimens from the lower levels of the mine at Austinville. In these specimens two varieties were noted, one very dark colored, "black chert," apparently of earlier development than the coarse white dolomite, and a light-colored variety, "white chert," which may be later than the sulphide mineralization.

STRATIGRAPHIC RELATIONS OF ZINC-LEAD MINERALIZATION

In this region the occurrence of lead and zinc minerals is not limited to a definite horizon or formation. On the other hand, mineral showings in formations other than the Shady are rare and as yet of no economic importance. Prospects are known in the Elbrook near Troutville, about 12 miles north by east of Roanoke, and in the Rome at Bonsacks and near Shawsville. The Taylor prospect may be in the base of the Rome or close to the Rome-Shady contact.

Lack of subsurface data makes it impossible to discuss the localization of ore shoots or the possibility of favored stratigraphic horizons within the Shady formation. It is known, however, that zinc minerals are found in both the saccharoidal and Patterson members. At Austinville it is stated that although zinc has been proved in the lower member, mining is confined at present to the saccharoidal member. The stratigraphic thickness through which mineralization is known in the Shady of the Austinville-Ivanhoe district exceeds 1,500 feet, and it may be much more, as the lower part of the Patterson member has not been prospected. Elsewhere in the area zinc minerals are known at the base of the Shady, just above the quartzite, but so far in no appreciable quantity. Along the highway 1 mile west by north of Jackson Ferry a little sphalerite has been found in dolomite of the basal or Patterson limestone member, associated with abundant pyrite. At the Martin prospect, about 3 miles southeast of Adwolf, sphalerite appears in the base of the Shady, just above the Erwin quartzite; in this region, however, the Shady is considerably thinner than in the Austinville-Ivanhoe area and lacks the distinctive Patterson member.

A fair showing of zinc sulphide appears in the saccharoidal dolomite just below the Ivanhoe limestone member in the roadway north of the hotel at Ivanhoe, a few hundred feet north of the railroad. Also above the quarry in the Ivanhoe limestone half a mile east of the town a light-colored crystalline dolomite bed intercalated in the Ivanhoe member shows sphalerite in a prospect.

The distribution of stopes in the top level of the mine at Austinville—the only part of the mine to which access was given—indicates ore shoots at several horizons. In a general way the stopes appeared to follow the bedding down the dip, but with a slight departure from the bedding at places.

STRUCTURAL RELATIONS OF ZINC-LEAD DEPOSITS

Views of previous writers.—Watson[25] called attention to the fact that "the district is one of intense deformation—folding, faulting, and brecciation" and described the ores as being of "the disseminated replacement breccia type." He stated further that the breccia zones are associated with faults and folds, but he made no further attempt to describe in detail the breccias or their close relationship with the various tectonic strain effects. In another paper[26] he stated that the ores closely follow structural lines and have always been found "in some part of an anticlinal fold in or near a faulted breccia zone." Incidentally, Watson believed that the zinc-lead ores of southwestern Virginia and eastern Tennessee were concentrated from the surrounding rocks by circulating meteoric waters.

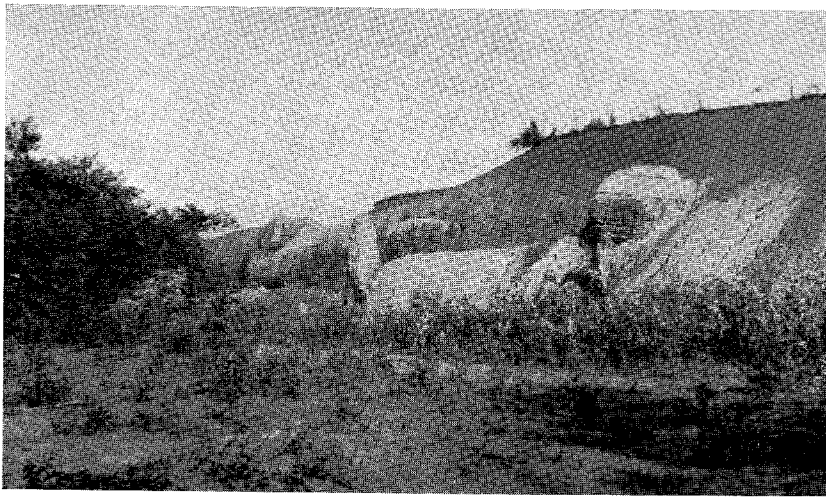
Nason[27] emphasized a direct relation between the Austinville ore bodies and faults. He also stated that "Mineralization occurs on jointing and fracture planes and . . . whole strata seem to have been replaced in brecciated, highly crystalline bodies."[28] He stressed association of the ore bodies with faulting and other fissuring, but, although recognizing that brecciation was important, did not suggest the several

[25] Watson, T. L., Lead and zinc deposits of Virginia: Virginia Geol. Survey Bull. 1, p. 132, 1905.

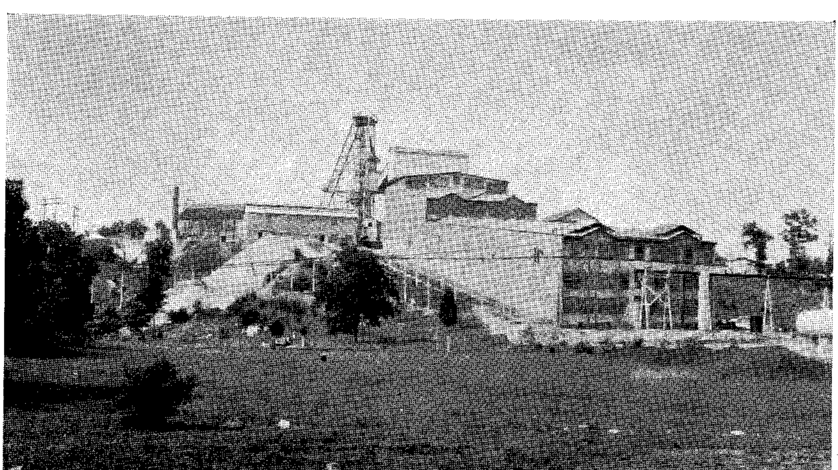
[26] Watson, T. L., Lead and zinc deposits of the Virginia-Tennessee region: Am. Inst. Min. Eng. Trans., vol. 36, p. 681, 1906.

[27] Nason, F. L., Characteristics of zinc deposits in North America: Am. Inst. Min. Eng. Trans., vol. 57, p. 830, 1918.

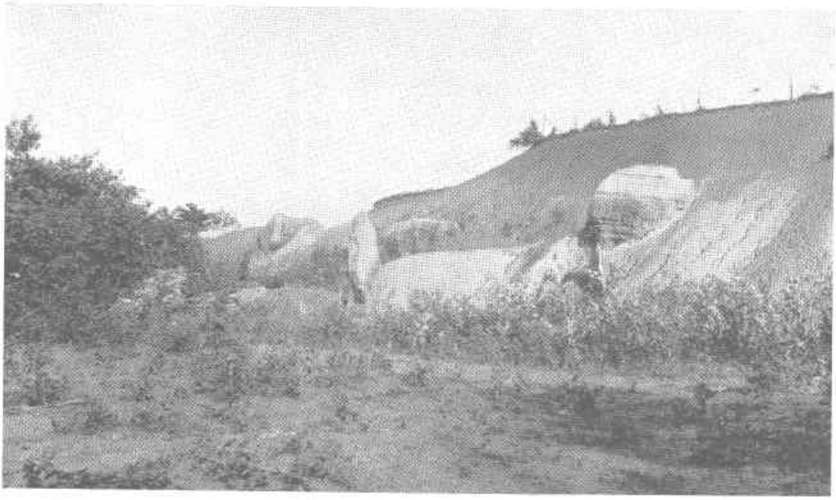
[28] Idem, p. 841.



A. Pinnacles in a pit of the Bertha district. On the northeast side of the road about half a mile east of Lone Star station. The pinnacles show very little brecciation and bedding planes are clearly preserved.



B. Bertha Mineral Co.'s plant at Austinville. Hoist and mine at the main shaft.



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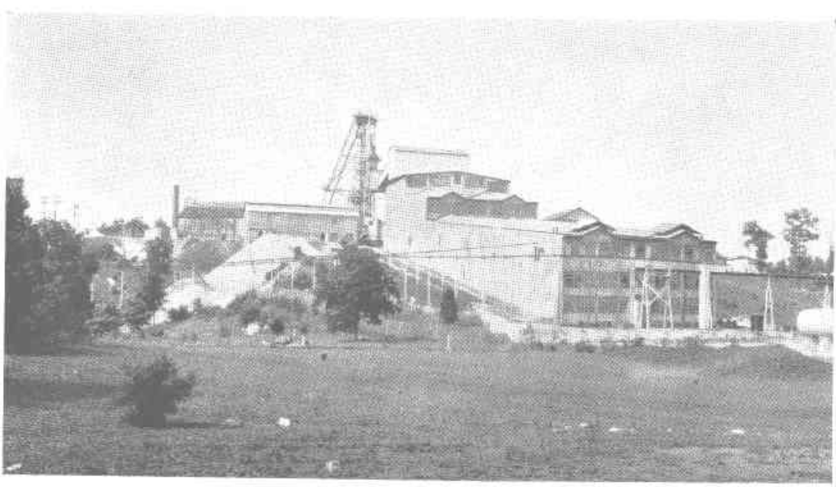

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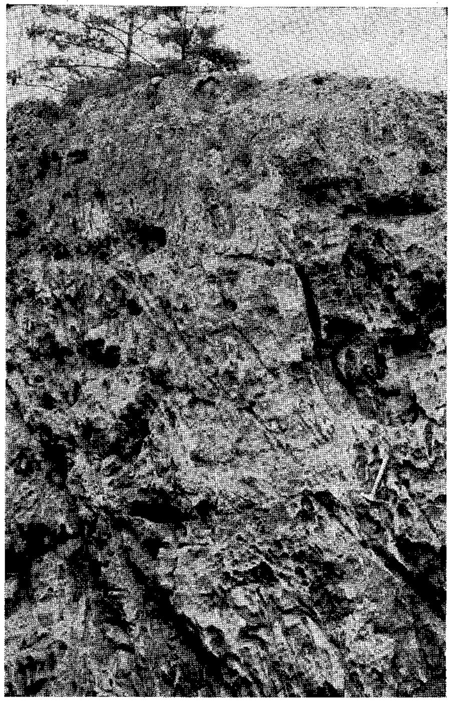
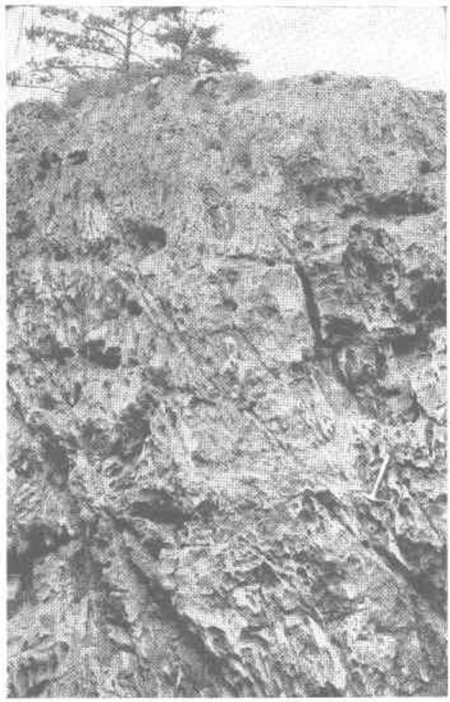


A. Mineralized sheeted zone in main pit at Austinville. Some walls show sheeting fractures and contain sulphide minerals. The fracturing obscures the original bedding.

B. Sharp dolomite pinnacles in main pit at Austinville. The pinnacles are characteristically jagged and highly brecciated, and in part carry sulphide ore minerals.



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tectonic and stratigraphic factors that have produced brecciation in the zinc area. Incidentally, Nason believed that the ores were deposited from waters of deep origin.

An entirely different explanation of the origin of the breccias in the Tennessee area has been offered by Ulrich,[29] who states that the breccias of the Mascot and Jefferson City areas were formed by the fracturing and spalling of the roofs and walls of caverns, "the pieces of rock making the accumulations of mainly angular fragments commonly referred to by geologists as breccia." He believes that the ores are confined to a definite stratigraphic horizon and that "this fact is simply and positively fatal to the conception that they occur in anything like true fissure veins or in fault breccias." Ulrich has not stated these views with reference to the Austinville deposits, but the general similarity between the structural, stratigraphic, and lithologic features of the Tennessee and Virginia deposits would imply a similar origin for both. The writer can not agree with the Ulrich views regarding the significance of apparent stratigraphic control and the origin of the breccia, for reasons that are stated in succeeding pages.

