

VIRGINIA DEPARTMENT OF AGRICULTURE
AND IMMIGRATION

GEOLOGICAL SURVEY OF VIRGINIA

THOMAS L. WATSON, GEOLOGIST IN CHARGE

GEOLOGICAL SERIES, BULLETIN No. 1.

Lead and Zinc Deposits of Virginia

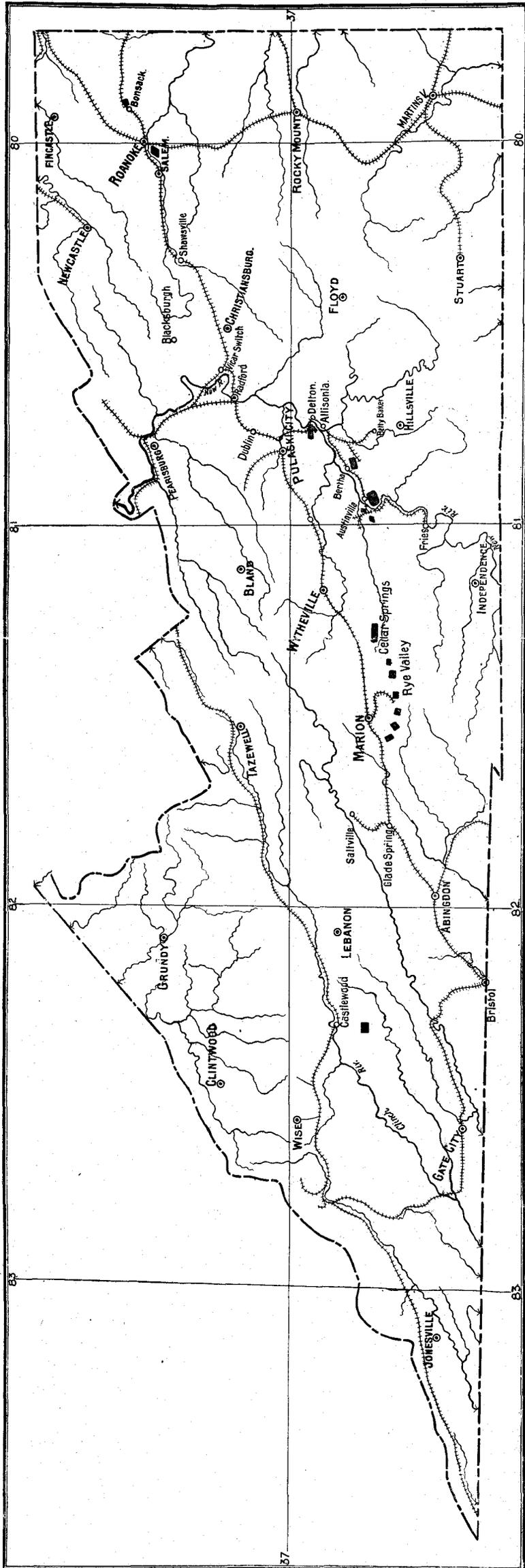
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MAP SHOWING LOCATION OF LEAD AND ZINC DEPOSITS OF SOUTHWEST VIRGINIA.

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VIRGINIA DEPARTMENT OF AGRICULTURE AND IMMIGRATION,
Richmond, Virginia, July 6, 1905.

In the summer of 1904 arrangements were made by the Virginia Board of Agriculture and Immigration, and the Board of Visitors of the Virginia Polytechnic Institute, for a Geological Survey of the mineral resources of Virginia. In accordance with this arrangement Dr. Thomas L. Watson, Professor of Geology in the Virginia Polytechnic Institute, was appointed Geologist in Charge of the Survey. Dr. Watson entered at once upon a field study of the Zinc and Lead Deposits of the State, devoting the latter part of the field season of 1904 and a part of the spring of 1905 to this problem. The field work was supplemented during the winter of 1905 by a chemical and microscopical study of the material collected during the summer and fall of 1904.

The results of this careful study of the zinc and lead deposits of the State are embodied in the present report, which is published as Volume I of the Geological Series of the Survey. The increasing demand for information on the zinc ores of Virginia makes this report especially opportune at this time, and it has been prepared to meet the needs of those seeking information on the Virginia deposits.

Committee of Publication:

J. M. MCBRYDE,

Member of Board of Agriculture and Immigration.

G. W. KOINER,

Commissioner of Agriculture and Immigration.

LETTER OF TRANSMITTAL

To the Members of the Virginia Board of Agriculture and Immigration and the Board of Visitors of the Virginia Polytechnic Institute:

GENTLEMEN—I have the honor to submit herewith a report on the Zinc and Lead Deposits of Virginia, and to request that it be published as Volume I of the Geological Series of the Virginia Survey.

Respectfully,

THOMAS L. WATSON,

Geologist-in-Charge.

Blacksburg, Va., July 6, 1905.

LEAD AND ZINC DEPOSITS OF VIRGINIA

INTRODUCTION

This report forms the first one of a series to be published on the geology of the mineral resources of Virginia. At present, field work is in progress on the following subjects, which as soon as completed separate reports will be published on them: Water Powers, Brown Iron Ores, Clays and Clay Industry, Cement Materials and Industry, and Building Stones. This report is based on the results of a field study of the lead and zinc region of Virginia, during the months of August and September of 1904, and a part of the spring of 1905. All the known deposits of these two metals in the State were visited and the district as a whole was studied as carefully as the time permitted. Specimens of the ores and the associated rocks were collected and studied both chemically and microscopically in the laboratory, and a large amount of chemical data in the form of analyses is incorporated.

Because of the active interest which is being manifested in the zinc deposits of Virginia, this report is published with the hope that it will be of service to those who may be engaged in the exploration for zinc, or who may be interested in the material development of that part of the State in which the deposits are found.

Establishment of the Survey and Acknowledgments.—At a meeting of the State Board of Agriculture held in Richmond the early part of August, 1904, an appropriation was voted for the purpose of making a geological survey of the mineral resources of Virginia. In order to further expedite this very important work and to increase the facilities for conducting it, the Board of Visitors of the Virginia Polytechnic Institute set apart the necessary laboratory space and equipment for adequately conducting the laboratory study, chemical and microscopical, of all material collected by the geologists in their field study of the various problems. The Professor in charge of the Department of Geology and Mineralogy in the Virginia Polytechnic Institute was appointed Geologist in charge of the Survey. The Survey is, therefore, under the direct supervision of the State Board of Agriculture and the Virginia Polytechnic Institute. The importance of such work to the State

of Virginia cannot be over-estimated, and too much credit cannot be accorded the gentlemen composing the two Boards for their action and recognition of a work which has been so greatly needed and yet entirely neglected by the State since the Rogers Survey from the years 1835-1841 inclusive.

To the gentlemen composing these two Boards the writer wishes to make very grateful acknowledgment for making the work possible. To the President of the Virginia Polytechnic Institute, Dr. J. M. McBryde, the writer owes more than he can acknowledge, for to him more than to any single individual is due whatever of value there may be in this report. He has had the counsel and guidance of Dr. McBryde throughout the work, which he most gratefully acknowledges. In the spring of 1905 the writer had the pleasure of visiting the Virginia-Tennessee lead and zinc region in company with Mr. H. Foster Bain of the U. S. Geological Survey, to whom he is indebted for many helpful suggestions. Especially indebted is he to Mr. Bain for the half-tone illustrations used in this report, from photographs taken on our visit over the area during the spring of 1905.

To Dr. W. E. Barlow, Mr. J. R. Eoff, Jr., and Mr. J. H. Gibboney, the writer is indebted for the many accurate chemical analyses used in this report.

The cordial interest shown in the work by the people of the lead and zinc district, and their willingness to coöperate in any way whatsoever, have been constant sources of encouragement and help to the writer. To name all of these would make too long a list, but to Mr. C. M. Hicks of Austinville, and Mr. J. D. James of Pulaski, the writer is especially indebted for many courtesies.

HISTORICAL

The lead and zinc mines of Virginia may be grouped into two divisions: (1) Those of Southwest Virginia, limited to the Great Valley region; and (2) those of the Crystalline belt or Piedmont region, east of the Blue Ridge mountains. Barring the slight production of these ores from the Faber mine in Albemarle county, near the western margin of the Crystalline area, practically the total production of these ores in Virginia has come from the Southwest Virginia area.

The first authentic records of lead mining in Virginia seems to date back more than 150 years, and the Austinville mines in Wythe

county, Southwest Virginia, were the site of the first work. Surface exposures of the ore in the limestone decay led to the discovery of the metal in this locality. Who the first discoverer was the writer has been unable to find out. Colonel Chiswell, a native of Wales and one of the earlier adventurers in Southwest Virginia, appears to have been one of the first operators of the Austinville mines. His operations at Austinville commenced in the year 1750 and closed shortly after the beginning of the Revolutionary War in the year 1776, covering a period of about 25 years. From that time to the present day mining has been carried on almost continuously in the Virginia area.

Systematic mining in the Wythe county area dates back about 75 years. At that time the larger portion of the lead produced by the Wythe county mines is reported to have been hauled in wagons to Baltimore, Maryland, a distance of several hundred miles. In the year 1843 the Wythe Lead Mines Company, which had acquired possession of the Austinville mines, commenced the manufacture of shot. For many years thereafter much of the lead produced from these mines was made into shot of very excellent quality and an air-shaft, 262 feet deep, was utilized as the shot tower.

For a long period of years after the Virginia mines had been operated, the zinc ores were either unrecognized, or, if recognized, they were regarded as of little value. Hence, the early work was confined exclusively to that of mining lead and the leaving behind of the zinc ores. The mining of zinc ores in this region dates back to the year 1879, when the Bertha mines were first opened and a small shipment of the ore was made to Providence, Rhode Island. Since that time the production of zinc ores has increased and that of lead ores has proportionately decreased until, for some years, the Virginia mines have been more important as a source of zinc than of lead.

Much if not most of the ores yielding the lead made into bullets for use by the Confederate soldiers in the Civil War was produced by the Virginia mines, principally those of Wythe county, with some from the mines near Faber, in Albemarle county.¹ Ore was first discovered on the property near Faber, in Albemarle county, in the year 1869.

The ores mined are calamine, hydrous silicate of zinc; smith-

¹ For a more complete historical description of the Wythe and Albemarle county lead and zinc mines see pages 56-57 and 68-71 of this volume.

sonite, carbonate of zinc; sphalerite, sulphide of zinc; galena, sulphide of lead; and cerussite, carbonate of lead. In order of production calamine and smithsonite have been the most important ores of zinc, and sphalerite of less importance. In the future, however, sphalerite will undoubtedly form the important source of zinc from the Virginia mines.

PREVIOUS WORK

No systematic report treating of the zinc and lead deposits of Virginia as a whole has been published. Numerous papers, usually brief in character, have been published from time to time by various writers on individual mines, particularly those of Wythe county, which treat more especially of the economic and engineering phases of the properties than of the geology. There are, however, several noteworthy exceptions to this of papers published in which much geological information that is of value has been developed.

Numerous papers have been published on the geology of Southwest Virginia, but with several exceptions these do not bear directly on the geology of the immediate localities of the zinc and lead deposits and, therefore, are not noted in the bibliographical list appended below.

Four of the folios of the Geologic Atlas of the United States, published by the United States Geological Survey, have been completed for parts of Southwest Virginia; and they include areas in part over which some prospecting for zinc and lead has been done. These are the Pocahontas, Tazewell, Bristol and Estillville folios. They contain topographic sheets, areal and economic geologic sheets, and structure sections of the areas studied, with descriptive text.² The folios do not cover, however, any portion of the present productive area of the zinc and lead deposits in Virginia

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The list which follows below includes all titles of the principal papers published relating to the zinc and lead deposits of Virginia.

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²These folios may be obtained from the Director of the U. S. Geological Survey Washington, D. C. The price is 25 cents each.