Relation to regional features.—Interpretation of the structural relations of the mineralized zones in this region is necessarily based only upon surface observations and is consequently limited to the larger features as indicated by areal mapping. So far as their distribution is shown by prospects or mineralized exposures, it is evident that mineralized areas are characterized by thrust faults, cross faults ("flaws" or tear faults?), and prominent anticlines. This suggests a broad areal relation between structural features and ore deposits. At Austinville the ore bodies are obviously located on the faulted and highly brecciated southeastward dipping limb of a very prominent anticline. Other prospects at and near Ivanhoe are located in part on the crest and southeast limb of the anticline, in part in an area of northwestward-dipping beds crossed by a flaw or tear zone of considerable displacement. At Carter Ferry a prospect appears in proximity to a minor cross fault; similar conditions exist between Speedwell and Cedar Springs.

At Cedar Springs the prospects are located on a small, closely folded anticline (Fig. 1), which shows definite signs of shear and cross fracture, although no well-defined thrust fault can be mapped through the prospects. At Sugar Grove the lead mine of the Rye Valley Mining Co. is in a zone of close folding and probably minor thrust faulting (Fig. 2). The several prospects between Sugar Grove and Adwolf are all in or near zones of prominent thrust faulting.

[29] Ulrich, E. O., Origin and stratigraphic horizon of the zinc ores of the Mascot district of east Tennessee (author's abstract of address before Geological Society of Washington, November 26, 1930): Washington Academy Sci. Jour., vol. 21, no. 2, pp. 30-31, 1931.

On the other hand, the pits in the Bertha territory, 7 miles northeast of Austinville, are in an unfaulted area where the rocks dip at low angles and indicate a broadly synclinal structure. There is no apparent alignment or other distributional pattern of the workings. In these

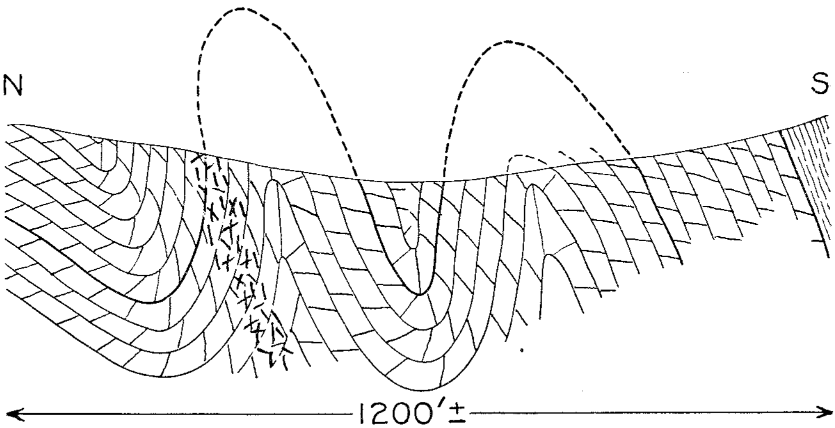

Figure 1.—Diagrammatic cross section showing interpretation of structural relations at the open cuts at Cedar Springs.

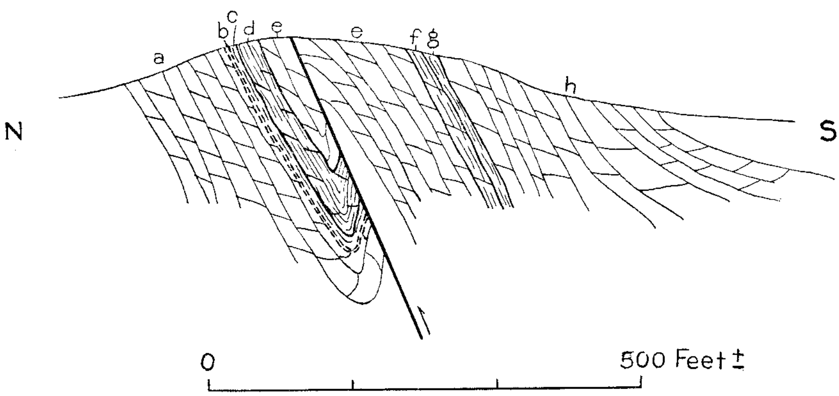

Figure 2.—Section through Chamberlain mine of the Rye Valley Mining Co. at Sugar Grove. (Modified after Ball and Thompson to conform to surface attitudes.) a, Dolomite, saccharoidal in part; b, highly brecciated zone carrying galena, etc.; c, dark-gray to black shale; d, shaly dolomite; e, dolomite, saccharoidal in part; f, shaly gray dolomite; g, dark-gray, nearly black shale, 4 feet exposed; h, dolomite, massive to thin platy, gray.

pits the ores consisted entirely of oxidized minerals of zinc and iron. No lead minerals were found here, and indeed sphalerite was conspicuously rare throughout. Grains of the mineral may be found here and there in the underlying dolomite, but in general the pinnacles are impressively barren of the mineral. It is possible that concentration of zinc in this area represents transportation by solutions of low temperature at shallow depth from other eroded mineralized zones into the broad synclinal basin. The metal may indeed have been derived from higher beds, now removed by denudation, or from lower beds once superimposed by overthrusting but also removed by denudation. The bedrock pinnacles in the pits at Bertha show very little fracturing as a rule, compared with the pinnacles at Austinville, which, unlike those in the Bertha territory, contain sulphides. Other features of the Bertha area are discussed on pages 97-99.

The geographic relations of mineralized areas to major structural features are shown by Plate 2.

Relation to brecciation and fissuring.—The zinc sulphides of southwestern Virginia characteristically occur in a breccia of dolomite rock cemented by coarsely crystalline white dolomite. Most of the fragments are angular rather than otherwise and show little mutual displacement. In large measure the mineralized breccia is of the crush or shatter type, which in some places shows hardly more than a "cracked" effect. No matter how the origin of the breccias and the associated zinc may be interpreted, surface evidence indicates that zinc deposits should be sought only in areas that show pronounced brecciation and mineralization by white "gangue" dolomite, and that these areas will as a rule be near zones of thrust faulting.

Brecciation of the country rock was accomplished in part by complex systems of fracturing and cross fissuring. In the Austinville mine it is not possible to correlate zones of mineralization with definite fracture systems without access to the deeper underground workings. However, there is probably significance in the fact that surface distribution of zones of prominent and intense fissuring reflects also in a general way the areas of known mineralization. Particular significance can probably also be attached to the mineralized zones of cross fracturing described as sheeting. (See pp. 66-68.) These zones may well represent the structural failure of the rocks in response to forces that in less distributed form or acting nearer the surface would have produced displacement of the flaw type.

GENERAL CONSIDERATION OF THE ZINC-LEAD DEPOSITS

Under the limitations imposed upon this investigation an attempt to discuss the details of occurrence and origin of the zinc-lead deposits would be unwarranted and hazardous. Nevertheless, certain broad facts of areal geology and apparent mineral distribution allow a few theoretical generalizations as to the conditions that probably favored mineralization. Whatever suggestions may accordingly be made are based upon a study of the areal geology and such analogy as can be logically and fruitfully drawn between the known geologic conditions, and the apparently closely similar zinc territories at Mascot and Jefferson City, Tennessee. The Tennessee deposits[30] occur in dolomites of lower Paleozoic age, within the Appalachian Valley and, together with the Virginia deposits, constitute the belt of Appalachian zinc deposits. In a general review of zinc-lead occurrences in the Appalachian belt, D. F. Hewett, of the United States Geological Survey, and the writer visited the mines of the American Zinc Co. of Tennessee at Mascot, and of the Universal Exploration Co. at Jefferson City. Complete access was given to the mines and office maps, and ten days were spent in observing conditions both underground and on the surface. Here the zinc sulphides occur in tectonic breccias closely similar to those in the Virginia area, and definite relations between abundant fractures, local dislocations, and the sulphides were observed.

Origin of the breccias.—The characteristic occurrence of the Virginia ores in highly brecciated dolomite beds leads to an inquiry as to the origin of the breccias. The regional stratigraphic and structural features suggest two hypotheses of origin: the breccias represent the material that has collapsed into open caverns, under the influence of gravity or of tectonic forces; or the breccias are directly of tectonic origin and as such doubtless were produced by the same general orogenic forces that caused the folding and faulting.

Probably the most significant evidence favoring the collapse hypothesis is the seeming limitation of the ore bodies to definite stratigraphic horizons within the enclosing formation. In the Mascot area, for example, several prospects lie along the belt of outcrop of a definite stratigraphic horizon, according to Josiah Bridge.[31] Minor prospects along this belt may be considerably removed from this horizon, but the major prospects seem to be closely restricted to it. The prospected belt (8 to 10 miles long) follows the outcrop of beds in the lower part of the post-Nittany portion of the Knox dolomite. Other zinc belts in Tennessee show mineralization at other horizons, according to Secrist.[32] The hypothesis that stratigraphic limitation of breccias indicates their origin in caves or that they were formed while the beds were practically horizontal in attitude is debatable. This point is discussed in subsequent paragraphs. If the breccias that carry the sulphides were formed by the collapse of solution caves one would expect to find vugs or other open cavities, great variation in size of fragments, depositional structures common to caves, "cave earth," and associated joint planes in the roof that were once widened by solution. Such evidences are entirely lacking. The similarity of the gradation from

[30] Secrist, M. H., Zinc deposits of east Tennessee: Tennessee Dept. Education, Div. Geology Bull. 31, 1924.
[31] Unpublished manuscript.
[32] Secrist, M. H., op. cit.

brecciated into unbrecciated rock in both hanging and foot walls is, on the other hand, strong evidence against the cave hypothesis of origin. Crosscuts of ore bodies from footwall into hanging wall show first a general cracking of the beds into large angular blocks, scarcely displaced; then a gradual transition into more complexly shattered rock with very little mutual displacement of fragments; next, more uniform and finer breccia of the rubble type; and then the same conditions in reverse sequence. The zone of rubble breccia is comparatively thin. An additional feature of the cracked and shattered zones is the occurrence of definite systems of fractures rather than haphazard arrangement of blocks.

In the southwestern Virginia region the distribution of the exposures of mineralized breccias both on the surface and in mines indicates that they are not limited to a stratigraphic horizon. In a broad way, however, with very few exceptions, zinc and lead minerals have been found only in the Shady dolomite. Within the Shady the mineralization has been limited to dolomite beds, which constitute 60 to 80 per cent of the formation. In view of the lithologic character of the overlying Rome formation, in which thick shale beds are abundant, it is scarcely surprising that there was to a large degree a restriction of circulation of the mineralizing solutions to the underlying thick, competent, easily brecciated dolomite formation.

The arrangement of the stopes at Austinville as seen from the top level may indicate at least three horizons within the saccharoidal member of the Shady at which ore was mined. Although a close survey of the ground was not permitted there is in places a definite suggestion that the stopes, though nearly following the bedding down the dip, cross the bedding at a very sharp angle, probably not more than 5° to 10°. The idea that ore occurs at more than one horizon is also borne out in a general way by the distribution of zinc minerals in the surface workings.

The apparent restriction of ore bodies in the mines of the Appalachian zinc belts to definite stratigraphic zones tends to divert one from consideration of the tectonic origin of the breccia, on the presumption that orogenic crushing would not be so prominently controlled by bedding. In considering the deformation of a thick, brittle, competent formation, such as the Shady dolomite, under very great load, the initiation of brecciation long before thrust faulting starts must necessarily be accepted. At first the effect would be a cracking through thick zones, albeit with a distinct tendency to follow certain more brittle beds. These zones, weakened by cracking, would have a strong tendency to localize stress effects in later, more intense stages of the deformative period. Failure by thrust faults would tend to follow the prepared paths roughly parallel to the bedding but necessarily would depart from this parallelism in the culminating stages and in positions on and near the crests and troughs of folds. These conditions are found, of course, only on the limb of a fold that dips moderately toward the source of the pressure. In the Virginia region the southeastward-dipping limbs, which are the longer ones and commonly the only remaining portions of asymmetric anticlines in the Appalachian Valley belt, display these bedded breccias. In the southeastward-dipping strata there is more nearly a parallelism between original compressive forces and bedding. In the southwestern Virginia region all known prospects, except a few in the Ivanhoe district, lie in beds that dip to the southeast. A statistical study of 58 prospects and mines of eastern Tennessee[33] shows that 42 are in southeastward-dipping beds, 5 in northwestward-dipping beds, 4 in approximately horizontal beds, 1 in vertical beds, and 1 in southwestward-dipping beds. There are no data available for the remaining 5 prospects.