- The Mineral Wealth of Southwestern Virginia. Transactions, American Institute Mining Engineers, 1877, Vol. 8, pp. 338-348; *Ibid.* Vol. 5, p. 81.
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USES OF ZINC

Zinc has a bluish-white color when pure, and a specific gravity of 6.86 to 7.3. At the ordinary temperature zinc is quite brittle. Between temperatures of 100° and 150°C. it can be rolled into thin sheets, but above 200°C. it becomes brittle again. It melts at a low temperature, 412° to 434°C., and it boils at a temperature of 1040°C. When heated in the air it burns with a bluish flame, forming zinc oxide. Zinc alloys readily with the common metals, forming with copper a number of alloys known as brass.

The use of zinc in the arts and its production on a commercial basis is of comparatively recent date.³ Zinc was first manufactured in America at the Government Arsenal in Washington about 1838. However, the putting into practice the principle upon which the modern process of zinc smelting is based, was discovered in Silesia in 1799, or thereabouts.⁴ In America oxide works were established in 1851, although the regular manufacture of spelter did not begin until later, 1858-1860.⁵ In 1903, 59,562 short tons of zinc oxide and 159,219 tons of spelter were manufactured.⁶ In 1904, the production of spelter amounted to 186,702 short tons.*

Zinc is used for a great variety of purposes. The Mineral Industry for 1899, Volume VIII, estimated that of the spelter consumed in the United States in 1899, 50 per cent. was used in galvanizing; 15 per cent. in brass making; 20 per cent. in the form of sheet; and 15 per cent. for other purposes which included a great variety of minor uses. It will be observed from this that the most important use for spelter is in galvanizing.

Zinc oxide, commercially known as zinc white, is made from the spelter in Europe; but in the United States it is made directly from the ore. At Austinville, in Wythe county, Virginia, the lower grade ores are being used in making zinc oxide, and the oxide is charged in the furnaces at Pulaski for making spelter. Zinc oxide or zinc white, is used chiefly as a pigment, either alone or mixed with white lead or barytes. It is also used less extensively in the manufacture of rubber goods.

The higher grade of Virginia spelter, made by the Bertha Mineral Company, at Pulaski, Virginia, is sold largely abroad for use in government work, for use in bronzes and brasses, and for friction metal. The lower grade spelter is used chiefly for galvanizing, although for some uses in galvanizing the higher grade has distinct advantages over the lower grade; such as for galvanizing telephone wire, which will admit of more bending when coated with the higher grade metal than when the lower grade is used.

³ Ingalls, W. R., *Production of Zinc*, 1902, pp. 1-6.

⁴ Ingalls, W. R., *Op. Cit.* p. 4.

⁵ Ingalls, W. R., *Op. Cit.* p. 14.

⁶ Kirchoff, Charles, Quoted by H. F. Bain in *Bulletin No. 246, U. S. Geological Survey*, 1905, p. 12.

* *Mining Magazine*, 1905, Vol. XI, p. 771.

PRODUCTION

The production of zinc in Virginia properly dates back to the very beginning of the mining of the ores in the State in 1879, when the Bertha mines were first opened. Mining of the ores in Virginia has continued from that date to the present, the output being greater in some years than in others. It is impossible, however, to give accurate figures for either the total production, or the production by years for any period of consecutive years, of the Virginia mines. The years for which statistics of zinc ore production in the Southeastern United States are available, the production in Virginia is combined with that of Tennessee and the two States are rated together as one area. The Mineral Industry, Volume II, gives the annual production of zinc ore in Virginia and Tennessee from 1887 to 1893 as follows:

<i>Years</i>	<i>Tons (2000 lbs.)</i>
1887	8,420
1888	11,500
1889	12,906
1890	14,969
1891	20,286
1892	20,295
1893	21,000

The same authority states that Tennessee produced 3,799 tons of blende, zinc sulphide, in 1899, and 3,968 tons in 1900. There are no recent statistics of the production in Virginia, but the annual output from the Virginia mines from 1894 to 1903 inclusive, would probably not exceed 15,000 tons. Practically the entire production from the Virginia mines, from the beginning in 1879 to the present time, March 1905, consisted of the soft ores, carbonate, smithsonite; and silicate, calamine, largely the latter, assaying about 40 per cent. metallic zinc.

In 1893, the Bertha mine alone, in Wythe county, Virginia, was producing 200 tons of ore per day, hoisted from 17 shafts, with a working force of 300 men.⁷ This mine was reported at that time as yielding 12,000 to 15,000 tons of unwashed ore to the acre, and the ground was reported as being worked over at the rate of from three to four acres per year. The zinc ores are now regarded as having been practically exhausted at the Bertha mine, and the

⁷ Moxham, E. C., Engr. and Ming. Jour. 1893, Vol. LVI, p. 544.

mine is being worked at present for brown iron ore. Working out of the ore at Bertha has been followed by a decrease in production of zinc ores in Virginia. This condition has been productive of more systematic search than formerly for new deposits of zinc ore over the Virginia district, and at present much prospecting is in progress over parts of Southwest Virginia. Recent exploitation has by no means been in vain; and while the development work has not been carried far enough in some places, it has in others, and it is believed that in the future the production will entirely equal if not exceed that of former years. However, the main production in the future will be of original sulphide ores, blende, and not, as in the past, of soft ores, silicate and carbonate.

THE GEOGRAPHICAL AND GEOLOGICAL DISTRIBUTION OF THE LEAD AND ZINC DEPOSITS

Geographical Distribution.—Excepting the single deposit in the extreme southwestern part of Albemarle county, the known workable deposits of lead and zinc in Virginia are limited to the Great Valley province west of the Blue Ridge. This province crosses the State in a general northeast-southwest direction. All mining and prospecting for lead and zinc ores in the Valley province have been confined to its southwestern half, extending from and including Roanoke county on the northeast, to and including Scott county on the southwest. Ores both of lead and zinc are known to occur either sparingly or in quantity in the following southwestern counties of the State: Roanoke, Montgomery, Pulaski, Wythe, Smyth, Bland, Tazewell, Russell and Scott. Of this number, only one county, Wythe, has shown as yet producing mines. More or less prospecting has been attempted, however, in a majority of the counties named, and very small amounts of the ores have been mined in a number of them. At present prospecting is in progress in the southwest corner of Wythe county at Cedar Springs, and ten miles west at Rye Valley in Smyth county. The conditions are very encouraging at both localities.

It can be definitely stated that perhaps in a majority of the localities where lead and zinc ores have been noted in the counties of Southwest Virginia, the occurrence of these amounts to scarcely more than a trace, and that workable deposits of them do not occur. In a number of localities, however, indications appear favorable to

the existence of workable deposits of the ores, though developments are lacking upon which to base a definite statement.

Sparing amounts of lead sulphide, galenite, are known to occur in many of the counties in the Piedmont region of Virginia east of the Blue Ridge, more especially in association with the ores in some of the gold and copper mines. Possibly with one or two exceptions, workable quantities of lead ore do not occur over this area of the State. Thus far Albemarle county furnishes the only locality in the Piedmont region where lead and zinc have been mined. A description of the Albemarle mine is given on pages 56-67 of this report.

Geological Distribution.—The occurrence of zinc and lead ores in Southwest Virginia is limited to the magnesian limestone of Cambro-Ordovician age, known as the Shenandoah limestone. As elsewhere shown in this report the Shenandoah limestone is the equivalent of the Valley limestone or formation No. II of Professor Wm. B. Rogers. The known workable deposits of zinc and lead ores occur near the eastern side of the Valley, though several promising prospects are opened near the western side. Vertically they are found in the limestone from near the bottom to the top. Lead and zinc ores have been reported from a limestone in Southwest Virginia of Lower Helderberg, Lewistown, age, but this needs further study and confirmation.

Where observed, the occurrence of lead and zinc ores over the Piedmont region, is in micaceous schists of different mineralogical types. The exact age relations of which have not yet been determined, but were grouped by the older geologists as Archæan.

ASSOCIATION OF THE LEAD AND ZINC ORES

As a rule, the ores of lead and zinc are intimately associated over the Virginia area; where the ores of zinc occur those of lead are likely to be intermingled in more or less quantity with the former. This is naturally what would be expected, but the zinc ores are the dominant ones in the Virginia localities. Not in a single instance where developments have been at all extensive do ores of lead occur in quantity sufficient to justify the working of them alone. On the contrary the properties have proved to be, in each case, zinc properties with more or less of the lead ores intimately associated with those of zinc. The two mines which practically produced all

the lead mined in the State when first opened, the Austinville mines in Wythe county and the Faber mines in Albemarle county, have proved on depth to be zinc properties. Lead ores are still found in the mines of these two counties but the dominant ores are zinc.

GENERAL GEOLOGY

Physiography

The Virginia lead and zinc deposits are, with one exception, limited entirely to the Great Appalachian Valley of Southwest Virginia, which is bounded on the southeast and northwest, respectively, by the Blue Ridge and the Cumberland Plateaus. The Appalachian Valley forms a long, narrow belt, whose general surface is depressed below that of the highlands on either side. It has a general north-east-southwest trend which conforms to the structural axes of the Appalachians. It is not a simple valley, but is a structural belt of marked irregularities, composed of successively smaller valleys separated by moderately high and fairly steep-sided ridges, which in many places present a relief of as much as a thousand feet and more. When studied in detail the general surface of the Valley is very different in different localities. In places the surface relief is not great, while over much of the belt the surface is rougher and in places is so rough and broken that it is difficult to cross.

The Valley shows a gradual increase in altitude of 2000 feet at the Tennessee-Virginia line to 2500 or 2700 feet at its highest point on the divide between the New and Tennessee rivers. From this point it descends to 2200 feet in the valley of New river to 1000 or 1500 feet in the James river valley.

The Valley occupies a belt of intensely folded strata, which in many cases have been broken across and thrust for considerable distances out of their original position. It owes its characteristic features directly to the structure and character of the rocks. The valleys are usually deep and narrow and have been determined by the soft and weaker underlying shales and limestones. The form and altitude of the ridges are determined by the character of the rock and the position of the strata composing them. In other words the lines of drainage over the region are well adjusted to the rock structure. The streams have established their courses largely on the soft rocks, shale and limestone, which form the valleys, and

they have avoided the harder and more resistant rocks such as sandstone and quartzite, which are ridge forming.

The Appalachian Valley has been a land area since early Mesozoic time. During this time the region has not remained stationary with respect to sea level, but field evidence indicates several periods of uplift followed by intervals of quiescence. Each period of elevation caused increased activity to the streams and to the atmospheric agents in general, which resulted in the lowering or down-wearing of the surface. The periods of quiescence which followed each uplift, were sufficiently long to enable the streams to establish a system of base-levels over the entire region; and the region was also stationary for a time sufficient to admit of the interstream areas being lowered to an approximately uniform level. The harder and more resistant rocks, such as sandstone and quartzite, were never entirely reduced, but they mark partially unreduced residuals which stand in relief above the general level of the erosion plane.

Accordingly, evidence favoring several periods of base-leveling and planation is recorded over the Virginia area. The oldest and most extensive peneplain was probably formed in Cretaceous time. The surface of the Cretaceous peneplain is believed to be marked by portions of the crestline of Cove, Little Walker, Big Walker, Rich, and East River mountains over the central and western parts of the Southwest Virginia Valley region. The period of quiescence which resulted in the formation of the Cretaceous peneplain, was interrupted by a gradual uplift which raised the surface much above its former position. This elevation was not equal over all parts of the region and the plain was warped by differential uplift. Following this period of uplift were periods of quiescence of shorter duration, which resulted in the formation of other peneplains during the Eocene and Neocene periods. More recently the region has again been elevated and the major streams have cut down their valleys nearly or quite to base-level.

Drainage.—The Appalachian Valley region of Southwest Virginia is included mostly within the basins of the New and Holston rivers, and is drained by them and their tributaries. A part of the eastern portion of the region is within the basin of Roanoke river and is drained by its tributaries. The southwestern part of the Valley, in Virginia, is drained by Powell, Clinch, and Holston rivers and their tributaries, which flow in prevailing southwesterly courses. New river crosses the Valley region in a

general north-south direction and has cut across the numerous ridges forming deep and narrow V-shaped gorges. Its tributaries, which enter from the east and west sides, flow in many cases for long distances, approximately along the strike of the rocks. In many instances, however, the tributaries have turned and cut across a bounding ridge to again take up its course along the strike of the rocks on the opposite side of the ridge. The Roanoke river, formed by several branches which head in the Valley region, flows south-eastward across the Piedmont and Coastal Plain regions of Virginia and North Carolina into the Atlantic ocean.

Stratagraphy

The rocks included within the limits of the zinc and lead area of Southwest Virginia range from Lower Cambrian to Carboniferous in age. They are, without exception, of sedimentary origin. They include shales, sandstones, conglomerates and limestones presenting considerable variety in composition and appearance. They have been subjected to the action of more or less intense metamorphism and in consequence are considerably changed, as a rule, both lithologically and structurally.

Excepting the Albemarle Zinc and Lead mine at Faber's station, in Albemarle county, the known workable deposits of these metals in Virginia are confined to the Shenandoah limestone, which is shown below to be of Cambro-Ordovician age. Description, therefore, of the rocks belonging to the Devonian and Carboniferous strata are omitted, and only description of the Shenandoah limestone and the formation next above and below the limestone is given.

The Russell Formation.—This formation, consisting usually of alternating shales and thin beds of limestone, with, in places, thin sandstones, was named by Campbell⁸ for Russell county, Virginia, where large areas of it are exposed with its characteristic fauna. In the Russell county area the rocks belonging to this formation contain the *Olenellus* fauna, and consequently are of Lower Cambrian age. The probable correlative of this formation further east in Montgomery and Pulaski counties is designated by Campbell⁹ the Graysonton formation. Campbell remarks on the unfossilifer-

⁸ Campbell, M. R., *Geologic Atlas of the U. S. Estillville Folio, Kentucky-Virginia-Tennessee*, U. S. Geol. Survey, 1894.

⁹ Campbell, M. R., *Paleozoic Overlaps in Montgomery and Pulaski Counties, Virginia*, *Bulletin, Geol. Soc. Amer.* 1894, Vol. V, p. 175.

ous character of the Grayson formation, but from its relations to the overlying Shenandoah limestone concludes that it is probably of Middle or Lower Cambrian age. The Russell formation can, perhaps, be further correlated as the probable equivalent of the upper part of Rogers¹⁰ formation No. 1, or Potsdam.

Where stratigraphic breaks do not disturb the sequence of the rocks over the area comprising the zinc and lead deposits of the State, an unknown thickness of red, green and gray shales, and interbedded thin limestones, lies immediately beneath the Shenandoah limestone in apparent conformity with it. The thin beds of limestone are usually impure, more or less siliceous. The shales are both siliceous and argillaceous, rarely entirely free from carbonates. As a rule, the formation affords conclusive evidence of much disturbance, being considerably crushed, crumpled and folded. No reliable estimate of its thickness could be made at any point within the area.

The general character of the shales and of the interbedded limestone of the Russell formation over parts of the zinc and lead area is indicated in the following chemical analyses:

	I	II	III ¹¹
Silica (SiO ₂).....	62.29	54.95	42.62
Titanium oxide (TiO ₂).....	1.19	.48	undet.
Alumina (Al ₂ O ₃).....	17.35	21.41	22.45
Iron oxide (Fe ₂ O ₃).....	4.73	5.00	4.22
Manganese oxide (MnO).....	.13	.21	trace
Magnesia (MgO).....	.92	—	0.92
Lime (CaO).....	.34	.23	11.97
Soda (Na ₂ O).....			0.35
Potash (K ₂ O).....			2.26
Water (H ₂ O).....			4.25
Carbon dioxide (CO ₂).....			10.20
Total.....			99.24

- I. Thinly laminated purplish red shale; fine textured; somewhat siliceous; closely jointed and interbedded with shaley limestone. One-half mile south of Delton, in a shallow cut along the zinc mines railroad, Wythe county, Virginia. Thomas L. Watson, analyst.
- II. Thinly laminated purplish red shale; fine textured; closely jointed and penetrated by knife-edge stringers of white calcite. Wertz property, two and three-quarter miles S. 55° W. from Roanoke city, Roanoke county, Virginia. Thomas L. Watson, analyst.
- III. Shaley limestone. Bluish (slate) gray and thinly laminated. East limits of Roanoke city, Roanoke county, Virginia. Dr. W. E. Barlow, analyst.

¹⁰ Rogers, Wm. B., Reprint of the Geology of the Virginias, 1884, p. 203 *et seq.*

¹¹ Total insoluble residue is 69.19 per cent. in 1 : 1 HCl.

The Shenandoah Limestone.—This is the principal zinc and lead ore-bearing formation in Southwest Virginia. The name Shenandoah was proposed by Darton¹² in 1892 for the limestone of the Shenandoah valley of Northern Virginia, where it outcrops over extensive areas. It forms the great Cumberland, Shenandoah and East Tennessee valleys. The formation was first described as such by Darton¹³ in the vicinity of Staunton, Virginia. This limestone was called by Rogers¹⁴ the Valley limestone, and has been correlated with the Knox dolomite of Eastern Tennessee. As shown by Campbell,¹⁵ however, the Knox dolomite represents but a part of the Shenandoah limestone in Southwest Virginia, the latter limestone including all of the Knox formation and at least 1500 feet of Cambrian strata beneath it.

Where exposed the lower portion of the Shenandoah formation is usually unfossiliferous but it is probably of Cambrian age, while the upper portion is fossiliferous in many places and is certainly of Ordovician age. In the eastern slaty beds of the Shenandoah limestone, near Natural Bridge, fossils have been found and determined which indicate Middle Cambrian age for the lower portions of the Shenandoah limestone.¹⁶ In 1892 additional fossils were found which are of Cambrian age.¹⁷ The line of division between the Cambrian and Ordovician apparently is not indicated by any physical break in the limestone and the formation is regarded therefore as a lithologic unit of Cambro-Ordovician age.

The eastern portion of the Staunton quadrangle, as mapped by Darton, is underlaid by the Shenandoah limestone, which comprises several members. The lowest of these is described as a thick series of dark magnesian limestone, grading upward into a series of lighter colored beds, which contain nodules and layers of chert irregularly distributed. The upper member of the limestone is described as a purer and more thickly bedded formation, having a thickness of from 200 to 350 feet and very fossiliferous.¹⁸ According to Campbell¹⁹ there appears to be no way of distinguishing the

¹² Darton, N. H., *American Geologist*, Vol. X, p. 13.

¹³ *Ibid.*

¹⁴ Rogers, Wm. B., *Reprint of the Geology of the Virginias*, 1884, pp. 169-173, 209-217.

¹⁵ Campbell, M. R., *Geologic Atlas of the U. S. Pocahontas Folio*, U. S. Geol. Survey, 1896.

¹⁶ Walcott, C. D., *Amer. Journal of Science*, July 1892, p. 53.

¹⁷ Walcott, C. D., *Ibid.* December 1892, p. 478.

¹⁸ Darton, N. H., *Geologic Atlas of the U. S. Staunton Folio*, U. S. Geol. Survey, 1896.

¹⁹ Campbell, M. R., *Ibid.* Bristol Folio, U. S. Geol. Survey, 1899, p. 3.

top from the bottom of the Shenandoah limestone where exposed in the Bristol quadrangle.

In certain localities in Southwest Virginia the extreme top of the Shenandoah limestone is distinguished by a few feet of a dark blue, sparingly fossiliferous limestone. In other localities, notably in the vicinity of the city of Radford along New river in Montgomery and Pulaski counties, the top of the formation is marked by heavy beds of a limestone conglomerate, the exact significance of which has not been fully determined. Campbell is of the opinion that the presence of the conglomerate indicates the existence of overlaps in early Paleozoic time, "probably during the deposition of the Shenandoah limestone itself."²⁰ The lower or basal portion of the Shenandoah limestone is somewhat shaley in places.

Throughout the zinc and lead area of Southwest Virginia the Shenandoah limestone shows considerable variation in character; it usually contains much chert in the form of nodules and layers. The chert as a rule is not regularly distributed through the limestone, and in some beds it is entirely absent. It shows much variation in color and texture, varying from very dark, nearly black to very light in color; from compact texture and typically banded to porous or spongy and oölitic masses without banding, the cavities of which are frequently lined with a quartz druse. Over the Southwest Virginia area the chert is more abundant in some beds of the limestone formation than in others, and to this extent it can probably be relied on as a criterion for subdividing the formation. The limestone is very much folded and crushed, and is usually interlaced by innumerable vein-like lines and knife-edge stringers of white crystallized calcite and dolomite, which recement the limestone fragments. Except in certain places in the limestone, the filling of calcite and dolomite more nearly simulate veins, but along the fault directions particularly, the rock has been frequently crushed and broken into smaller masses and fragments and recemented by the filling of calcite and dolomite which form a typical limestone breccia. It varies from a fine granular, dark blue, nearly black, rock to a fine and fairly coarse crystalline, light gray, nearly white limestone. In places, there appear occasional bands of a homogeneous, compact and dense textured, light gray limestone within the formation, which doubtless would prove to be a fair grade of lithographic

²⁰ Campbell, M. R., *Paleozoic Overlaps in Montgomery and Pulaski Counties, Virginia*. Bulletin, Geol. Soc. Amer., 1894.

limestone. The formation is still marked in other places by bands or streaks of a nearly pure limestone, well suited to the making of lime, for which it has been quarried at a number of points. The Shenandoah limestone, however, is generally a heavy bedded, dark blue to gray, dolomite, with an estimated thickness of not less than 4000 feet.

The following chemical analyses serve to indicate the general character of the Shenandoah limestone over Southwest Virginia:

	I	II	III	IV	V
Insoluble residue.....	2.90 ²¹	0.594	0.45	0.20	—
Silica (SiO ₂).....	trace	.073	trace	trace	7.37
Titanium oxide (TiO ₂).....	none	none	none	none	.09
Alumina (Al ₂ O ₃).....	0.43	0.344	0.24	0.37	1.92
Ferric oxide (Fe ₂ O ₃).....	0.94	0.19	0.17	0.22	0.29
Ferrous oxide (FeO).....	—	—	—	—	0.63
Manganese oxide (MnO).....	none	0.193	0.37	trace	none
Lime (CaO).....	30.06	29.085	29.50	30.71	28.39
Magnesia (MgO).....	18.41	20.54	19.93	21.56	18.30
Baryta (BaO).....	none	none	trace	none	—
Potash (K ₂ O).....	0.24	0.22	0.56	0.12	1.09
Soda (Na ₂ O).....	0.21	0.38	1.03	0.10	0.09
Water (H ₂ O) 100°C— }.....	3.30	2.58	3.73	3.92	0.09
Water (H ₂ O) 100°C+ }.....					0.49
Carbon dioxide (CO ₂).....	43.98	45.40	44.01	43.88	41.85
Phosphorus pentoxide (P ₂ O ₅).....	none	none	none	none	0.03
Sulphuric anhydride (SO ₃).....	none	none	none	none	—
Total.....	100.47	99.599	99.99	101.08	100.63

- I. Limestone. Massive grayish black fine granular, crushed and recemented with stringers of pure white calcite. Martin property, two and three-quarter miles southwest of Roanoke city, Roanoke county, Virginia. Dr. W. E. Barlow, analyst.
- II. Limestone. Grayish white and moderately coarse crystalline. Specimens taken from the 190-foot level in the Austinville zinc and lead mines, Wythe county, Virginia. Dr. W. E. Barlow, analyst.
- III. Limestone. White, coarsely crystalline, and crushed. Specimens taken from the 80-foot level at bottom of open cut, in the Austinville zinc and lead mines, Wythe county, Virginia. Dr. W. E. Barlow, analyst.
- IV. Limestone. White and medium crystalline. Specimens taken from the 80-foot level at bottom of open cut, in the Austinville zinc and lead mines, Wythe county, Virginia. Dr. W. E. Barlow, analyst.
- V. Limestone. Staunton, Augusta county, Virginia. George Steiger, analyst. Bulletin, U. S. Geological Survey, No. 228, p. 306.

²¹The residue consisted of 1.39 per cent. of sand and clay and 1.51 per cent. of matter lost on ignition—apparently carbon.

Partial analyses of specimens of the Shenandoah limestone collected from other lead and zinc openings in Wythe, Smyth and Russell counties, Virginia, are given elsewhere in this report in the description of properties under the above-named counties, which may be compared with the analyses given above.