Localization of mineralization.—The writer believes that the rocks were prepared for the reception of zinc and lead sulphides through the action of tectonic forces, presumably at the end of the Paleozoic era. The folds and thrust faults of the region were the outstanding results of this period of compressive stress. The local zones of brecciation were developed in more brittle rocks at the same time. Most of the breccia was of the crush or shatter type, within the zones of which narrower fault-rubble breccias were formed in the later stages of strain. Some of these were formed by slipping more or less parallel to the bedding. There was thus developed a site for deposition, in part by the replacement of a chemically susceptible formation and in part by the filling of fractures. The zones of brecciation may or may not have been the channels by which the solutions that deposited the zinc arose from depth, but there is a suggestion, in the close association or proximity of mineral exposures and prospects with known zones of cross or tear faulting and sheeting at Carter Ferry, Austinville pits, Ivanhoe (tear fault), and between Cedar Springs and Speedwell (zone of cross shearing), that such zones of fracture may have been very effective in providing available channels of access for solutions of deep origin. If solutions arose along such channels, they necessarily spread laterally into the breccia zone of thrust origin. The nature of the breccia zones and the depth to which the present deposits are known to extend indicate rather clearly that the solutions rose from considerable depth. Although fancy may play with the idea that there was some hydrothermal connection with deep sources whence sprang also the sulphides of the near-by "gossan lead," the fact remains that there is at present no valid clue to the ultimate source of the zinc and lead minerals and the associated pyrite and fluorite.

[33] Secrist, M. H., op. cit.

If the structural control of the sites of deposition suggested in the foregoing paragraphs is correct, ore deposits must be sought in areas of pronounced brecciation and dolomitization, and most of these seem to be directly associated with areas that show folding and thrust faulting. Any structural feature that might contribute to the localization or intensity of brecciation would have important collateral value. Thus zones of cross fracturing, as shown by flaws, sheeting effects, or sharp deflections of anticlinal axes, may have acted in favor of exceptional concentration in places, without necessarily limiting ore bodies to such positions. It should be borne in mind, however, that the discovery of ground thus prepared for mineral reception gives no assurance that the mineralizing solutions ever reached the particular locality. Brecciation of the rock was merely one of the most favorable conditions for ore deposition. An equally necessary requirement is that the zone so brecciated should have continued to or connected with the channels through which mineralizing solutions circulated.

That the solutions were of deep circulation and rose along fault or breccia channels would, therefore, appear to be indicated by the following facts: The breccias are of tectonic origin and are genetically associated with deeply extending thrust zones; and the mineral bodies extend to depths of at least 1,500 feet, possibly 2,000 feet, below the top of the Shady formation.

The fact that no unconformities occur in the stratigraphic thickness of 2,000 feet involved in the Shady dolomite renders it extremely unlikely that the breccia zones could have been due to the collapse of caverns, which would necessarily have been formed at comparatively shallow depths and would have been closely related to one or more old erosion surfaces.

The relation of mineralization to overthrusting, as postulated in this report, is by no means a new conception in the study of ore deposits. Indeed, it is probable that the preparation of ground by thrust-faulting is very common in areas where the beds have favorable lithologic characteristics and orogenic forces have acted. There is difficulty in recognizing thrust planes as such where they are essentially parallel to the bedding. This fact is pointed out by Butler,[34] who states that "deposits associated with thrust faults are an important type in the Big and Little Cottonwood districts, Utah . . . The fault planes generally cut the beds at small angles. To this approximate parallelism of fault planes and bedding can probably be attributed the failure of those geologists . . . to recognize the thrust faulting . . . Both the brecciation and replacement occurred most extensively in limestone. The limestone is most thoroughly brecciated where it has been overridden

[34] Butler, B. S., Relation of ore deposits to thrust faults in the central Wasatch region, Utah: Econ. Geology, vol. 14, pp. 172-175, 1919.

by hard massive quartzite, although the amount of brecciation varies considerably in different beds of the limestone . . . Where limestone was thrust over limestone the brecciation varies in degree but frequently extends through a rather thick zone."

A clear and impressive example of ore deposition related to breccias in limestone-dolomite beds deformed by thrust faulting has been described recently by Hewett.[35] In the Goodsprings area, Nevada, large tabular deposits occupy breccia zones along thrust faults that are nearly parallel to the bedding of the enclosing partly dolomitized limestone. "The largest ore deposits have been found in the fracture and breccia zones that trend nearly parallel to the bedding."

[35] Hewett, D. F., Geology and ore deposits of the Goodsprings quadrangle, Nevada: U. S. Geol. Survey Prof. Paper 162, p. 9, 1931.

OCCURRENCES OF ZINC AND LEAD IN VIRGINIA

Numerous zinc and lead prospects are scattered along the Great Valley in Virginia from Shenandoah County to Scott County, and unprospected showings have been reported from time to time at a number of additional localities. Zinc and lead minerals have also been reported from places outside the main part of the Valley, both in the Valley Ridges northwest of the Blue Ridge and in the crystalline area southeast of it. The only noteworthy localities in these outlying areas are the property once operated by the Albemarle Zinc and Lead Co., near Faber, Albemarle County, and a mineralized belt in Louisa and Spotsylvania counties, where some lead and zinc ores have been mined.

The following pages describe briefly the known occurrences in Virginia. Those in Wythe and Smyth counties are also included, although some of them are mentioned in connection with other parts of the report.

It was not possible to make a study of the numerous prospects and showings outside the mapped area, but several of the prospects were briefly visited by the writer. The summary of occurrences outside Wythe and Smyth counties is therefore drawn partly from the writer's observations and largely from the literature and is presented here as an outline of distribution and stratigraphic occurrences.

In most places the showings of mineral are scant and economically unimportant. The localities at which mines, prospects, and mineral showings (unprospected exposures) have been reported in literature or have been seen by the writer are shown on Plate 3. For convenience, the localities are listed in two groups, namely, those in the crystalline area, east and south of the Blue Ridge crest, and those in the Valley and Ridge province, north and west of the Blue Ridge crest.

CRYSTALLINE AREA

ALBEMARLE COUNTY

In 1849 a galena deposit was discovered 2 miles east by north of Faber (Nelson County), which is 21 miles southwest of Charlottesville. Later sphalerite was recognized as a prominent associated mineral. The deposit is situated at the northeast end of Shiloh Mountain, near its junction with Appleberry Mountain,[36] near the head of the ravine but just south of the col between Ivy and Bear creeks.

This mine has special interest because it has been operated intermittently over a long period and displays uncommon mineralogic and lithologic features. It was visited briefly by the writer in October, 1930, but no attempt was made at that time to examine it in detail, as very little of value can be observed on the surface, and the underground

[36] See topographic map of the Covesville quadrangle, U. S. Geological Survey, 1929.

workings are not accessible. Several articles have been written about the property, and these are listed in the bibliography. Statements concerning operations appeared in volumes of Mineral Resources of the United States prior to 1917. The mine has not been worked since 1916.

During the War between the States the mine was worked by the Confederates. Until the early 1900's it was exploited only for lead. In 1905 the Albemarle Zinc & Lead Co. completed an 80-ton concentrating plant, and both lead and zinc were produced for a time. In 1915 the mine was reopened by the Atlantic Lead & Zinc Co., and development work was carried on during 1916. A 100-ton concentrating mill was constructed. According to reports there has been little or no production since 1916.

At the time of the writer's visit no underground workings were open. Inspection of the dump shows an association of galena, sphalerite, quartz, fluorite, calcite, and a little chalcopyrite. Very small quantities of arsenic and antimony were reported by Watson.[37]

No assays were made in connection with this report, but the galena is reported to be appreciably argentiferous.

According to J. M. Boutwell[38] the "zinc occurs in a vein in metamorphic crystalline schists of undetermined but probably Cambrian or pre-Cambrian age parallel and adjacent to a diorite dike. The ore consists of blende associated with galena in a gangue of quartz and fluorspar." In 1915 C. E. Siebenthal[39] reported as follows: "The Albemarle mine . . . is on a vein traceable for several miles and averaging 4 feet in width. Three shafts have been prospected in the vein to a depth of 300 feet and for 1,000 feet in length." According to Watson[40] chlorite schist is the ore-bearing rock, although several varieties of schist—sericitic, talcose, and chloritic—"alternating or interbedded with a quartz-mica conglomerate schist," make up the country rock of the region.

A series of basic dikes ("diabase and diorite") cut the schist. "The vein is reported to have been traced for a distance of several miles on this and the adjoining properties. It varies in width, but will average about 4 feet; strike N. 45° E. exactly paralleling the diorite dike 25 feet away on the northwest side, and dips 80°-85° NW. Where opened it is of the lenticular type, composed of bulbous or lenticular bodies of fluorspar admixed with some quartz through which the ore, blende and galena, is distributed . . . A marked banded structure is frequently indicated, particularly near the wall, which is due to included plates of the schist . . . The ore . . . occurs prin-

37 Watson, T. L., Lead and zinc deposits of Virginia: Virginia Geol. Survey Bull. 1, p. 65, 1905.

38 U. S. Geol. Survey Mineral Resources, 1906, p. 467, 1907.

39 Idem, 1915, pt. 1, p. 870, 1917.

40 Watson, T. L., op. cit., p. 57.

cipally in the fluorspar-quartz lenses, although the schist next to the lenses is often more or less impregnated. The blende and galena may occur in separate bands and irregular masses distributed through the lenses, or they may occur intimately admixed in a single band or mass in the same lens."[41]

SELECTED REFERENCES

Boutwell, J. M., U. S. Geol. Survey Mineral Resources, 1906, p. 467, 1907.

Seamon, W. H., The Faber lead and zinc mines: The Virginias, vol. 6, p. 47, 1885.

Siebenthal, C. E., U. S. Geol. Survey Mineral Resources, 1915, pt. 1, p. 870, 1917.

Watson, T. L., The lead and zinc deposits of Virginia: Virginia Geol. Survey Bull. 1, pp. 56-67, 1905.

LOUISA AND SPOTSYLVANIA COUNTIES

Small quantities of lead and zinc have been recovered as by-products at certain mines in the "pyrite belt" of Louisa and Spotsylvania counties, and about 1915, special interest was centered in the possibilities of developing commercially important zinc-lead ore bodies. The Allah Cooper and Arminius mines, near Mineral, in Louisa County, and the Holladay (Valzinco) mine, in Spotsylvania County (Virginia Lead & Zinc Corporation) about 15 miles northeast of Mineral, were the scenes of zinc-lead ore production or development at this period.

A zone of marked mineralization is strongly suggested by the distribution of gold, pyrite, and lead-zinc mines and prospects along a belt that extends north-northeasterly from Mineral (5 miles east of Louisa) to Rapidan River, a distance of 30 miles. In this area the rocks are chiefly mica schist or quartz-sericite schist. Large granite areas are exposed a few miles to the west and to the east. Some geologists believe the schists to be of Cambrian age, others hold to the belief that they are pre-Cambrian. The granite intrusions of this part of the State are probably post-Carboniferous. According to J. H. Cline[42] "the rocks composing the belt in which these sulphide bodies occur are schists of probable lower Cambrian age. Dikes of both acid and basic types are comparatively numerous . . . The schists are dominantly of the quartz-sericite type, but chlorite and hornblendic schists are fairly common, and in places there are calcareous varieties. The larger ore bodies occupy fissured zones chiefly in the less siliceous portions of the schist series."

[41] Watson, T. L., op. cit., p. 63.

[42] Cline, J. H., The Louisa-Spotsylvania mineral district of Virginia: Manufacturers' Record, vol. 70, p. 50, July 20, 1916.

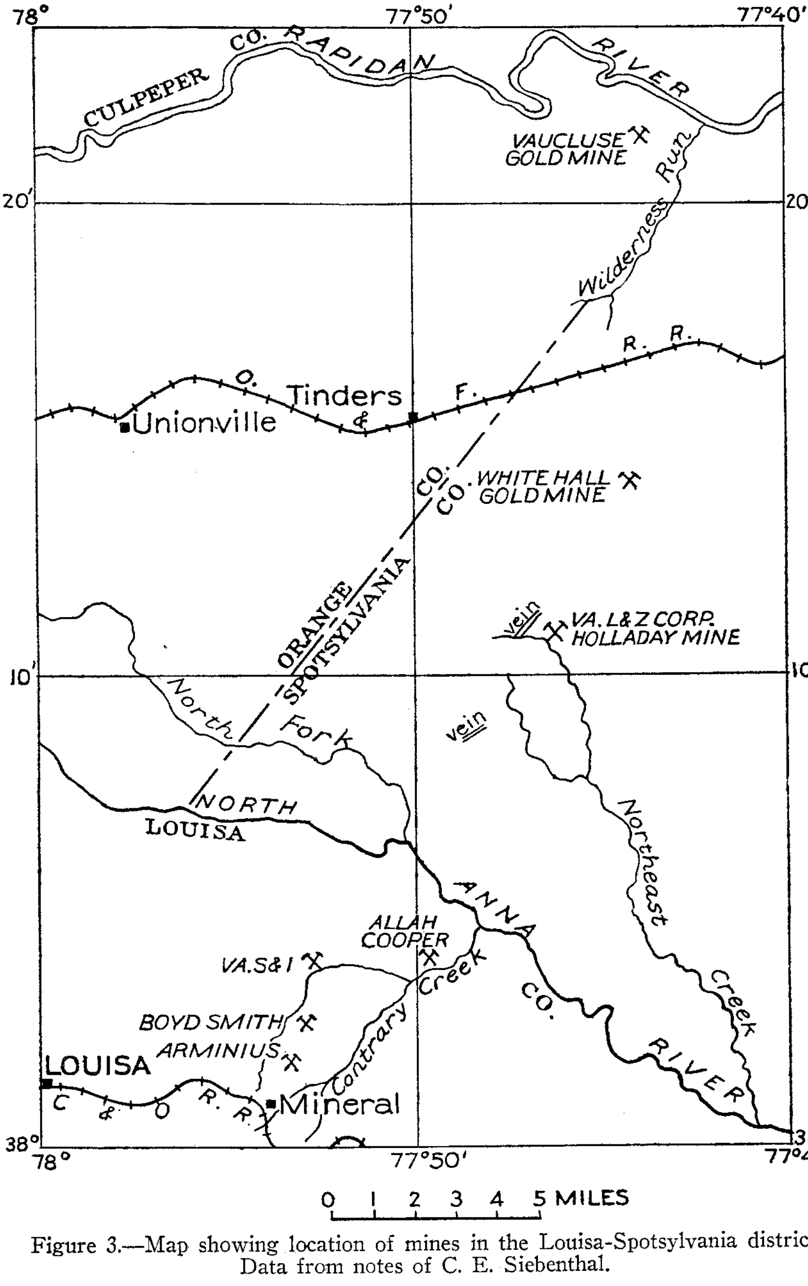

Figure 3.—Map showing location of mines in the Louisa-Spotsylvania district. Data from notes of C. E. Siebenthal.