The Chickamauga Limestone and Martinsburg Shale.—The Chickamauga limestone is named from Chickamauga creek in Walker and Catoosa counties, Georgia, where the rocks of this formation seem best developed. Over parts of the Georgia area, especially in Polk county, this formation includes a considerable thickness of slate overlying the limestone, and designated by Hayes as the Rockmart slate. Hayes correlates the formation in the Georgia area with the Trenton, Chazy or Maclurea of Smith and Safford.²² To this Spencer²³ adds the Hudson. In Virginia, Campbell²⁴ states that the Chickamauga limestone is probably equivalent to the base of Rogers' No. III.

Over Southwest Virginia where the rock sequence is normal, the Shenandoah limestone is overlaid by a blue flaggy, fossiliferous limestone, which is heavier bedded toward the base and is designated the Chickamauga limestone. Its basal portion is usually characterized by a heavy blue bed carrying much black chert, which serves to fix the boundary of this with the underlying formation in many places. The Shenandoah limestone is usually characterized as an impure gray magnesian limestone, which at times will serve in a general way to separate it from the fossiliferous blue beds of the overlying Chickamauga limestone.

The average thickness of the Chickamauga limestone for Southwest Virginia is probably less than 1000 feet. Like the shale formation (Russell) underlying the Shenandoah limestone, the Chickamauga limestone has no value as a zinc and lead-bearing formation in Virginia.

In the vicinity of Staunton, Virginia, and to the north near Martinsburg, West Virginia, in the Great Valley, the Chickamauga limestone is lacking and the Shenandoah limestone passes upward into a series of shales, for which Darton²⁵ proposed the name Mar-

²² Hayes, C. W., *The Overthrust Faults of the Southern Appalachians*. Bulletin, Geol. Soc. Amer., 1891, Vol. II, p. 143.

²³ Spencer, J. W., *The Paleozoic Group*. Geol. Survey of Georgia, 1893, p. 45.

²⁴ Campbell, M. R., *Geol. Atlas of the U. S. Pocahontas Folio*, U. S. Geol. Survey, 1896.

²⁵ *American Geologist*, Vol. X, p. 13.

tinsburg shale. Prosser²⁶ correlates the Martinsburg shale with the Utica and Hudson shales of the Mohawk Valley in New York.

Structure

The rocks of the zinc and lead region of Southwest Virginia consist entirely of sedimentary deposits laid down during the Paleozoic era. No igneous rocks are known to be exposed at present anywhere within the region. When originally laid down on the sea bottom these rocks must have preserved an approximately horizontal position. Over most of the region, however, the original position of the rocks has been profoundly disturbed. They have been intensely folded and in many places broken by great faults, along which the strata have moved to unknown distances.

Folds, principally of the anticlinal and synclinal types, are represented over the southwestern region, many of which are over-turned and closed, while others are more gentle and open. The prevailing trend of the folds is approximately northeast-southwest. The unsymmetrical type of fold is the rule. To this extent, at least, the folding harmonizes well with the normal Appalachian type in preserving somewhat gentler dips on the southeast side, and correspondingly steeper ones on the northwest.

The structure over much of the region is considerably complicated, largely by reason of the frequency of profound faulting. In many places the intense folding has been accompanied by faults of great but unmeasured displacement. The faults are of the over-thrust type with the fault-planes dipping southeast at varying angles. In case of the major thrust faults an approximate general parallelism in strike is observed along a northeast-southwest direction. Stated somewhat differently, the major thrust faults maintain parallelism to the lines of folding or to the main anticlinal axes. Exceptions are noted in the case of minor or cross faults in which the direction of fault and strike is independent, and the faults further bear apparently no relation to the folds. Both low and steep dips are somewhat common to the fault-planes. A number of the major thrust faults are traceable for several hundred miles in the direction of the strike. Minor faults characterize many parts of the region.

²⁶ Prosser, C. S., The Shenandoah Limestone and Martinsburg Shale, *Jour. of Geol.* 1900, Vol. VIII, pp. 662-663.

THE ORES AND ASSOCIATED MINERALS

The minerals of the lead and zinc region of Virginia are not numerous as to species, but they are confined chiefly to a few of the commoner forms. They may be divided with respect to the plain of ground-water level into (a) the original sulphide forms, which include sphalerite, galenite, pyrite, and scant chalcopyrite, found at and below the level of ground-water; and (b) the secondary or oxidized forms, which have been derived from the original sulphide minerals and occur in the residual decay, clays, of the fresh rock. The altered or oxidized minerals include smithsonite, calamine, limonite, and cerussite. Some unaltered galenite is found in the residual clays of some of the mines associated with the oxidized mineral forms mentioned above.

A number of minerals of the non-metallic type are found associated with the metallic forms enumerated above. Named in the order of their importance they are dolomite, calcite, fluorite, quartz and barite. None of these have any commercial value in their occurrence in the Virginia mines. Quartz in association with fluorite, is only known in the Albemarle Zinc and Lead Mine, in Albemarle county. Some calcite is also reported from this mine. Fluorite is the principal gangue mineral at the Albemarle Zinc and Lead Mine, and is also found at Cedar Springs in Wythe county; on the McCarter place in Rye Valley, Smyth county, and sparingly at two other mines in the same county. Barite in association with the lead and zinc ores occurs at only two places in the State, namely, the Bertha Zinc Mines, and the New River Mineral Company's Mines near Ivanhoe, Wythe county.

THE ORES

Lead Ores

Galenite.—Also known as galena, lead sulphide; which when pure it contains theoretically, 86.6 per cent. of metallic lead and 13.4 per cent. of sulphur. As a rule, however, such a high percentage of lead is rarely found in galenite, except in selected pieces. In the Virginia mines galenite may occur both in the form of crystals, usually cubes, rarely as cubo-octohedrons, and as granular and massive granular.

Galenite occurs in many localities in the State, especially in association with the zinc ores in the zinc mines; and with pyrite, gold

and chalcopyrite in some of the gold and copper mines. Other occurrences of the mineral, not in association with the sulphide minerals mentioned, have been noted in the limestone of a number of counties in Southwest Virginia. In most of these localities the galenite is present in scarcely more than traceable quantity and is, of course, without commercial value. In a few of the localities the mineral apparently promises well and may prove to be present in workable quantity.

Selected specimens of galenite collected by the writer from the Austinville Zinc and Lead Mines, Wythe county, Virginia, yielded Mr. Jas. H. Gibboney the following results on analysis in the laboratory of the Virginia Polytechnic Institute.²⁷

	Per Cent.
Lead (Pb).....	73.89
Zinc (Zn).....	9.31
Iron (Fe).....	.22
Sulphur (S).....	16.20
Silica (SiO ₂).....	.54
Total.....	100.16

Recalculating the analysis and proportioning the sulphur with the percentage amounts of lead and zinc found necessary to form the sulphides of the two metals, according to the formulas, PbS and ZnS, we get:

	Per Cent.	
Lead sulphide (PbS).....	85.29	
Zinc sulphide (ZnS).....	13.87	
Iron (Fe).....	.22	} FeS ₂ equivalent 0.46 percent.
Sulphur (S).....	.24	
Silica (SiO ₂).....	.54	
Total.....	100.16	

Practically all of the lead produced in Virginia from the earliest mining to the present time has been from lead ores, principally galenite, associated with zinc ores in the zinc and lead mines of Wythe and Albemarle counties. In the early mining at Austinville, Wythe county, only the lead ores were removed and used, the zinc ores being discarded.

The galenite, lead sulphide, forms the original mineral from which the oxidized lead ores were derived. Excepting the lead carbonate, cerussite, found in largest quantity perhaps in the Austin-

²⁷ Average of three analyses.

ville mines, galenite is the only lead ore which occurs in sufficient quantity to be mined.

Cerussite.—This is lead carbonate and it is also known as white lead ore. It is a secondary mineral derived from the alteration of galenite in the zone of oxidation. When chemically pure cerussite contains 83.5 per cent. of metallic lead. It has been noted in more than a trace only at one locality in the State, namely, the old Wythe Lead and Zinc Mines at Austinville, in Wythe county, where it is not an altogether uncommon ore among the altered forms.

It occurs distributed through the residual clays of the limestone as stringers and small irregular masses. The earthy form greatly predominates. As such the clayey admixture is readily identified by its weight, specific gravity. Crystals grouped in clusters and aggregates of white and light grayish color, distributed through the clay, are not uncommon. It further occurs as a white powder-like coating on the crystals and masses of granular galenite.

Anglesite.—Anglesite, the sulphate of lead, and a secondary mineral derived from galenite, while sparingly present in some lead districts is, to the writer's knowledge, unknown in the Virginia mines.

Zinc Ores

Sphalerite.—Theoretically, sphalerite contains 67 per cent. of metallic zinc and 33 per cent. of sulphur. Sphalerite is also known as zinc blende, and by the miners it is commonly called "black jack," or simply "jack." It is the most important ore over much of the Virginia district; and it forms the original zinc mineral from which the secondary zinc ores, concentrated above ground-water level, have been derived. It is found usually below the level of ground-water, and in some of the mines not yet worked to this depth it has been found but sparingly; especially true is this of the original Bertha mines in Wythe county.

In the Virginia mines, the sphalerite varies in color from yellow, through brown to nearly black; the black color being due to impurities, particularly iron. In some of the larger mines, especially the Austinville mines in Wythe county and the lead and zinc mines near Faber's station in Albemarle county, sphalerite is associated with much galenite, lead sulphide, in places; some pyrite, iron sulphide; and occasionally with very little chalcopyrite, copper-iron sulphide.

The occurrence of sphalerite in the Virginia mines is in the form of disseminated grains, masses and stringers in the magnesian limestone of the southwestern part of the State; and in similar form but mostly as stringers in quartz-fluorite lenses intercalated in a crinkled talcose schist in Albemarle county. At Cedar Springs, Wythe county, and Rye Valley, Smyth county, blende of exceptional quality is found, as indicated in the analyses below. It is of yellow color, massive in form with perfect cleavage, but not preserving outward crystal form.

Sphalerite, as stated above, is rarely free from impurities, some of which have an important bearing on the market value of the ore. Chief among these impurities are probably lead and iron, for which deductions in price of the ore are made should the amount of impurities exceed a certain percentage.

The following analyses made on selected pieces of sphalerite collected by the writer from the Virginia mines in Albemarle, Wythe, and Smyth counties, serve to indicate the general character of the mineral:

	I	II	III	IV
Zinc (Zn).....	65.01	66.76	66.94	62.11
Sulphur (S).....	31.93	33.44	33.26	34.45
Iron (Fe).....	1.94	.50	.30	3.44
Lime (CaO).....	.08	trace	trace	.05
Magnesia (MgO).....	none	trace	trace	none
Silica (SiO ₂).....	.33	.10	.08	.26
Total.....	99.29	100.80	100.58	100.31
Zinc sulphide (ZnS).....	96.94	99.56	99.86	92.70

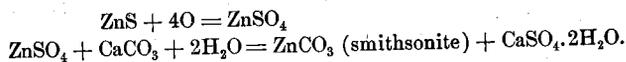
- I. Sphalerite collected by Thomas L. Watson from the Austinville Zinc and Lead Mines, Wythe county, Virginia. Mr. Jas. H. Gibboney, analyst.
- II. Sphalerite collected by Thomas L. Watson from Cedar Springs, Wythe county, Virginia. Mr. J. R. Eoff, Jr., analyst.
- III. Sphalerite collected by Thomas L. Watson from the Scott Place, Rye Valley, Smyth county, Virginia. Mr. Jas. H. Gibboney, analyst.
- IV. Sphalerite collected by Thomas L. Watson from the Albemarle Zinc and Lead Mines near Faber, Albemarle county, Virginia. Mr. Jas. H. Gibboney, analyst.

Smithsonite.—Smithsonite is the carbonate of zinc, which theoretically contains 64.8 per cent. of zinc oxide and 35.2 per cent. of carbon dioxide. The equivalent of metallic zinc in smithsonite is 52 per cent. when pure. The smithsonite of the Virginia mines

is a secondary mineral formed by the alteration of sphalerite in the belt of oxidation, probably in the following manner:

ZnS (sphalerite) by simple oxidation is changed to $ZnSO_4$ (zinc sulphate). If the zinc sulphate ($ZnSO_4$) reacts on calcium carbonate ($CaCO_3$), smithsonite ($ZnCO_3$) is produced.