Gossan outcrops indicate the position and general direction of the mineral belt, which includes the Arminius pyrite mines, the Boyd-Smith, the Allah Cooper, and Holladay mines, and doubtless this feature is of prime importance in prospecting. It may be necessary to pass through a considerable thickness of this weathered zone before zinc and lead minerals are reached.

Grasty reported[43] that the Holladay vein can be traced by its gossan for a distance of 1,300 feet, and that at the end of 1916 about 900 feet of drifting had been done on the different levels, chiefly from No. 1 shaft, which at that time reached a depth of 250 feet. A second shaft reaching a depth of 125 feet was sunk 1,200 feet northeast of No. 1.

The Holladay (Valzinco) mine was operated by the Virginia Lead & Zinc Corporation, and the ore was shipped to the Allah Cooper Mill of the Boyd-Smith Mines, Inc. On December 1, 1916, the Allah Cooper property, including mine and mill, was taken over by the Virginia Lead & Zinc Corporation. The capacity of the mill was rated at 50 tons per day.

According to Lindgren[44] the Holladay vein is well defined, cuts sericite schist, and has a course of N. 40°-45° E. magnetic, and a dip of 65°-70° SE., while the trend and dip of the schist are about N. 25° E., and 50° SE., respectively; hence, the ore body cuts across the schist at a sharp angle. The vein is lenticular. The constituents of the ore in order of deposition are (1) quartz and chlorite, (2) pyrite, (3) sphalerite, (4) chalcopyrite, and (5) galena. Chalcopyrite rarely exceeds one per cent. The vein has a maximum width of 10 feet, and averages about 4 feet.

Lead and zinc were also produced at the Allah Cooper mine (Boyd-Smith Mines, Inc.) about 9 miles south by west of the Holladay mine.

The Arminius pyrite mine, developed to a depth of 1,300 feet, produced some zinc and lead as a by-product. According to Eckel[45] the main ore body attained a maximum width of 60 feet; the vein has a strike of N. 20° E., and dips 60° SE. A cross cut on the 1,000-foot level struck a parallel ore body. The ore was reported to contain silver.

Figure 3 is a key map of the Louisa-Spotsylvania district compiled from the notes of C. E. Siebenthal.

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Cline, J. H., The Louisa-Spotsylvania mineral district of Virginia: Manufacturers' Record, vol. 70, p. 50, July 20, 1916.

[43] Data in files of C. E. Siebenthal, U. S. Geol. Survey.
[44] Report in files of C. E. Siebenthal, U. S. Geol. Survey.
[45] Notes in files of C. E. Siebenthal, U. S. Geol. Survey.

Hill, J. M., and Siebenthal, C. E., U. S. Geol. Survey Mineral Resources, 1915, pt. 1, pp. 20, 870-871, 1917.

Speed, F. B., Jr., Lead-zinc mining in Virginia: Eng. and Min. Jour., vol. 102, p. 511, 1916.

VALLEY AND RIDGE PROVINCE

SHENANDOAH COUNTY

Lead and zinc showings have been prospected on the Wine property, about 1 mile south of Moore's Store and 5 miles west by north of Quicksburg. The prospects are nearly a quarter of a mile west of the road, in an area of low relief, underlain by dolomite beds. In this vicinity the dark dolomites containing the mineral are greatly shattered and display zones of shatter breccia. The waste pile shows a breccia of dark dolomite cemented by coarse white dolomite. Translucent colorless quartz is an associated gangue mineral. The beds strike N. 55° E. and dip 47° SE. Two pits are located along the strike which the mineralized zone apparently follows, but no other relation to bedding could be determined.

No zinc mineral was found in the material from the lead pits, but at a point near the road and about 100 feet higher stratigraphically a sphalerite-bearing breccia has been prospected. Brecciation dies out rather abruptly both above and below the prospected beds. The beds are probably of Beekmantown age.

Zinc prospecting is also reported on the northwest side of a low divide about 1¼ miles southeast of the Wine prospect. According to Charles Butts[46] the prospect is probably in the Mosheim limestone.

BOTETOURT COUNTY

Troutville.—About 1½ miles northeast of Troutville, west of the highway, galena and an oxidized zinc mineral occur in a dolomite breccia cemented by white dolomite. The exact relations of the mineralization to bedding are not visible. The country rock is the Elbrook formation.

Bonsacks.—Six miles northeast of Roanoke, at the edge of a railroad cut about half a mile north by east of the railroad station at Bonsacks, a shallow shaft was sunk in rather massive dark-gray finely crystalline dolomite beds underlying red shale. The beds belong to the Rome formation, have a general strike of N. 30° E., and dip 55°-65° SE. Pyrite and traces of sphalerite are present; chalcopyrite has also been reported. The crackle breccia of dolomite is veined with white dolomite. Evidences of mineralization are very scant.

Regarding mineralization at Bonsacks, Kemp[46a] states: "Near

[46] Personal communication. See Butts, Charles, Geologic map of the Appalachian Valley of Virginia: Virginia Geol. Survey Bull. 42, 1933.

[46a] Kemp, J. F., Ore deposits of the United States and Canada, 5th ed., p. 249, New York, 1903.

Bonsacks the gossan of the ore was exposed, but not recognized for a long time, in a cut of the Norfolk & Western Railroad. The mine yielded rich earthy oxidized ores, which, however, passed in depth into a very intimate and rebellious mixture of zincblende and pyrite."

Martin prospect.—About 2½ miles southwest of Roanoke and the same distance northwest of the old Rorer iron mines, on the Martin property, several shafts and a pit about 150 by 20 feet (trend N. 20° E.) have been made in dark-gray finely crystalline dolomites, crackled and veined with white dolomite. Here the lithologic characteristics and position with respect to red beds of the Rome appear to be about the same as at the Bonsacks prospect. Although much work was done in an attempt to locate and develop an ore body, no ore is to be seen in place. The dump pile shows an abundance of pyrite largely oxidized to limonite, and some associated dark-gray sphalerite disseminated in the rock and dolomite gangue. Galena has been reported. The prospect pits are in a broad valley, just above stream level, and good exposures of bedrock are lacking in the immediate vicinity, but a short distance toward the southeast exposures show a general northeast strike with dip 30° SE.

MONTGOMERY COUNTY

Lead and zinc minerals have been reported at several places in Montgomery County, but no favorable prospects have been discovered. Watson[47] reports the following localities at which mineral has been prospected or is exposed:

On the Langhorn and Wills estates, about 2½ miles southeast of Shawsville and at the east side of Bony's Creek. This is the "Langhorn zinc mine," which includes several test pits on the ridge and in a tributary ravine. The "prospects" are apparently in dolomite beds of the Rome formation. Only slight traces of zinc and lead have been reported.

On the Walker and Vaughn properties, south of the railroad between Shawsville and Big Tunnel.

About 2 miles south of Christiansburg.

On the Cloyd property, on New River about 8 miles southwest of Blacksburg.

The reported occurrences of lead and zinc in Montgomery County constitute meager showings and do not yet warrant serious consideration.

PULASKI COUNTY

Delton mines.—The open cuts known as the Delton mines, on the Clark property, are about 1 mile south of Delton and 2 miles north by east of Allisonia. They were opened in 1902 by the Bertha Mineral

[47] Watson, T. L., Lead and zinc deposits of Virginia: Virginia Geol. Bull. 1, p. 73, 1905.

Co. The pits were worked for "soft ores" of zinc for about a year and a half. Later they were operated for iron ore. Calamine and smithsonite were the zinc minerals obtained; galena and sphalerite were reported present, the latter more sparingly.

The Delton zinc pits are situated within an extensive area of Rome beds, apparently the central part of a broad synclinal basin. Considerable minor deformation is displayed, and in one of the pits strong local distortion of the beds is apparent. The nearest known major thrust lies 1 mile to the south, but local dip variations and the presence of a distinct minor fault in the pit indicate a deformed zone, including some shearing. The local fault plane strikes about N. 30° W. and dips 63° NE.; the beds on the east side strike N. 85° W. and dip 32° N.; and the beds on the west side strike N. 30° W. and dip 50° NE.

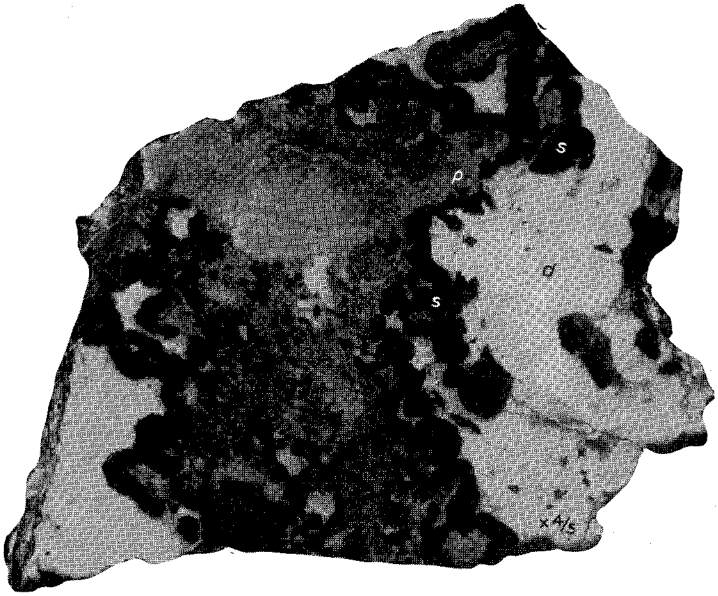
The dolomite is rather dark gray, very fine grained, mostly even bedded, thin blocky to thin platy, and in places very highly fractured.

Prospects at Allisonia.—Several test openings have been made along both sides of New River east of the ferry at Allisonia, 1 to 1½ miles south of the Delton pits. The openings lie on land owned or leased by D. S. Forney, Graham & Robinson, and Henderson Flanagan. Recently some diamond-drill prospecting was done by an outside company. The presence of zinc and lead minerals in a belt that crosses the river is said to have been demonstrated.

About a quarter of a mile east of the ferry, in the bluff on the north side of the river, several tunnel openings may be seen. The dumps show a breccia of dark dolomite carrying the usual white dolomite as a cement. Sphalerite, galena, pyrite, quartz, barite, and a very little calcite are also present. Two varieties of sphalerite, very dark greenish gray and light yellow, are intimately associated in the white dolomite portions, but the grains within the rock material are almost entirely of the dark variety. The quartz is transparent, colorless, and milky and occurs in part as well-formed crystals, obviously later than the other minerals.