One set of reactions is as follows:



In the zinc mines of Wythe county, Virginia, smithsonite forms a fairly important ore of zinc. It occurs here in the residual clays derived from the magnesian limestone, concentrated usually in the bottom portions of the clays and resting immediately on the irregularly weathered surface of the limestone. It is intimately associated with calamine, which is described below.

Smithsonite occurs both in the granular and earthy form, principally the latter, as crystalline incrustations, and as a porous or spongy material with the cavities sometimes filled with a powdery earthy form of the ore. In color it may vary from light gray through yellow to brown, according to the impurities present.

Samples apparently of mixtures of smithsonite and calamine in which smithsonite greatly predominated, from the Falling Cliff Zinc Mine at Bertha, Wythe county, Virginia, yielded Mr. F. P. Dewey the following results on analysis:²⁸

	I	II
Zinc oxide (ZnO).....	61.99	59.88
Carbon dioxide (CO ₂).....	25.88	29.07
Silica (SiO ₂).....	7.07	4.83
Iron oxide (Fe ₂ O ₃).....	1.44	4.07
Alumina (Al ₂ O ₃).....	.66	.14
Manganese oxide (MnO).....	.11	.21
Lime (CaO).....	.16	.57
Magnesia (MgO).....	.21	.35
Water (H ₂ O).....	2.58	1.46
Total.....	100.10	100.58

Recalculating these results by allotting first, to the lime and magnesia the necessary amount of carbon dioxide to form calcite and magnesite, respectively, and assuming the overplus of carbon dioxide to combine with zinc oxide to form smithsonite; and pro-

²⁸ Dewey, F. P., Note on the Falling Cliff Zinc Mine. Trans. Amer. Inst. Min. Engrs., 1881-82, Vol. X, p. 111.

portioning the overplus zinc oxide with the necessary amounts of silica and water to form calamine, the following percentages of smithsonite and calamite are obtained from the two analyses:

	I	II
Smithsonite ($ZnCO_3$).....	75.52	79.99
Calamine ($Zn(OH)_2, SiO_2$).....	22.22	12.05

Calamine.—Calamine is a hydrous silicate of zinc which contains theoretically 67.5 per cent. of zinc oxide, or its equivalent, 54.16 per cent. of metallic zinc.

Like smithsonite, calamine is a secondary mineral derived from the alteration of sphalerite in the belt of oxidation. It is much more abundant than smithsonite in the Wythe county mines, and until recently it has been the principal ore of zinc mined in this county. In fact the principal source of zinc in Virginia has been from this ore, calamine. In occurrence it is closely similar to that of smithsonite, with which it is intimately associated. It is indeed very difficult, and in some cases impossible, to separate the two ores, so intimately admixed are they.

In the Wythe county mines, calamine occurs in the residual clays, usually in the bottom portions, immediately on and next to the irregular weathered surface of the underlying limestone. Beautiful white incrustations of the mineral presenting both mammillary and stalactitic surfaces, have been observed at times between layers of the more solid massive zinc ore. Granular, massive and honeycomb forms of calamine are quite common. Much of the calamine in the Bertha mine is reported to have been in sheet form, rarely in contact with the limestone, but concentrated several inches away from the limestone surface and having the intervening space filled with a mixture of loose powdery calamine and smithsonite.

The following chemical analyses of specimens of calamine from the Wythe county mines show the general character of the ore:

	I	II	III
Silica (SiO_2).....	23.95	25.01	25.33
Zinc oxide (ZnO).....	67.88	67.42	67.15
Water (H_2O).....	8.13	8.32	7.47
	99.96	100.75	99.95
Total.....			
Sp. Gr.....	3.338	—	3.40

I. MacIrby, Chem. News, 1873, Vol. 28, p. 272.

II. Genth, F. H., Proc. Amer. Phil. Soc., 1885, Vol. 23, p. 46.

III. Jones, A., Journ. Amer. Chem. Soc., 1892, Vol. 6, p. 620.

A specimen of calamine from the Falling Cliff Mine, Wythe county, Virginia, yielded Mr. F. P. Dewey the following results on analysis:²⁹

	Per Cent.
Zinc oxide (ZnO).....	61.84
Silica (SiO ₂).....	24.47
Water (H ₂ O).....	8.27
Iron oxide (Fe ₂ O ₃).....	2.10
Alumina (Al ₂ O ₃).....	1.24
Lime (CaO).....	0.53
Magnesia (MgO).....	0.21
Manganese oxide (MnO).....	0.16
Carbon dioxide (CO ₂).....	1.80
Total.....	<u>100.62</u>

Recalculating these results in the same way as described above under smithsonite, Mr. Dewey's analysis yields the following percentages of the minerals calamine and smithsonite:

	Per Cent.
Calamine (Zn (OH) ₂ , SiO ₂).....	88.52
Smithsonite (ZnCO ₃).....	3.26

In a paper entitled "Contributions to Mineralogy" Dr. Genth makes the following statement concerning the occurrence of calamine at the Bertha Zinc Mines in Wythe county: "A peculiar variety of calamine which closely resembles hydrozincite, occurs as an incrustation upon a ferruginous calamine, the principal ore at the Bertha Mine, Pulaski county, Virginia."

"It is earthy and cryptocrystalline and some of the incrustations had a thickness of 5 mm. I observed that after ignition it was dissolved by dilute hydrochloric acid almost instantaneously, far more readily than the hydrous mineral."³⁰

An analysis by Dr. Genth gave:³¹

	Per Cent.
Silica (SiO ₂).....	25.01
Zinc oxide (ZnO).....	67.42
Water (H ₂ O).....	8.32
Total.....	<u>100.75</u>

²⁹ Dewey, F. P., Note on the Falling Cliff Zinc Mine. Trans. Amer. Inst. Min. Engrs., 1881-82, Vol. 10, p. 111.

³⁰ Genth, F. A., Contributions to Mineralogy. Proceedings Amer. Phil. Soc., 1886, Vol. 23, p. 45.

³¹ Genth, F. A., Ibid., p. 46.

"*Buckfat*."—"Buckfat" is the name applied by the miners to a mixture of the common clay with the minerals calamine and smithsonite. It is not a definite mineral but is in reality a lean ore too low, as a rule, in zinc to be profitably used in the present practice of smelting. The zinc content shows wide variation, however, ranging oftentimes much higher than that given in the analysis below. It is both hard and soft and is accordingly called by the miners "hard buckfat" and "soft buckfat." Its separation from the rich ores is effected by hand-sörting and by subsequent washing and jigging. Treatment which consisted in violent washing in water of the "soft buckfat" and crushing and jigging of the "hard buckfat," was practiced at the Bertha mines previous to the conversion of the ore into spelter.

A chemical analysis of a zinc-bearing clay from the neighborhood of the Bertha Zinc Mines, Pulaski county, Virginia, yielded Mr. Heyward the following results:

	Per. Cent.
Silica (SiO_2).....	37.38
Alumina (Al_2O_3).....	24.67
Iron oxide (Fe_2O_3).....	6.34
Zinc oxide (ZnO).....	12.10
Magnesia (MgO).....	.27
Potash (K_2O).....	.47
Soda (Na_2O).....	.27
Water (H_2O) 100°C—.....	6.69
Water (H_2O) 100°C+.....	10.35
Total.....	98.54

Iron Ores

Iron ores are very abundant in the lead and zinc district of Virginia and in places they have been rather extensively mined. In several instances mines formerly worked for zinc ores are now being worked for iron ores. At several points along the Cripple Creek branch of the Norfolk and Western railroad a number of blast furnaces have been in operation from time to time, for some years, within close proximity to the zinc mines of Wythe county.

Pyrite, the disulphide of iron, is rather a frequent associate of galenite and sphalerite in some of the Virginia lead and zinc mines. It occurs in the fresh rock below the belt of oxidation. In the Austinville lead and zinc mines, pyrite is disseminated through the magnesian limestone in places, in the form of small grains and

crystals, in intimate association with the sulphides of zinc and lead. It is by no means uniformly distributed through the rock but, in places, it is sufficiently concentrated to be noticeable, and rarely, if ever, is it present in quantity large enough to be hurtful to the lead and zinc ores.

Limonite, hydrous oxide of iron and also known as brown hematite and yellow ochre, has wide distribution over the district. It is limited to the belt of oxidation and is, in part at least, a product of the alteration of pyrite. The old Bertha zinc mine in Wythe county, until recently the largest producer of calamine and smithsonite in Virginia, is being worked at present for brown iron ore. Likewise, brown hematite has been mined at other mines in the district which were originally zinc producing.

Hematite, the anhydrous oxide of iron and known as red iron ore and red ochre, is less common in the lead and zinc district than limonite or the brown ore. The light and deep red colored clays which occur so abundantly with the lead and zinc ores in some of the mines of Southwest Virginia, within the zone of weathering, owe their color largely if not entirely to the presence of hematite.

Manganese Ores

The black oxide of manganese occurs in many places in the residual clays of the lead and zinc district. It has been observed at times, mainly as a coloring matter, in the form of very impure wad, and is entirely without commercial value.

Copper Ores

These have no importance in the Virginia lead and zinc mines, as they have been noted only in traces in a few of them. Occasionally very small amounts of the original copper ore, chalcopyrite, copper-iron sulphide, impregnates very sparingly the fresh rock below ground-water level in several zinc mines of the State. To the writer's knowledge, other common ores of copper are unknown in the lead and zinc mines of the State.

ASSOCIATED MINERALS

The associated minerals found in the Virginia lead and zinc mines are limited both as to species and occurrence. These are, named in the order of their importance, dolomite, calcite, fluorite,

quartz and barite. Of these, calcite, fluorite and quartz, have been noted in the lead and zinc mine near Faber's station in Albemarle county, where they form the gangue minerals. Calcite occurs only sparingly at this mine, while quartz and fluorite constitute the principal gangue minerals. Fluorite is the dominant mineral. In the Southwest Virginia mines dolomite and calcite form the most common minerals with some barite and less fluorite. Here the dolomite and calcite occur filling the fractures between the magnesian limestone fragments, forming a distinct limestone breccia.

Calcite.—Calcite, calcium carbonate, in the form of limestone is one of the most common minerals of the region. It further occurs with dolomite in massive crystalline form filling the fractures between the broken limestone fragments which cement them together as breccia. It is prevailingly white in color and frequently occurs in perfect cleavable masses of the rhombohedral type. A specimen of the white, cleavable massive calcite collected by the writer at Cedar Springs Zinc Mines in Wythe county gave Mr. J. R. Eoff, Jr., the following results on analysis:

	Per Cent.
Calcium carbonate (CaCO_3).....	98.89
Magnesium carbonate (MgCO_3).....	.78
Iron and Alumina ($\text{Fe}_2\text{O}_3 + \text{Al}_2\text{O}_3$).....	.10
Silica (SiO_2).....	.34
Total.....	100.11
Sp. Gr.....	2.66

In 1878 Professor F. P. Dunnington reported the occurrence of aragonite, orthorhombic calcium carbonate, crystals containing lead from the Austinville mines in Wythe county. The following analysis of the aragonite crystals was made by Dunnington:³²

	Per Cent.
Lime (CaO).....	51.819
Lead oxide (PbO).....	6.087
Carbon dioxide (CO_2).....	41.800
Iron oxide (Fe_2O_3).....	.033
Silica (SiO_2).....	.012
Water (H_2O).....	.070
Total.....	99.821
Sp. Gr.....	3.078

³² Dunnington, F. P., Proceedings Amer. Chem. Soc., Vol. II, No. 1, p. 14. The *Metallic Review*, 1878, Vol. II, p. 284, March-August.

Dolomite.—Dolomite, calcium-magnesium carbonate, is much more common than calcite over the Virginia area. Like calcite it occurs largely as composing the country rock and in crystallized massive form filling the spaces between the broken limestone fragments.

In both occurrences it is associated with calcite and is more abundant. Individual crystals of either calcite or dolomite are rare. Small perfect rhombs of calcite are found lining minute cavities in the limestone of the New River Mineral Company's mines near the western limits of Ivanhoe.