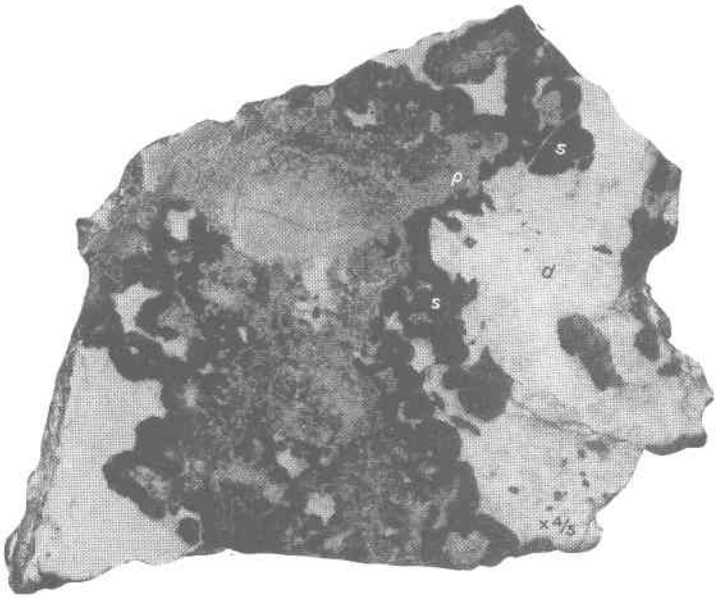
The Forney prospects include several tunnels in the bluff on the north side of the river, about 50 to 75 feet above the flood plain, and a shaft on the south side of the river, reported to have discovered zinc sulphide. A coffer dam constructed in the river between the tunnels and the shaft disclosed zinc ores in the river bed. Boyd[48] reports that about 1880 Flannigan and Graham & Robinson were mining zinc ore about 2 miles below the mouth of Reed Island Creek. "The greatest mass of ore is found at the junction of the white silicious limestone with the blue and white lamellated wavy limestone . . . The mine was opened by a tunnel three hundred and thirty feet long. There

[48] Boyd, C. R., Resources of southwest Virginia, p. 40, New York, Wiley & Sons, 1881.



A. Ore from adit level of the Austinville mine. It shows small remnants of saccharoidal dolomite (mottled medium gray), coarse white dolomite (d), sphalerite (s, dark), and pyrite (p, flat gray). The sphalerite and pyrite are generally closely associated. X $\frac{5}{8}$.

B. Breccia ore in saccharoidal dolomite from pinnacle on property of Ivanhoe Mining & Smelting Corporation. Fragments of dark-colored dolomite are cemented and partly replaced by white dolomite and sphalerite, the latter chiefly as disseminated grains in the matrix. X $\frac{5}{8}$.



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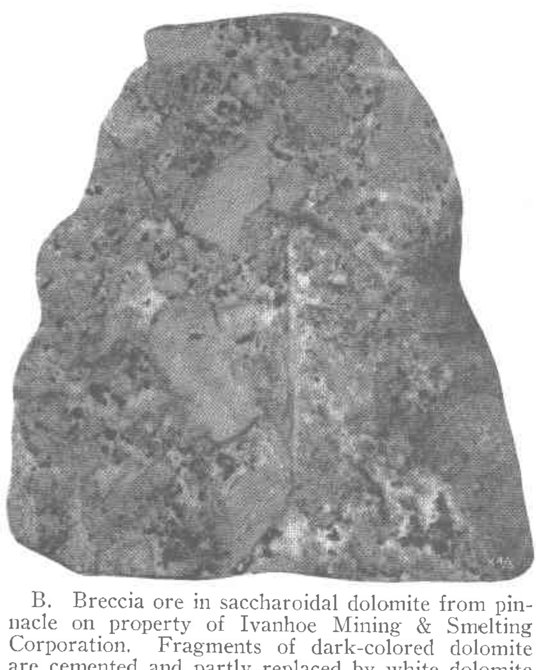

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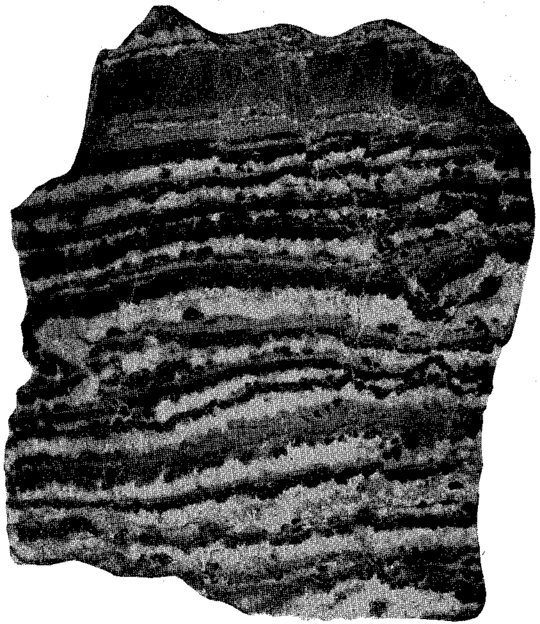
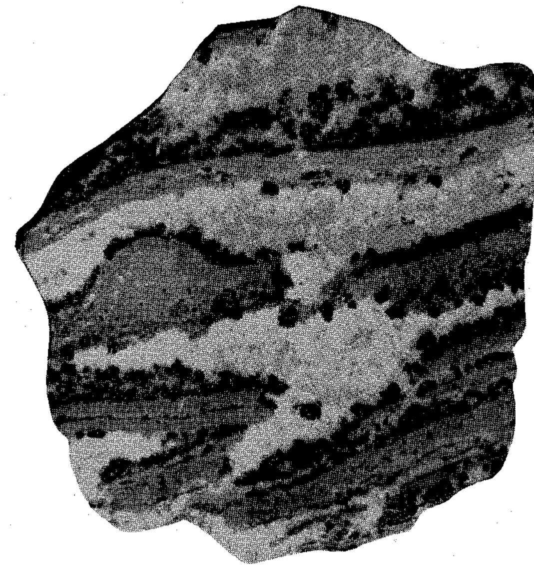


A. Banded ore from 80-foot shaft on the property of the Ivanhoe Mining & Smelting Corporation. Shows bedding replacement by coarse white dolomite and sphalerite (dark). X $\frac{3}{4}$.



B. Banded ore from Ivanhoe. Light, "gangue" dolomite; medium gray, rock dolomite; dark sphalerite. X $\frac{4}{5}$.

A. Banded ore from 80-foot shaft on the property of the Ivanhoe Mining & Smelting Corporation. Shows bedding replacement by coarse white dolomite and sphalerite (dark). X $\frac{3}{4}$.

B. Banded ore from Ivanhoe. Light, "gangue" dolomite; medium gray, rock dolomite; dark sphalerite. X $\frac{4}{5}$.

are occasional displays of ore east of this point, but of no great consequence as yet."

Overthrusting has affected the prospected area. As shown on the geologic map (Pl. 1), this deformation is related to the Laswell overthrust. The prospects are partly or wholly in thick dolomites of the Rome formation.

WYTHE AND SMYTH COUNTIES

GENERAL STATEMENT

The mines and prospects of Wythe and Smyth counties lie within the area covered by Plate 1. The geology of this area has been described in some detail in this report. As yet the only important production of zinc and lead ores in Virginia has come from mines in Wythe County, chiefly Austinville. For a few years the Bertha district produced high-grade oxidized zinc ores, until the deposits were apparently exhausted. This district produced the first zinc ores to be mined in Virginia and the Austinville district produced the first lead ores. In later decades, production for a brief period was reported from the Cedar Springs and Sugar Grove (Rye Valley) districts. At present the Austinville and Ivanhoe districts are the sole producers, and the latter has contributed so far only small amounts, chiefly oxidized ores.

As almost no underground examination of mineral territory in these counties has been possible, the mines and prospects are but briefly treated in the following paragraphs. The properties are listed successively from east to west. A great many test pits have been made from time to time in places throughout the area and doubtless some of them have long since been forgotten, so that the following annotated list, though giving an adequate picture of mineral distribution and development, may not be a complete record of all known occurrences of zinc and lead minerals in this region.

BERTHA DISTRICT

The area bounded on the east by Dry Pond Mountain, on the south by Foster Falls Mountain, and on the west and north by New River, which may be called the Bertha basin (Pl. 21, B), contains several pits from which zinc and iron ores have been mined. All the zinc ores were superficial concentrations of silicate and carbonate in the residual clays derived from weathering and leaching of the Shady dolomite. Sphalerite has been found at several places, but in quantities insufficient for exploitation. The amount of associated sphalerite in the underlying bedrock is strikingly small, and in most parts of the Bertha territory sphalerite is entirely absent or present only in traces. This leads to the belief that the zinc sulphide from which the Bertha ores were derived by oxidation either was concentrated from beds, once existing above the present surface, that have been removed by erosion and solution or was brought into this area by solutions from some other mineralized territory. The latter explanation is thought to be unlikely because of the lack of fractures which would seem to be necessary for such concentration. It is significant also that in general the pinnacles now exposed in the zinc pits of the Bertha district show a remarkable lack of shattering or other fracture phenomena. (See Pl. 22, A.) In this condition there is a suggestion that adequate circulatory channels were lacking, and the concentration may have come from beds at higher horizons. Galena is conspicuously lacking in the district. Disseminated pyrite is present but generally not prominent. Large masses of pyrite have been reported in places.

The pits of the Bertha district lie in an area where the bedrock shows low dips. Although horizontal in places, the beds conform to the broad east end of the Galena synclinal basin. There is a gentle west or southwest pitch to the basin. So far as can be discovered, the region is not much disturbed by faulting, except where the quartzite blocks bordering it on the east and south have overridden it. Possibly a normal fault or flaw of northwest trend in the northern part of the basin crosses New River between Barren Springs and Lone Ash railroad stations. Exposures in the basin are extremely rare, as the terrane is covered by a thick mantle of residual clay. Pinnacles in the pits and the scattered exposures of bedrock show, for the most part, a decided lack of the type of brecciation that is so common in other areas where sulphide mineralization is apparent, or where faults may be traced with assurance, although in a few places characteristic brecciation and cross slicing are well developed. (See Pl. 19.)

The Bertha mines were originally developed as zinc properties, but with the exhaustion of the zinc ore resources the properties were exploited for brown iron ores, with which the zinc silicate and carbonate minerals were associated. The Bertha zinc ores were noted for the purity of the zinc product.

Because of their superficial character the Bertha deposits were largely mined by open-cut methods. In places the residual clay mantle in which the ore occurred is approximately 100 feet thick, and it was found more economical to sink shallow shafts, from which tunnels that wind sinuously between and around the pinnacles were driven. The methods of mining are described and illustrated in a paper by Case.[49]

The following properties were exploited or prospected at one time or another in the Bertha district:

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[49] Case, W. H., The Bertha zinc mines at Bertha, Virginia: Am. Inst. Min. Eng. Trans., vol. 22, pp. 511-536, 1894.

Bertha mines, half to three-quarters of a mile west and northwest of Glenwood.

Falling Cliff mine, about half a mile southwest of the Bertha mines.

Manning and Squiers pits, east and northeast of the Bertha mines.

Graham and Robinson pits, about a quarter of a mile east of Glenwood.

Squiers property, near Patterson, at east end of Foster Falls Mountain.

The presence of zinc minerals has also been reported from the Forney and Sayers properties, along Little Reed Creek north of Patterson.

PROSPECT AT CARTER FERRY

About 1,000 feet west of the Carter Ferry landing, prospecting in the north wall of the ravine disclosed a mineralized breccia in the saccharoidal member of the Shady formation. The prospect is apparently a few hundred feet east of the Carter Ferry fault.

MINERALIZED EXPOSURES NEAR GALENA

At Laswell galena veinlets and sparse zinc sulphides occur disseminated in pinnacles of the Patterson member, just above the Laswell overthrust near the north side of the iron pits and about a quarter of a mile east of the highway. At this place zinc appears to have contaminated the iron ores, but no appreciable body of zinc ores was uncovered.

Traces of sphalerite have been noted in the brecciated saccharoidal dolomite along the Austinville road about a mile south of the fork between Laswell and Galena.

At the bend of the highway on the north side of New River about a mile west of Jackson Ferry traces of sphalerite were noted with abundant pyrite in the somewhat brecciated "warty" dolomite beds at the base of the Patterson member. One-third to half a mile west of this point, it is reported, some prospecting was done.

Just east of the railroad bridge over Shorts Creek at Jackson Ferry galena and sphalerite with white dolomite are exposed in a brecciated zone of the saccharoidal member. The fractured zone apparently trends at right angles to the strike and appears again in the Foster Falls road to the south, where traces of mineralization may be found.

AUSTINVILLE DISTRICT

The Austinville mine of the Bertha Mineral Co. (subsidiary of the New Jersey Zinc Co.) is just south of New River at Austinville. The property includes nearly all the territory bounded by the road leading to Ivanhoe Ferry on the southwest, the road leading southwest to Gray's School, the road leading east to Bethany, and the roads leading northwest and northeast from Bethany to Jackson Ferry and New River. The company has also prospected by drilling a small tract lying east of the State highway at Jackson Ferry, south of the low escarpment that may represent a continuation of the New Castleton fault. Within this area between Jackson Ferry and Austinville considerable drilling has been done. Mining has been confined to the vicinity of Austinville. The main plant is shown in Plate 22, B.

Several shafts have been sunk on the plateau south of New River, the main shaft to a depth of more than 700 feet. From the New River bluffs at least three adits or tunnels have been driven, one of which is nearly 1,500 feet long to the point it meets the main shaft, 235 feet below the collar. Levels are established at 100-foot intervals below the 235-foot level. The main shaft is said to reach a point nearly 500 feet below the river level.

The writer was admitted only to the top or adit level. The arrangement of stopes here seems to indicate superimposed ore (breccia) zones. It was stated that in several places a plane of movement roughly parallel to bedding was found below the ore zone.

So far as they were observed, galena and sphalerite occur in breccia, but zones of barren breccia are also present. Although the writer was not permitted to trace the breccia zones through the mine, it is apparent from the adit level drift, which follows the strike of the beds, that there is marked variation in degree of brecciation along the strike, although a breccia zone generally passes rather gradually into slightly brecciated or cracked portions. Mineralization likewise varies; it is more concentrated in highly brecciated portions and decreases without abrupt termination in many places. Hence stopes are developed at intervals along the drift, which in general follows the strike of the rock bedding. It was stated that the breccia beds and hence the contained ore bodies are lenticular both in plan and section. No information is at hand regarding the succession of ore bodies down the dip.

Crosscutting fracture systems were noted in the adit level, but it was not satisfactorily demonstrated that they were formed prior to mineralization. Some, at least, are certainly post-mineral. The surface workings show fracture systems similar in attitude to those underground, and, in part, steep crosscutting fractures at angles of 60° to 80° to the strike were found to be mineralized with galena; the zinc carbonate also present in them may, of course, represent zinc that has migrated from other places where the original mineral was sphalerite, or it may represent sphalerite deposited in these fractures. In places, however, minute cross fractures showed both zinc and lead sulphides;

this is especially true of an exposure in the bluff of New River, where sphalerite, galena, and barite occur in systems of cross fractures along which minute displacements have occurred.

The mineral association in the Austinville mine comprises sphalerite, galena, pyrite, dolomite, barite, quartz, and fluorite.

A polished surface of an ore specimen is shown in Plate 24, A.

Fluorite is reported from several places in the lower levels. Quartz is present as cherty material, apparently pre-mineral in part and post-mineral in part.

The several large surface pits have yielded large quantities of the oxidized minerals, calamine, smithsonite, and more rarely cerussite. Some of the pinnacles show considerable impregnation by sulphides. Characteristic pinnacles are shown in Plate 23, B, and a mineralized sheeted zone in Plate 23, A.

At the New River bluff slightly more than 4,000 feet due west of the main shaft the river cuts across the crest of the Austinville anticline. The dark-colored dolomite beds of this bluff show many minute fractures in and near which galena, sphalerite, pyrite, white "gangue" dolomite, and barite have been deposited. At this place, a few feet above river level, is a short tunnel, "Chiswell's Hole," said to be the point of first discovery of the lead ores in the region. The stratigraphic horizon at this point is about the top of the Patterson member as defined in this report.

About 1¼ miles northeast of the main shaft of the Austinville mine, in the west wall of Clear Branch, prospect tunnels have disclosed the presence of sphalerite, galena, and pyrite with white "gangue" dolomite in a breccia of the saccharoidal dolomite member of the Shady.

SIMMERMAN PROSPECTS

On the Simmerman property, half a mile east of Ivanhoe Ferry, in a valley tributary to New River, two prospects in the saccharoidal dolomite show the presence of sphalerite, galena, and pyrite, in the usual breccia. A feature of this occurrence is the presence of purple fluorspar.

IVANHOE DISTRICT

General features.—The stratigraphic conditions and in part the structural conditions of the Austinville area continue across New River into the vicinity of Ivanhoe, and the separation of the two districts is largely one of convenience. The Austinville anticline crosses the two bends of the river between Austinville and Ivanhoe with a pronounced southwesterly pitch. On the west side of the river it loses its identity as a simple fold by broadening, becoming flatter, and spreading into an area of broad low warpings. The type of mineralization is essentially the same in the two districts, but as yet there has been no discovery of concentration in the Ivanhoe area that is comparable with that at Austinville.

Barndollar prospect.—Just across the river from "Chiswell's Hole," in the river bluff three-quarters of a mile west by south of Austinville, two shafts about 950 feet apart have been sunk near the crest of the anticline, one on the flood-plain terrace near the river to a depth of 67 feet (collar 25 feet above the river), the other on the higher terrace to a depth of 162 feet (collar about 50 feet above the river). The bearing between the shafts is N. 47° E. The axis of the anticline trends about N. 60° E. at this point and appears to pass about 50 feet north of the lower shaft. As the dip of the rocks is about 45° SE. in the line of the higher shaft, it penetrates higher beds than the shaft on the flood plain.

These shafts were sunk in 1930 but at the time of the writer's visit were not accessible. Material in the dump shows mineralized breccias of light saccharoidal dolomite from the higher shaft and dark-gray wavy-bedded or "ribbony" dolomite (Patterson limestone member) from the lower shaft. Sphalerite, white "gangue" dolomite, barite, and finely disseminated pyrite are present. Many small pre-mineral fractures transverse to the bedding carry fragments of wall rock and minerals. In addition, sulphides follow the wavy bedding fractures and are also disseminated. (See Plate 26, B.)

Jackson prospect.—On the Jackson farm, at a point about 1,800 feet northwest of the Barndollar prospect, in the low bluff near the farm house, sphalerite shows in brecciated dolomite. Very little prospecting has been done here. The beds are in the saccharoidal member of the Shady formation, not far below the Ivanhoe limestone.

Slightly more than half a mile west of the Jackson prospect and a few hundred feet west of the limestone quarry of the National Carbide Co., a prospect shaft sunk in light-gray crystalline dolomite shows the presence of sphalerite in dolomite breccia. The stratigraphic position is within the Ivanhoe limestone member.

Price property.—On the Price property, within the town of Ivanhoe, near the hotel, oxidized zinc ores were mined in 1874-75, according to reports.

In exposures along a street north of the Price property and north of the railroad a fair showing of sphalerite appears with white "gangue" dolomite, some barite, and sparse galena in a breccia of saccharoidal dolomite. The horizon is just below the base of the Ivanhoe limestone and approximately the same as that on the Jackson farm, nearly 1½ miles to the northeast. This locality has not been prospected.

Ivanhoe Mining & Smelting Corporation.—The properties of the Ivanhoe Mining & Smelting Corporation are located in Ivanhoe, chiefly south and west of the village. They were worked originally by the New River Mineral Co. and the Lobdell Car Wheel Co. for iron ores, which were smelted at the Ivanhoe furnace. Zinc ores were known to be present, however, and recently the Ivanhoe Mining & Smelting Corporation has prospected for zinc and has produced and shipped some ores, chiefly oxidized, from the pits. No deep mining has yet been attempted, but considerable diamond drilling has been done in anticipation of underground exploitation. The deepest shaft is 80 feet deep and is 1,000 feet south of the Ivanhoe schoolhouse.

The shaft was sunk in 1914, and from it about 200 feet of drifting was done northeast and southwest along the strike of the beds. A post-mineral fault that cuts off the ore body was encountered in the southwest drift 110 feet from the shaft. Banded ore formed by the replacement of dolomite along the bedding planes by sphalerite and coarsely crystalline white dolomite was encountered in the upper half of the shaft, and brecciated gray dolomite ores in the lower half. The ores here carry sphalerite, pyrite, and a very little galena. Plates 24, B, and 25 show characteristics of the ores.

At several places on the property oxidized ores have been mined by stripping and by sinking shallow shafts; at the Church Hill workings such shafts were being sunk in the summer of 1931, and besides oxidized ores, some sulphide ores were being recovered. Plate 26, A shows ore from a prospect shaft at these workings. The horizon lies within the saccharoidal member of the Shady.

Unlike those at Austinville, the Ivanhoe operations are carried on in an area of northwestward-dipping beds, essentially the north limb of the Austinville anticline, but here somewhat modified and with lower dips. The Ivanhoe flaw, or transverse fault (p. 64), cuts across the property in a northwesterly direction, and the 80-foot shaft is close to this fault. The flaw is mineralized, as shown by drilling and by mineralized exposures of saccharoidal dolomite west of the schoolhouse.

The Church Hill workings are situated in an area of low dips (15° to 20°) and are in the block east of the Ivanhoe flaw, probably at least 1,000 feet from the fault zone.

Zinc minerals have been found at several other points on the property of the Ivanhoe Mining & Smelting Corporation west of the workings mentioned above. These localities include the Lobdell Car Wheel Co.'s pits, the Abraham Painter property, and the Quesenberry prospects.

AREA SOUTH OF CRIPPLE CREEK

It is reported that at the Porter iron pits, 1¼ miles southwest of the village of Cripple Creek, there was a showing of oxidized zinc minerals.

The iron pits of the Virginia Iron & Coal Co., 2 miles directly south of the village, are said to have produced several carloads of zinc ore. No sphalerite was seen here, but pyrite is prominent, and primary zinc sulphide may have been completely transformed into oxidized minerals. The country rock is probably dolomite in the Patterson member, but just south of the pit a heavy quartzite talus slope indicates the Lower Cambrian quartzite near by, which forms an overthrust block from the south and east, as shown by Plate 1. Dips in the dolomite area are variable but generally toward the east and southeast and indicate an overriding of the formation by the quartzite beds. The iron ore was removed almost at the fault contact. The dolomite is brecciated and carries coarsely crystalline white dolomite in bands parallel to the bedding and as the matrix of the breccia.

Mineral has also been reported[50] in Cove Branch, 4 miles east of Cripple Creek village, at a point in the Shady dolomite area half a mile south of Cove School.

SAND MOUNTAIN AREA

A prospect for lead and zinc on the Riggles property, half a mile east by south from Mountain View School, on the north side of Sand Mountain, a spur of Lick Mountain, shows brecciated dark-colored dolomite beds carrying coarse white dolomite, barite, quartz, sphalerite ("resin," very dark gray or nearly black), galena, chalcopyrite, bornite, and in places stains of malachite and azurite. The rock is chiefly a crackle breccia and is very near the contact of the Rome and Shady formations but probably is in the Shady. Sand Mountain is an overthrust block of Erwin quartzite. The fault is about half a mile south of the prospect. The character of the breccia as disclosed by the dump material and exposures suggests that this zone may be the outer portion of a brecciated zone related to a more pronounced zone elsewhere, possibly toward the major thrust at the south.

At the west end of Sand Mountain, a quarter of a mile south of Mount Ephraim Church, in the dolomite valley east of the road, a prospect discloses sphalerite in a breccia of Shady dolomite. Two pits of unknown depth have been made about 75 feet apart along a line bearing N. 55° E. The rock is white and gray dolomite of finely saccharoidal texture. It has been brecciated largely by simple cracking and carries veins of coarse white dolomite and calcite, to which the grains of light-colored sphalerite are commonly peripheral. A little milky quartz is present in the matrix of the breccia, and sphalerite and pyrite are also disseminated in the rock. The percentage of both coarse white gangue carbonate and sphalerite in the material exposed in the dump pile is comparatively low.

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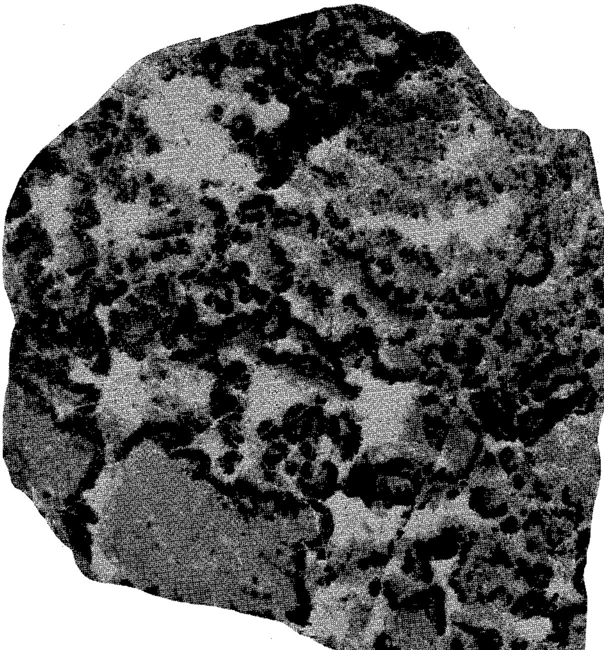
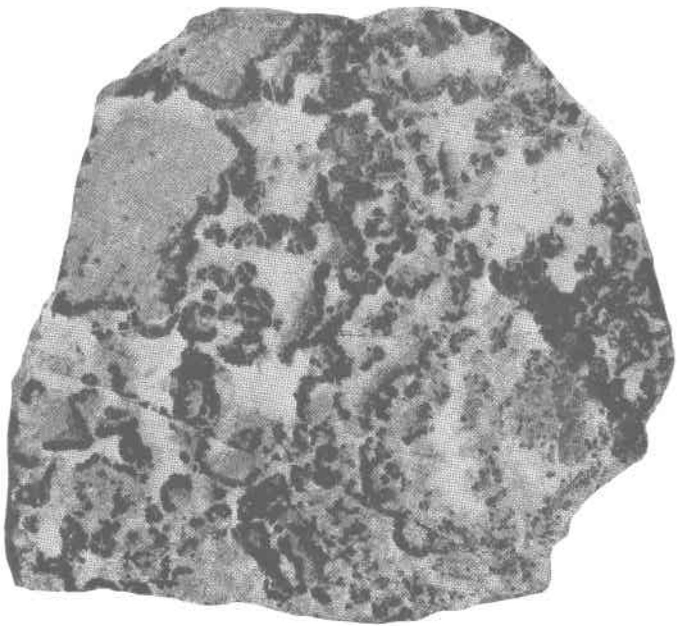
[50] See Boyd map of 1888.