The general character of the mineral dolomite is shown in the analyses given below, made by J. R. Eoff, Jr., on specimens collected by the writer from the zinc mines in Wythe county.

	Austinville	Cedar Springs
Calcium carbonate (CaCO_3).....	54.85	54.75
Magnesium carbonate (MgCO_3).....	44.58	45.11
Iron and Alumina ($\text{Fe}_2\text{O}_3 + \text{Al}_2\text{O}_3$).....	.48	.66
Silica (SiO_2).....	.22	.22
Total.....	100.13	100.74
Sp. Gr.....		2.97

In each of these analyses the ratio of calcium to magnesium is 1 : 1, which is the ratio of normal dolomite.

Fluorite.—Also known as fluorspar, calcium fluoride. This is much the most abundant mineral found at the Albemarle Zinc and Lead Mine, near Faber, Albemarle county. Here it occurs in both large and small lenses in the crinkled schist, usually of white color, though the violet shade is fairly common. It has been sparingly found at several localities in Southwest Virginia, in association with the metallic sulphides. The principal ones are Cedar Springs, Wythe county, and the McCarter place in Rye Valley, Smyth county. Fluorspar occurs in the Southwest Virginia region (1) as distributed through and enclosed by the blende; (2) as distributed through the dolomite and calcite filling of the limestone breccia; and (3) in association with dolomite and calcite filling and lining small cavities or vugs in the limestone. See figures 1 and 20. It is violet in color, though some green fluorspar is reported to have been found in one of the Cedar Springs openings.

Quartz.—This mineral is found in direct association with the lead and zinc ores only at the Albemarle Zinc and Lead Mine near Faber in Albemarle county. It is admixed with the fluorspar, as

fluorspar-quartz lenses, which contain the lead and zinc ores distributed through them. Quartz is very much less abundant than fluorspar. Quartz in the form of chert is very abundantly distributed through the zinc and lead bearing Cambro-Ordovician limestone of Southwest Virginia, but the chert is rarely or never seen in close association with the ores. Quartz, in the form of perfect crystals and druses lining cavities, is very freely distributed through the limonite ores of the New River Mineral Company's mines just west of Ivanhoe. It has not been observed in these mines in association with the lead and zinc ores.

Barite.—Barite, barium sulphate, also known commercially as heavyspar has been found in small quantity in the Bertha zinc mine, in Wythe county. It seems not to have been conspicuous here. Barite is very abundant in the New River Mineral Company's mines just west of Ivanhoe. Here a little of the blende was observed to be enclosed by the barite-filling of the limestone.

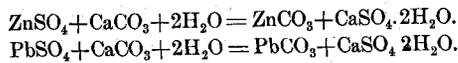
Barite is a common mineral over parts of the limestone region of Southwest Virginia and has been mined in several places, but it is not associated with the lead and zinc deposits except in the two mines mentioned above.

THE ALTERATION OF THE ZINC AND LEAD ORES

It has been pointed out elsewhere in this volume that the secondary ores of zinc and lead comprised within the belt of oxidation have been derived from original metallic sulphides, galenite and sphalerite. In the Virginia mines the important secondary ores comprise calamine, smithsonite and cerussite which have been formed from the sulphides by oxidation, carbonation, silication and hydration—weathering—above or near ground-water level. Moreover, practically the total output of zinc ores in Virginia has been from the Wythe county mines, which consisted almost entirely of calamine and smithsonite. At the old Bertha mines operations were confined to the zone above ground-water level and calamine and smithsonite were the only zinc ores removed. Similar conditions obtained at the Austinville mines, though much development work has been done near and below ground-water level in the original sulphide ores, sphalerite and galenite.

Sphalerite, zinc sulphide (ZnS), and galenite, lead sulphide (PbS), by oxidation are changed to zinc sulphate ($ZnSO_4$), and lead sulphate

(PbSO_4). The sulphate solutions react on the enclosing limestone according to the following equations:



It is probable that a second set of reactions may result, whereby the zinc sulphate formed from the oxidation of the zinc sulphide, sphalerite, reacts on the soluble calcium bicarbonate formed from the interaction of the percolating atmospheric waters containing carbon dioxide in solution on the limestone, to form zinc carbonate. In this case at least one intermediate step is involved, namely, the conversion of the basic zinc carbonate, under natural conditions, into the normal zinc carbonate, smithsonite.

The reaction between the two solutions, zinc sulphate and calcium bicarbonate, results in the formation of a basic zinc carbonate which is a mixture of $\text{ZnCO}_3 + \text{Zn}(\text{OH})_2$, the molecular proportions of which vary according to the conditions under which the precipitation takes place. Whether the conversion of the basic carbonate into the normal carbonate takes place in nature, and under what conditions, are questions as yet unanswered.³³ Laboratory experiments conducted in the Virginia Polytechnic Institute laboratories have conclusively proved the formation of the basic zinc carbonate when the two solutions, zinc sulphate and calcium bicarbonate, react on each other.

That a similar reaction takes place in nature as outlined above is shown possibly in the occurrence of the mineral hydrozincite, a basic zinc carbonate, corresponding perhaps to the formula, $\text{ZnCO}_3 \cdot 2\text{Zn}(\text{OH})_2$, in the zinc mines of Missouri, New Jersey, and elsewhere. In the same way probably hydrocerussite, a basic lead carbonate, is formed, though sparingly, corresponding perhaps to the formula $2\text{PbCO}_3 \cdot \text{Pb}(\text{OH})_2$.

The Zinc Ores.—Below ground-water level in the fresh limestone, the mineral form of the zinc ore is the sulphide, sphalerite. Above this level in the belt of residual decay only the altered forms, oxidized ores of zinc, are found, calamine and smithsonite, the former, calamine, always predominating. Smithsonite is found in larger quantity in some mines than in others. Unaltered sphalerite seems

³³The chemistry of the changes involved in the transformation of the original sulphides, sphalerite and galenite, into the numerous secondary or oxidized forms is being investigated by the writer and Dr. F. D. Wilson, in the laboratory of the Geological Department of the Virginia Polytechnic Institute.

not to occur in the decay of any of the mines, but it is replaced instead by the two oxidized forms mentioned above.

Portions of the country rock next to the bottom portions of the loose decay, once containing grains and crystals of the sulphide ores, sphalerite and galenite, are now porous and open-textured in many places, a condition resulting from the removal of the sphalerite and galenite in solution. In many places where the alteration has been complete, apparently the rock is extremely cavernous and presents a typical honeycomb appearance. In still other places the ores have been observed in the limestone in various stages of oxidation and the cavities left are either entirely vacant or are occupied by a film of iron oxide.

In the process of alteration the oxidized ores may be removed a short distance or they remain practically in place; usually migration is indicated.

The Lead Ores.—In the same mines lead ores are admixed in large and small proportions with those of zinc. Like that of zinc the mineral form of the lead in the fresh rock is the sulphide, galenite, admixed usually with sphalerite. In the belt of decay more or less closely associated with the secondary zinc ores, the oxidized form of lead is cerussite, lead carbonate, which is present in very appreciable quantity in the Austinville mines. In addition to the carbonate of lead, cerussite, a large proportion of galenite occurs in the weathered belt admixed with the secondary ores. This is in accord with the properties and behavior of the sulphide ores of zinc, lead and iron, all of which are found in the Wythe county mines. Galenite, lead sulphide, being more difficultly oxidizable than the sulphides of zinc and iron; and being greatly less soluble than the limestone in which it occurs, are circumstances which account chiefly for the presence of much galena admixed with the secondary ores in the weathered zone.

The cerussite is sometimes observed coating or incrusting the galenite and occasionally it has been noted in crystals on the galenite. In some specimens of the galenite not incrustated by the alteration product, cerussite, the surfaces appear dull and are much roughened, pitted from etching. The same specimens, when broken, show the bright metallic luster of the unaltered galenite, on the inside. A few specimens were noted, which were apparently all cerussite, but on breaking they proved to be only partially altered; the outer portions of the original galenite being entirely coated

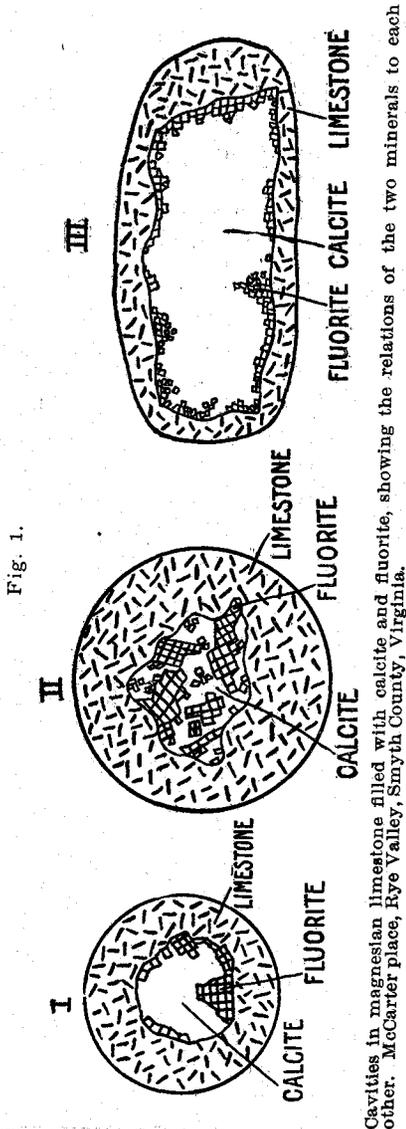
with a varying thickness of the lead carbonate, and the inner part composed of the fresh unaltered galenite. In still other specimens, limited to the zone of weathering, the alteration seemed complete, with no trace of the original sulphide ore indicated. Between these two extremes of alteration nearly all gradations are observed.

PARAGENESIS AND ASSOCIATION

No definite order of deposition of the original minerals can be positively made out. The metallic sulphides (lead, zinc and some iron) and the gangue minerals seem to have been introduced and crystallized at about the same time. The various sulphides are usually so intimately mixed as to preclude any attempt at determining the order of deposition. Variations in the association of the metallic sulphides and the gangue minerals, and the relations of these to the enclosing rock, are shown.

A common association is the more or less replacement of the country rock, limestone, on one or both sides of the fracture by the sulphides, and the filling of calcite and dolomite without metallic sulphides distributed through it. In places the broken fragments of the limestone are either partially or completely rimmed by a narrow band of sphalerite. At times both forms of filling rudely resemble banding on a small scale, in which it appears that the sulphides were perhaps introduced somewhat in advance of the gangue filling. When it is remembered, however, that all gradations are observed between this form of filling and those stated next below, where the evidence seems conclusive for contemporaneous deposition, it seems reasonable to assume that deposition of the ores and the associated minerals for the district as a whole, was made at about the same time. Moreover, cases are observed in which calcite and dolomite are entirely enclosed by the metallic sulphides and *vice versa*. Similar relations of fluorite to the sulphides, and fluorite to calcite and dolomite, are observed. As shown in figure 20 fluorite is entirely enclosed by the calcite-dolomite filling and also fluorite is entirely enclosed by blende. Again, the filling of very small cavities in the limestone by fluorite and calcite at the McCarter Place in Rye Valley shows in some cases a somewhat broken irregular lining of the cavity by fluorite next to the limestone, and the remainder filled in by calcite, as shown in figure 1. This association of fluorite and calcite points to a filling of fluorite in advance of the calcite; but occurring immediately along side of this