A. Zinc ore from Church Hill workings, Ivanhoe. Sphalerite (dark) in gray saccharoidal dolomite (medium gray) and coarse white ("gangue") dolomite. X $\frac{7}{8}$.

B. Ore from Barndollar prospect, Ivanhoe. Sphalerite (S) and coarse white "gangue" dolomite (D) occupy a prominent cross-cutting fracture seen diagonally across the left side of the section. This fracture zone also carries fragments of the rock material (R). White dolomite and sphalerite also occupy lenticular areas that are oriented along the bedding. Several small areas of barite (B) are shown. X $\frac{3}{5}$.



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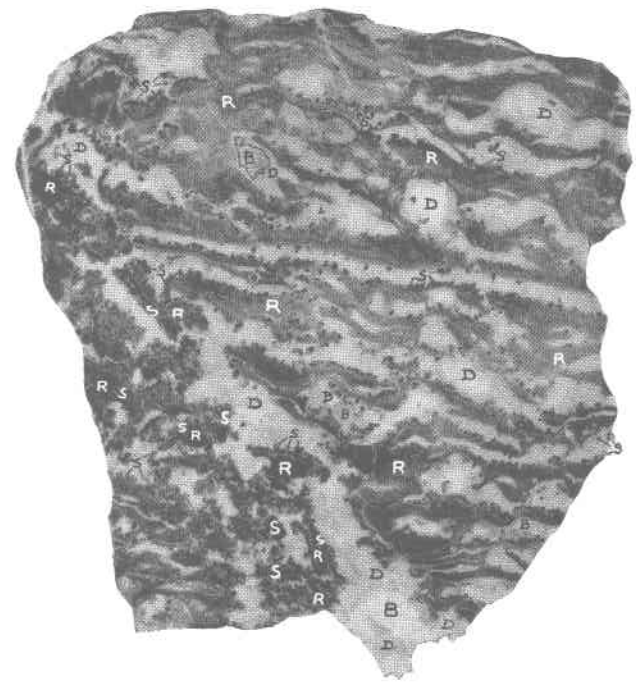

B. Ore from Barndollar prospect, Ivanhoe. Sphalerite (S) and coarse white "gangue" dolomite (D) occupy a prominent cross-cutting fracture seen diagonally across the left side of the section. This fracture zone also carries fragments of the rock material (R). White dolomite and sphalerite also occupy lenticular areas that are oriented along the bedding. Several small areas of barite (B) are shown. X $\frac{3}{5}$.

TAYLOR PROSPECT

A mile and a half S. 70° W. from the railroad station in Speedwell, at the west end of a prominent ridge, on the south side and near the top, some prospecting has disclosed zinc minerals in very dark-colored dolomite beds near the top of the Shady formation. Siliceous Rome beds cap the ridge. Sphalerite is present in a breccia of dolomite carrying white dolomite and quartz. A little galena also has been reported in this vicinity. This showing is remote from any known fault, although minor breaks may be present hidden by the deep clay covering in the valley area south of the ridge. The exposed beds in the ridge show only a moderate degree of brecciation.

CEDAR SPRINGS AREA

From a point about a quarter of a mile east by south of the mill at Cedar Springs, and extending for a quarter of a mile eastward along the strike of the beds of the Shady dolomite, a line of open cuts and prospect shafts indicates a mineralized zone from which zinc ores have been mined.

The openings were made in the Keesling property, first prospected by the Bertha Mineral Co., later operated by the Cedar Springs Zinc & Development Co. (1905) and the Columbus Mining Corporation (1907). A mill was built at this time, but apparently very little ore was treated, and since 1907 there has been no reported production from the property. Most of the work was done in an open cut 250 feet long, 10 to 25 feet wide, and about 30 feet deep, chiefly in bedrock. The clay mantle here is very thin. The beds strike N. 78°-88° E. and dip 75°-80° S. The rock is medium and dark-gray fine-grained dolomite in the Shady formation, not far below the contact with Rome beds. The beds in the vicinity of the prospect are closely folded, in places slightly overturned, and form a series of local asymmetrical compressed folds with eastward pitch. The steep fold at the open-cuts and roadside quarry is probably sheared by a steep thrust, and at points cross fracturing is evident. The exposures at the east prospect also display a small diagonal transverse thrust which, unimportant in itself, suggests the nature of some of the local adjustments that caused the pronounced brecciation of the beds in this area. The folds in this belt of exposures are not closely associated with a major thrust, although a thrust zone probably crops out about half a mile to the north. Figure 1 shows the interpreted structure in cross section, and Plate 1 indicates the broad structural setting.

The dolomite of the mineralized zone has been greatly shattered and cemented by coarsely crystalline white dolomite, forming the usual crackle and shatter breccias. The fragments are sharply angular and only slightly displaced. Cross fractures trending N. 10°-15° W. and dipping 65° W. are prominent. Sphalerite occurs chiefly in the matrix of the breccia in fractures and in part replaces the white dolomite. There is very little disseminated sphalerite within the near-by rock material. The sphalerite has unsually coarse texture, is in part light yellow, in part green, and is exceptionally pure. Pyrite and galena are very rare. Fluorite is present.

A quarter of a mile west of the open cut several pits in northward-dipping beds show the same mineralogic features.

Other prospects and reported zinc showings in the Cedar Springs area include the James property, about 1½ miles southeast of the village; the Davis property, three-quarters of a mile west of the James property and 1½ miles south of Cedar Springs, where lead is reported; the Bennington property, on Newland Creek, west of the Davis property; the Wilkinson property, 4½ miles southwest of Cedar Springs (lead); and the iron pits of the Lobdell Car Wheel Co., 5½ miles southwest of Cedar Springs and 2½ miles east by north of Sugar Grove, where oxidized zinc minerals were found with the iron ores.

RYE VALLEY MINING COMPANY

The lead mine of the Rye Valley Mining Co., Inc., is half a mile northwest of the schoolhouse at Sugar Grove. Three shafts, two of which reach a depth of 200 feet and the other 100 feet, were sunk in a low ridge on the north side of the South Fork of Holston River. The shafts are 100 feet apart along a line bearing N. 85° E., which coincides with the strike of the rocks. Very little can be seen on the surface. The rocks are dolomite beds of the Shady formation, here sharply folded and steeply inclined. Mineralization has occurred in a brecciated zone of variable width, which is reported to be as much as 23 feet but probably averages 1 to 2 feet, in dolomite below a compact fine-grained calcareous or dolomitic shale. The shafts are inclined 60° SE., following the dip of the beds. The workings could not be entered, but it is reported that at the bottom of the main shaft the vein turned upward for several feet and was abruptly terminated by a fault. Ball and Thompson[51] give essentially the section shown in Figure 2. This section has been modified slightly to accord with the surface dips on the south side of the fault.

The chief ore mineral is galena. Sphalerite is said to be present only at the 200-foot level. Pyrite is scarce. Dolomite, calcite, and fluorite are gangue minerals. According to R. N. Ward, of Sugar Grove, lump galena from this district assayed 2 ounces of galena and $6.50 in gold to the ton.

[51] Ball, S. H., and Thompson, L. H., The southwest Virginia lead-zinc deposits: Eng. and Min. Jour., vol. 102, pp. 735-737, 1916.

About 30 carloads of hand-sorted concentrate were shipped during the period of operation in the late nineties. Some years later a concentrating mill was built and the mines were reopened for a brief period, but there was practically no production.

Galena has been found in exposures along the railroad and South Fork a quarter of a mile southwest of the mine and is reported on the property of R. N. Ward, where some prospecting was done.

At a prospect pit 2,000 feet N. 85° E. from the shaft of the Rye Valley Mining Co., on the south side of the road, a thin brecciated dolomite bed below shale, carrying white dolomite and fluorite, is exposed. The stratigraphic and lithologic features are similar to those at the main shaft, but the beds here strike N. 65° E. and may be those of the section at the shaft duplicated by faulting. The distribution of beds and the pronounced variations in strike shown in the entire strip between this prospect and exposures half to three-quarters of a mile southwest of the mine clearly indicate an area of marked deformation. Together with the reported conditions in the mine, this is interpreted to indicate a local zone of minor thrust faulting. A major thrust zone with northeast trend is exposed between the mining property and the village of Sugar Grove.

CALHOUN PROSPECT

The openings made on the Calhoun property (Virginia Lead & Zinc Company, 1904), 2 miles west of Sugar Grove post office and about 500 feet north of the railroad at Teas, comprise a shaft and two pits. Exposures show Shady dolomite beds striking N. 65° E., with variable dips, but averaging 80° SE., in part much fractured. The breccia is of the shatter type. Milky quartz is present with white dolomite in the fractures. Mineral showings are scarce. No lead was found here.

SCOTT PROSPECT

The Scott prospect (Virginia Lead & Zinc Company, 1904, 1905), is 0.8 mile west by south from the Calhoun prospect. The workings are at the base of a low knoll on the west side of a small bend in the South Fork of Holston River. An inclined shaft here is reported to be 40 feet deep. The rocks dip steeply to the southeast. The dump material shows shatter breccia of medium-gray and dark-gray finely crystalline dolomite, cemented by coarse white dolomite. Coarse light-yellow sphalerite of the Cedar Springs type is present. No galena was seen. An analysis of the sphalerite given by Watson[52] shows it to be exceptionally pure, carrying more than 99.5 per cent of ZnS.

[52] Watson, T. L., The lead and zinc deposits of Virginia: Virginia Geol. Survey Bull. 1, p. 109, 1905.

A showing of zinc was also reported a quarter of a mile southwest of the prospect. A prominent thrust fault zone, the Teas fault, crops out about an eighth of a mile south of this locality.

LIVESAY PROSPECT

The Livesay prospect (Virginia Lead & Zinc Co., 1905), is in the bluff on the south side of the South Fork of Holston River, 1½ miles southwest of the Scott prospect. It is reported that both galena and sphalerite have been found here, but none were noted. The usual breccia with white dolomite is seen here. The location is on the line of continuation of the Quebec thrust fault, which is exposed about 1 mile to the southwest.

McCARTER PROSPECT

In 1905 several openings were made on the McCarter and adjoining properties at Quebec, about three-quarters of a mile southwest of the Livesay prospect. Here the usual breccia of Shady dolomite cemented by white dolomite has been formed in a fault zone and mineralized by sphalerite and fluorite. According to Watson,[53] the shaft showed the fault plane intersecting the beds at a sharp angle (15°), the fault having the steeper dip and forming the footwall of the breccia zone.

The Quebec fault zone crops out on the south side of the property, and the Teas fault less than a quarter of a mile to the south.

EXPOSURE WEST OF McCARTER PROSPECT

Two miles directly west of Quebec on the east side of the highway sphalerite and white "gangue" dolomite in the basal Shady beds are exposed along the road just above the contact with the Erwin quartzite. A thrust fault on which the Van Hoy prospect is situated is exposed an eighth of a mile north of this point.

VAN HOY PROSPECT

The Van Hoy prospect is 1¾ miles N. 80° W. of the McCarter prospect, at the base of the north slope of a quartzite ridge which has been overthrust upon Shady dolomite. A little blende was found, but the present showing is unimportant.

MARTIN PROSPECT

About 2 miles southeast of Adwolf several openings were made on the Martin property. Traces of sphalerite and galena were found. The location is within that part of a broad area of Shady outcrops where an anticline is indicated by the dips.

[53] Watson, T. L., The lead and zinc deposits of Virginia: Virginia Geol. Survey Bull. 1, p. 110, 1905.

SHOWINGS OUTSIDE THE MAPPED AREA

Lead and zinc minerals have been reported from the Barlow place, 2 miles southeast of Love's Mill and 3 miles southwest of Adwolf; the Osborn and Schaler properties, 4 miles west by south of Quebec; and the former Henderson place, in a ravine on the north side of Iron Mountain 5 miles southwest of Quebec.

TAZEWELL COUNTY

A lead-zinc prospect occurs in dense limestones in the base of the Nolichucky shale 1 mile southeast of the village of Cedar Bluff, about 12 miles west of Tazewell. The location is just south of the trace of a major overthrust that brings the Rome (†Russell) formation (Lower and Middle Cambrian) and the Copper Ridge dolomite (Upper Cambrian) upon Devonian shale. The location is in the Tazewell quadrangle, and the general geology of the area is described in the Tazewell folio of the Geologic Atlas of the United States.[54]

Zinc minerals are also reported by Boyd at a point 2 miles east of Springville, "near the end of Taylor's Ridge."

BLAND COUNTY

Showings of sphalerite and galena have been reported from the vicinity of Kimberling and No Business creeks, where they are associated with pyrite in limestone. A specimen of sphalerite from a point on No Business Creek above Holly Brook was reported to contain 4.44 per cent iron.[55] Oxides of iron and manganese are reported in association with the zinc minerals.

RUSSELL COUNTY

The Osborn zinc mine is on the George Osborn place, 7 miles south of Castlewood,[56] a quarter of a mile south of Copper Creek. The opening was made at the top of the Maryville limestone, just below the contact with the Nolichucky shale. A major thrust fault crops out just north of Copper Creek. The location is within the Bristol quadrangle, and the general geology is described in the Bristol folio.[57]

According to Watson, the ores were obtained chiefly from a large open pit and associated tunnels. The ore minerals were calamine, galena, and sphalerite. The property was operated about 1900 and later taken under option by the Bertha Mineral Co. Still later title reverted to the original operators.

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[54] Campbell, M. R., U. S. Geol. Survey Geol. Atlas, Tazewell folio (No. 44), 1897.
[55] Notes of C. E. Siebenthal, U. S. Geol. Survey.
[56] Watson, T. L., op. cit., p. 113.
[57] Campbell, M. R., U. S. Geol. Survey Geol. Atlas, Bristol folio (No. 59), 1899.

SCOTT COUNTY

The Bowman prospect is on the Frank Bowman farm, about 1½ miles northwest of Arcadia, Tennessee. Several pits and shafts were sunk along the mineralized horizon for a distance of a quarter of a mile. At one point a vein of massive sphalerite 6 to 8 inches thick was seen.

At this locality, a steep, strike thrust fault brought Nolichucky shale in the south, into contact with Copper Ridge dolomite. The dolomite was brecciated and mineralized with sphalerite, coarse white dolomite, some pyrite, and traces of chalcopyrite. Additional data are given by Secrist.[58]

[58] Secrist, M. H., Zinc deposits of east Tennessee: Tennessee Dept. Education, Div. Geology Bull. 31, pp. 33-37, 1924.

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APPENDIX A—TERMINOLOGY

In the foregoing description of the lithology of formations and sections certain terms are used which should be defined, not because of marked departure from common usage but because of definite limitations and consistency of use that are not general in the literature. Lithologic, structural, and textural terms are especially subject to either a too general application or an ambiguous use. Throughout the formational descriptions the writer has used these terms in the following sense.

1. **Textural terms.**—Refers to the grain pattern and grain size:

Granular.—Composed of individually visible grains. These grains may be *clastic* or *crystalline.*

Dense.—As opposed to granular refers to a mass wherein grains are so small as to be individually invisible to the unaided eye, the whole presenting a "stony" or aphanitic aspect.

Crystalline.—The individually visible grains display partial or complete geometrical outlines, such as are possessed by crystals, or else show by reflecting plane surfaces (cleavage faces) or cleavage traces that they are individual partial crystals, interlocking to form the mass.

Clastic.—The individually visible grains show by the irregularity or rounded character of their outlines and absence of interlocking that they are fragments in the exact sense of the term, held together ("cemented") by other dense or granular material.

Relative degrees of granularity are expressed by the following terms:

	Size (millimeters)
Very fine	Less than 0.5
Fine	0.5 to 1
Medium	1 to 2
Coarse	2 to 3
Very coarse	3+

The grain sizes indicated are given for the purpose of definite expression. In the field the grain sizes are not measured but are estimated so that the limitations given above are subject to personal and practical flexibility. For example, a rock texture described as medium crystalline signifies a granular mass in which the grains are of crystalline character and are judged to average between 1 and 2 millimeters in diameter.

2. **Massiveness or degree of massivity.**—The stratified character of sedimentary rocks imposes a structual weakness between layers whereby the rock cleaves or develops a jointing parallel to the bedding.

This may be termed bedding cleavage, or, where joints are developed, bedding jointing. The perfection of such planes and their spacing is dependent upon several factors, including porosity, variation in grain size, and others. Terms of massivity are used to describe in general the uniform continuity of characteristics. In sedimentary rocks, as there is generally a fair degree of uniformity along the bedding—that is, within a single lamination—the term describes essentially the frequency of structural failure, as expressed by jointing or cleavage, across the bedding. The following terms are used herein to describe the degree of massivity as displayed by such breaks. These terms are qualitative and relative. In the field the spacings have been estimated, but not measured. The figures of measurement are used solely for definitive purposes.

Shaly.—Very thin bedding cleavage, forming scales or extremely thin plates up to approximately a quarter of an inch thick. Characteristically displayed by argillaceous rocks.

Platy.—Plates up to about 2 inches thick; modified by the terms *thin* and *thick,* representing extremes.

Blocky.—Blocks between 2 and 6 inches thick, measured across the bedding; modified by the terms *thin* and *thick,* representing extremes.

Massive.—Blocks more than 6 inches thick, measured across the bedding.

3. **Color.**—Little definition is needed for terms denoting colors, except in the use of adjectival modifiers for depth of shade. As applied to the rocks of various gray shades, the following series was used for successive depths of shade between the limits of white and black: *white, light gray, medium gray, dark gray, black.* The unmodified term gray indicates a variability or mottling.

INDEX

STATE COMMISSION ON
CONSERVATION AND DEVELOPMENT

VIRGINIA GEOLOGICAL SURVEY
ARTHUR BEVAN, STATE GEOLOGIST

BULLETIN 43 PLATE 1

GEOLOGIC MAP AND INTERPRETATIVE GEOLOGIC CROSS SECTIONS ZINC AND LEAD REGION OF SOUTHWESTERN VIRGINIA

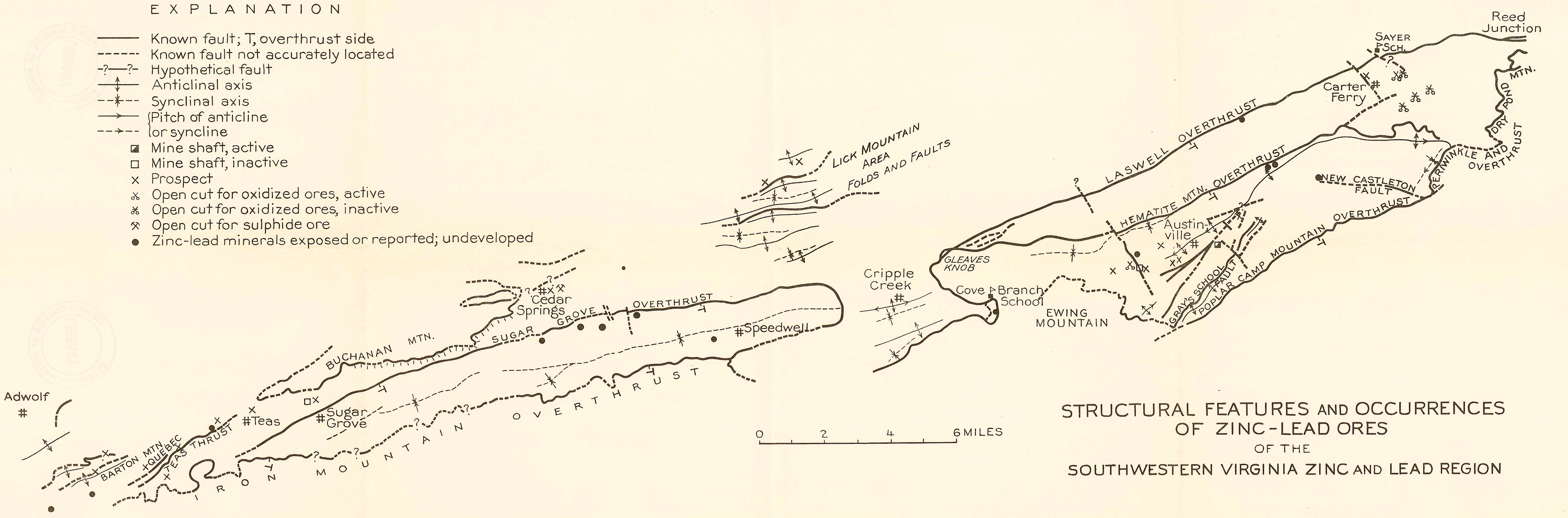
BY

L. W. CURRIER

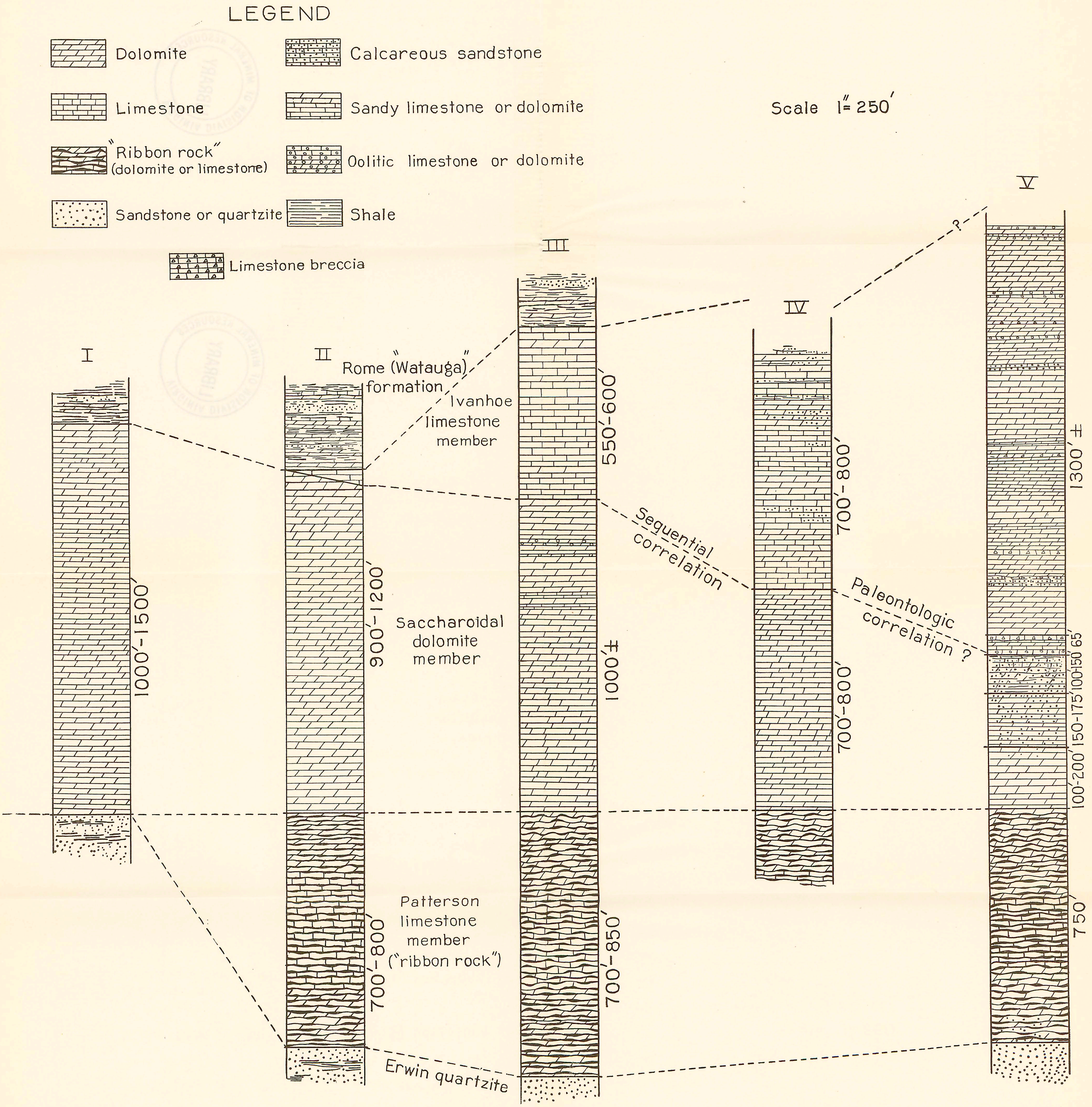
Surveyed in cooperation with
The United States Geological Survey
1930-1931

1935

Base from United States Geological Survey
Topographic maps.



STRUCTURAL FEATURES AND OCCURRENCES OF ZINC-LEAD ORES OF THE SOUTHWESTERN VIRGINIA ZINC AND LEAD REGION



COLUMNAR SECTIONS OF THE SHADY DOLOMITE

The sections, somewhat generalized, show variations from northwest to southeast across the area. 1, Northern belt; 2-5, southern belt; 1, Quebec-Lick Mountain; 2, Porter to southeast of Cedar Springs; 3, Ivanhoe, north limb of Austinville anticline; 4, Austinville, south limb of anticline, northern part of basin; 5, Austinville, southern part of basin.