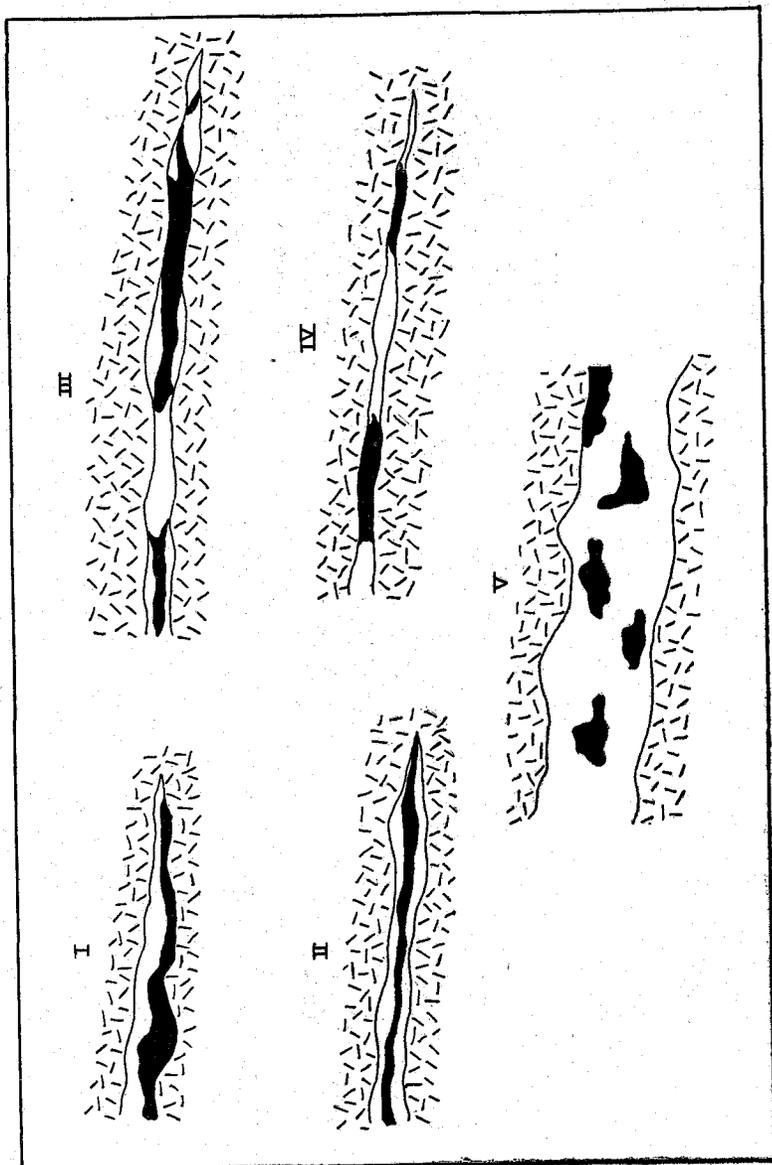
may be observed a similar cavity filled with intimately admixed fluorite and calcite from the walling to the center of the cavity,



where no doubt exists of the simultaneous deposition of the two minerals.

Equally common perhaps is the filling of the fracture in the

Fig. 2.



Calcite-dolomite-sphalerite filling in fractures of the Shenandoah limestone. Shows relations of calcite-dolomite to sphalerite in filling of fractures over Virginia zinc district. White is calcite-dolomite. Black is sphalerite. Dash areas are limestone. Natural size.

limestone by metallic sulphides and the gangue minerals without any replacement of the limestone by the sulphides indicated. In this case the sulphide ores are distributed through the filling of calcite and dolomite. In still other cases the fracture may be filled for its entire width at intervals along its length with the sulphides, and the intervening spaces filled entirely with calcite and dolomite, or with a mixture of the gangue and sulphide minerals, as shown in figure 2.

Sufficient developments in the fresh limestone are lacking upon which to base any statement of a grouping corresponding to a vertical order of succession of the dominant metallic sulphides. The idea prevails over the district that galenite, lead sulphide, is more abundant in the upper portions of the rock and decreases in depth, followed by an increase of blende. So far as developments have gone evidence is not wholly lacking to support this idea. At Austinville, where mining has been more extensive in the fresh limestone than elsewhere, blende indicates an increase over galenite in depth, although much galenite occurs at the depth thus far reached.

Little or no blende is found within the zone of alteration at the Austinville mine, while galenite is by no means an uncommon mineral within this zone. This is due, however, not to the absence of blende originally within the fresh rock of this zone, but more to the readiness with which blende alters than galenite. Indeed the large accumulations of the oxidized zinc ores, calamine and smithsonite, found within the zone of decay, affords every evidence of the presence originally of much blende in the fresh rock of this level.

SECONDARY ENRICHMENT

Because of the more extensive mining in the fresh limestone, the Austinville mine again becomes the only one in the district that can be looked to for evidence of secondary enrichment. The common evidences of secondary enrichment are wholly lacking in this mine, but the ore-bodies in the fresh rock are regarded as unmodified ores of primary deposition, or of first concentration. Careful study in the workings of this mine show the conditions to be against rather than favorable to secondary enrichment. Briefly stated these are:

- (1) Recrystallization from solution and cementation of the rock below, resulting in the closing of the original spaces which precluded the downward circulation of the waters.

- (2) The absence of lean sulphides necessary to produce precipitation. Sufficient pyrite in the limestone is lacking to precipitate zinc and lead as sulphides from their oxidized salts. On the other hand zinc sulphide as blende was present in places in sufficient quantity to have precipitated the lead salts as sulphide had the conditions been favorable to the subsequent downward circulating waters.
- (3) The conditions favorable to the conversion of sulphates into the carbonate and silicate of zinc, formed from the oxidation of the original sulphides. This follows in part at least from the statement made in (1); and as stated elsewhere the concentration of the oxidized zinc ores near and along the irregular weathered surface of the limestone in the bottom portions of the residual clays.

MODE OF OCCURRENCE

The Sulphide Ores.—The bulk of the Southwest Virginia ores belong to the disseminated replacement breccia type. As a rule the process of replacement has played an important part in the ore formation, but in some instances very little replacement of the limestone by the ore is indicated. In the latter case the ore would be more properly designated a straight breccia type in which a minimum or no replacement has occurred. On the other hand the ore at Austinville has originated largely through a replacement process.

The breccia is usually made up of sharp-angled fragments of the country rock, magnesian limestone, cemented by a matrix of white crystallized calcite and dolomite, and blende, with or without replacement of the limestone fragments. This type of ore-breccia is perhaps best shown at Cedar Springs, where a little violet fluor-spar is associated with both the calcite-dolomite filling, and the blende. The blende is exceptionally pure and it occurs in crystalline massive form with good cleavage development, but without crystal form. The breccia zones are associated with faulting and folding. Not all parts of the breccia zones are mineralized but the ore is distributed at somewhat irregular intervals. Where mineralized and so far as can be judged from developments, the ore continues with depth. Indeed there appears no reason why the ores should not extend in depth to near sea-level as sufficient "head"

was probably developed, provided the fractures and spaces extend through the limestone to that depth.

At Austinville, where the most extensive developments are made, clear crystallized calcite apparently does not occur, but the rock has been largely recrystallized and small "eyes" of the dark nearly unaltered rock distributed through the recrystallized portion. Here, jointing is freely developed, and ore concentration and replacement of the recrystallized limestone by the ores have taken place along the bedding and joint planes, mostly where the two sets of planes intersect, forming large and well defined ore-shoots. Thus far Austinville is the only place over the Southwest Virginia district where the ore-bodies take the form of well defined ore-shoots. Similar bodies of sulphide ores are developed near Tazewell in Claiborne county, Tennessee. As elsewhere explained the process of mineralization at Austinville began first by filling the fine cracks and then extending into and replacing the anhedra of dolomite by ore, along some crystallographic direction.

At Austinville there seems to be no well defined order of occurrence indicated in the relations of the sulphides to one another in the fresh limestone. The blende and galenite are intimately intermingled. Many parts of the limestone, both small and large, show all blende, with only here and there sparing dissemination of galenite through the rock, closely intermingled with the blende. Other parts of the limestone, usually much smaller in area, show a preponderance of galenite with little or no disseminated blende. The same relation holds true for the very small amount of pyrite present in the rock, which may be intermingled with the galenite or blende or both. The relations between the galenite and blende in the limestone as described above are made plain in figures 13 and 14.

The Oxidized Ores.—As already noted, the important oxidized ores of the Virginia limestone district comprise calamine, smithsonite and cerussite, formed from the sulphides, sphalerite and galenite. Where sufficient developments have been made, as in the Wythe county mines, the oxidized ores usually show much richness, and they are often concentrated in massive form as large irregular masses and layers. This is especially true of the calamine, which forms the dominant oxidized ore. So massive was the calamine in places in the old Bertha mines that blasting is reported to have been necessary at times for its removal.

Concentration of the oxidized ores in the Wythe county mines has taken place principally at and near the bottom of the residual clays, closely hugging the irregular weathered surface of the limestone. Frequently several inches separate the massive form of the ores, calamine and smithsonite, from the limestone. This space may be filled, and oftentimes is, with a loose powdery form of admixed calamine and smithsonite. At times the partially decayed limestone, in pulverulent granular form, partially or entirely fills the space. Much galenite is intermingled, in places, with the concentrated calamine and smithsonite in the lower portions of the clays. Usually, when associated with the oxidized ores in the way mentioned, the galenite is observed to diminish in quantity upward more rapidly than the calamine and smithsonite.

Smithsonite, which is present usually in quantity much smaller than that of calamine, is admixed, as a rule, with the calamine, and the two concentrated in the basal portion of the clays next to the limestone surface. Cerussite, carbonate of lead, occurs largely in stringer-form penetrating the clays; and as a coating on the masses and nodules of galenite. The stringers of cerussite show considerable variation in thickness and extent, but in the larger ones a nearly vertical position in the clays is often assumed.

As a rule the clays are highly ferruginous. Limonite, the hydrous oxide of iron, is found in more or less concentrated form in the clays and at some position in the clays just above the concentration of the zinc and lead ores. The limonite was derived in part, at least, from the oxidation of the original sulphide of iron, pyrite, disseminated through the limestone in association with the sulphide ores of lead and zinc, galenite and sphalerite. The limonite, as a rule, is of good grade, and it occurs so extensively in some of the mines originally worked for zinc ores, that attention is now given entirely to the mining of the iron.

The relations between the ores, the limestone and the clays, as described above, are brought out in figures 10 and 16.

THE RELATION OF THE ORES TO THE GEOLOGIC STRUCTURE

Folds.—It has already been pointed out that with one exception the zinc and lead ores of Virginia are limited in distribution stratigraphically to the Shenandoah limestone. Furthermore it was

shown that the limestone has been greatly disturbed over parts of the region, resulting in folding and faulting. Only in one locality have developments progressed sufficiently far in the mining of the ores to afford any indications, if they exist, of the possible relations of the ores in mode of occurrence to the geologic structure of the associated rocks.

At the Austinville mines in the extreme southern part of Wythe county mining operations have extended to some depth below local ground-water level into the unaltered sulphide ores, sphalerite and galenite. New river cuts across an anticlinal of the Shenandoah limestone near the mines. The accumulation of the ores is in the magnesian limestone strata which dip about 45° southeast, and form the corresponding limb of a faulted and subsequently eroded anticline. About eight and a half miles northeast of these mines, on the same (south) side of New river about one mile are located the old Bertha mines. Here operations were entirely limited to surface mining of oxidized ores over a belt about 1500 feet wide extending in the direction of the strike of the limestone, which is south 35° - 40° west. The dip of the limestone where measured was 25° northwest, with flatter dips reported.

Recent prospecting about 20 miles west of Austinville in the extreme southwest corner of Wythe county at Cedar Springs seemingly indicates that the ores occur on or near the faulted crest of an anticline. The distribution, therefore, of the ores in Wythe county is along a narrow belt which crosses the southern part of the county in a north of east direction. This belt is a structure zone—one of anticlinal folding and faulting, and the ores are deposited along and near the fault in the shattered and recemented limestone of the anticline. Precisely similar relations obtain in the East Tennessee lead and zinc district, which is a continuation southwestward of the Virginia district.

Over other parts of Southwest Virginia, beyond the limits of the Wythe county area, where lead and zinc occur, practically no developments have been made, hence no statement of the relations of the ores to the folds, if any, can be made.

Faults.—Examination of the Wythe county area further indicates a zone of intense metamorphism along an approximate north-east-southwest direction. The limestone of this zone shows distinct evidence of crushing and recementation. It has been largely

rendered moderately coarsely crystalline, nearly white in color, yielding practically a fairly coarse grained light gray marble, as shown in plates VIII and IX. As later explained the ore formed here and over Southwest Virginia district is of the disseminated replacement breccia type. It has already been pointed out that the district is one of faulting. Moreover the faulting has taken place in many cases along the anticlinal folds, and as a result the limestone has been shattered and recemented along the breakage direction, forming more or less distinct breccia zones. The ores have been deposited in these breccia zones, usually, showing much replacement of the limestone by them. It is not always possible to locate definitely the exact position of the fault, but wherever prospecting has been done and ore found its occurrence in the brecciated limestone is noted.

In the underground workings of the Austinville mines, breakage lines in the limestone which conform to three directions of the compass can probably be referred to faulting. Above ground these breakage lines are much less apparent, and so far as could be determined in the workings below the surface the fractures are apparently confined to the limestone. Careful examination failed to reveal any localization or accumulation of the ores in these lines of breakage below the surface, but they impregnate the crushed and recrystallized limestone on one or both sides of the breakage lines.

At the Osborn zinc mine in Russell county faulting is very distinctly shown in the openings. At Cedar Springs in Wythe county, and in Rye Valley, Smyth county, faulting is equally apparent.

LOCALIZATION OF THE ALTERED ORES

Alteration of the original sulphide ores into oxidized forms within the zone of weathering has resulted in the localization of the secondary ores mostly on or near the irregular weathered surface of the limestone between the limestone and the residual clays. See figures 10 and 16. Some accumulation of the ores has further taken place in the partings and open spaces in the clay, and may occasionally partially penetrate the irregular fractures of the limestone. Seams of the oxidized ores are frequently observed in the residual clays, ramifying in all directions. Both the cerussite, lead carbonate, and calamine, hydrous zinc silicate, conform in part, in places, to this mode of occurrence in the Wythe county mines.

AGE

Since the ores have been shown to follow rather closely the faulted breccia zones they were formed after the period of deformation which resulted in the folding, faulting and shattering of the limestone near and along the lines of breakage. This period of deformation probably dates back to late in, or after the close of, the Carboniferous. The original sulphide ores must antedate the secondary ores, since the latter were derived from the former by the usual processes of atmospheric decay. The altered or secondary ores originated with the periods of peneplanation, of which there were several, the earliest and most extensive one being of Cretaceous age, followed by later and less extensive ones cut during Eocene and Neocene times. The original sulphide ores may be as old as the Permian or as young as late Mesozoic, but evidence is lacking on which to fix their age more definitely.

DESCRIPTION OF THE MINES

Since the ores of lead and zinc are distributed to some extent over parts of two geologically unlike areas, the deposits naturally group themselves into two provinces: (1) Those deposits occurring in the Crystalline area; and (2) those deposits occurring in the Great Valley region of Southwest Virginia. This division of the lead and zinc deposits of Virginia into two districts is adhered to in the description of the mines below.

THE CRYSTALLINE AREA

General Statement.—The Crystalline area comprises the middle province of the State, named the Piedmont Plateau, which forms a part of the continuation of the same province to the north and south of Virginia. In Virginia the Crystalline area extends eastward from the Blue Ridge to the fall-line, which line marks the contact in the overlap of the Crystalline area by the more recent Coastal Plain sediments. In Virginia as in the states immediately north and south, the fall-line is not a straight contact line between two geologically unlike areas, but it is marked by considerable irregularity. It enters Virginia at a point on the Potomac river, several miles west of Washington, D. C., and is traced in a general southward direction, passing within approximately two miles west of Fredericksburg; close to the cities of Richmond and Petersburg,

and the town of Emporia in Greenville county, thence southwestward through the Carolinas and Georgia.

Geologically, the Piedmont Plateau is composed essentially of a complex of granite-gneiss-schist rocks. These include both igneous and sedimentary masses. The rocks are referred in part to pre-Cambrian and in part to post-Cambrian age. The age and structural relations of the rocks composing this geologically complex area are yet far from being solved.

Distribution of Lead and Zinc Ores.—Lead and zinc ores have as yet been observed in workable quantity only in one locality within the limits of the Crystalline area, namely, near Faber, in Albemarle county. In addition to the occurrence in Albemarle county, galenite, sulphide of lead, has been noted in very sparing quantity in a number of counties within the Crystalline area, where it occurs in association with other sulphide ores in some of the gold, copper and pyrite mines of the State. At none of these localities, however, can the mineral galenite be seriously considered commercially, for the reason that its occurrence amounts to barely more than a trace in quantity.

The ores of zinc are less widely distributed within the Crystalline area than those of lead. The only development in this area is in the southern part of Albemarle county near the Nelson county line. Only the sulphides of the metals, lead and zinc, are known to occur in the Crystalline area. These are galenite, sulphide of lead; and sphalerite, sulphide of zinc.

ALBEMARLE COUNTY

The Albemarle Zinc and Lead Company's Mine

Historical.—The first discovery of lead and zinc ores in Albemarle county, Virginia, was made in 1849 by an old gentleman named Burford. A piece of lead ore found by Burford on the surface of his property, which occupied the east slope of Butler's Mountain, two miles northeast of Faber, a station on the Southern Railway, led to the discovery. The fragment of ore was carried by Burford to Faber's Mill, now Faber, and melted by William Faber in his blacksmith's forge. Messrs. William Faber and Nicholas L. Martin purchased the property of Burford and with their farm hands opened it up in a crude way. Enough work was done by them to sufficiently develop the vein to enable them to sell it at a

good profit to a northern party whom it is claimed, removed a good quantity of lead ore. The ore was shipped to New York for smelting and it is said to have contained some silver, a part of the ore running as high as 31 ounces of silver to the ton. The owner having failed to meet some of the deferred payments on the property, it was again sold under mortgage to the first party. More recently, the property has been sold to a party of Philadelphia capitalists, who are now operating it under the title of the Albemarle Zinc and Lead Company, Inc."

The mine was worked by the Confederates during the Civil War and it is claimed that their government paid a royalty on 7,204 pounds of lead mined. It was being worked by the Confederates when General Sheridan crossed the Blue Ridge at Rockfish Gap, but work was abandoned during the raid.

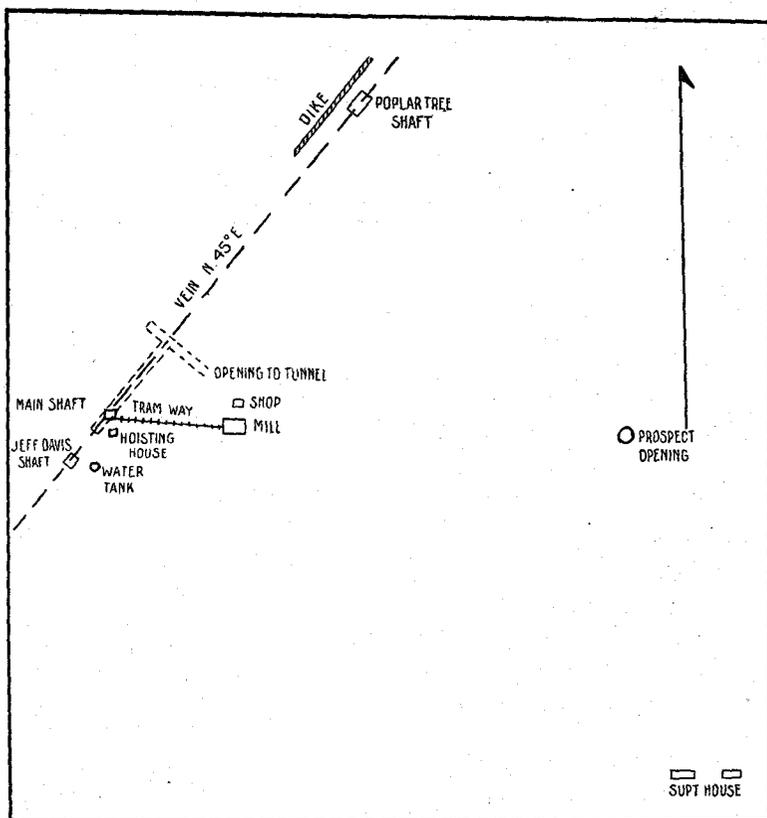
Until recently the property was worked entirely for lead, or for it and silver which the lead contained, the zinc ore having been overlooked by all previous workers. The present owners are just completing an 80-ton concentrating mill and are further actively engaged in underground developing.

Description.—The property includes about 750 acres, located two miles slightly north of east from Faber, a station on the Southern Railway, just across the Nelson county line in Albemarle county. The main developments consist of three shafts sunk at depths of 25, 50 and 120 feet on the vein at a distance of something less than 1,000 feet between the two extreme shafts. In addition to the three shafts the vein was cut by an adit level run into the hill slope and a cross-cut run from the adit tunnel in and along the vein for a distance of 140 feet, which extends beyond the middle and deep shaft. Map, figure 3, is a sketch of the workings and plant.

As indicated on the accompanying map, figure 4, the area in which the openings have been made is located in the eastern foot hills of the Blue Ridge and its topography is correspondingly rough and irregular, composed of a pronounced hilly type. The rocks are metamorphosed crystalline schists cut by a series of basic igneous dikes of diabase and diorite. The microscope reveals several types of the schist, which are easy of differentiation in the field in the moderately fresh outcrops. These are thinly schistose sericitic, chloritic and talcose schists, alternating or interbedded with a quartz-mica conglomerate schist. (See plate IV, figure A). The

sericite is quite garnetiferous in places, filled with small perfect crystals of red garnet. The chlorite schist is the ore-bearing rock. It is thinly fissile and strongly crinkled, the axes of the crinkling making an angle of about 90° with the plane of fissility as nearly as

Fig. 3.

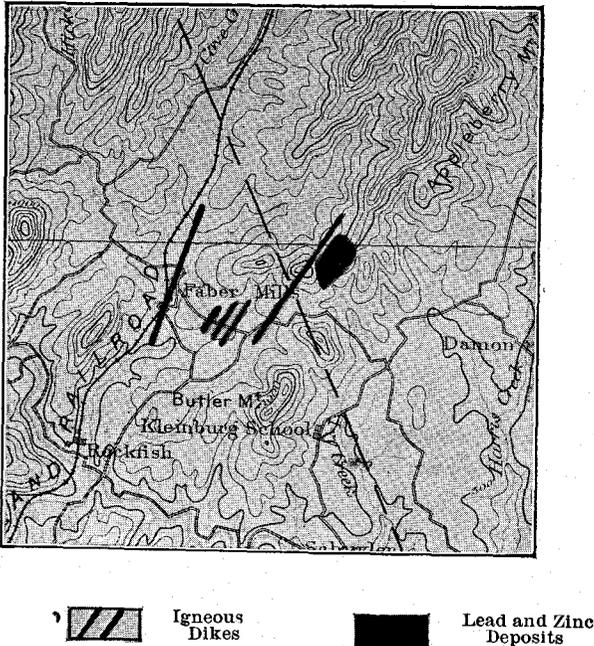


Plan of Albemarle Zinc and Lead Company's Mine, near Faber, Albemarle County, Virginia.

could be determined. It contains little or no quartz and feldspar but is largely composed of the ferromagnesian silicates. By the addition of quartz, this grades into the conglomerate-schist, which is composed of quartz, a little feldspar, and some mica which is more or less altered to chlorite. The rock contains small fragments of granite, gneiss and schist which are orientated in the direction of the

schistosity and are partly crushed and mashed from pressure effects. The fragments are in part rounded and in part angular. A few pieces of calcite were observed and a scant sprinkling of chalcopyrite occurs. This rock is also cut by thin stringers of quartz and pegmatite. Figure 5 is a cross-section of the gulch in which the mine openings are made and which shows the relations of the crinkled schist to the conglomerate schist.

Fig. 4.



Map of Lead and Zinc Deposits in Albemarle County.
Based on the Buckingham Sheet, U. S. G. S. Geology by Thomas L. Watson.
Scale $\frac{1}{2}$ inch=1 mile. Contour Interval 100 feet.

Study of this series of rocks both in the field and in the laboratory leaves no doubt of its sedimentary origin. The strike is N. 45°-50° E. and the dip is 70°-85° N. W. The exact age of these rocks is yet undetermined. Rogers mapped them as pre-Cambrian or Archaean, but more recent work further north in Pennsylvania and Maryland, in similar areas, probably indicates a younger age, as late as Cambrian and possibly post-Cambrian. Not until more

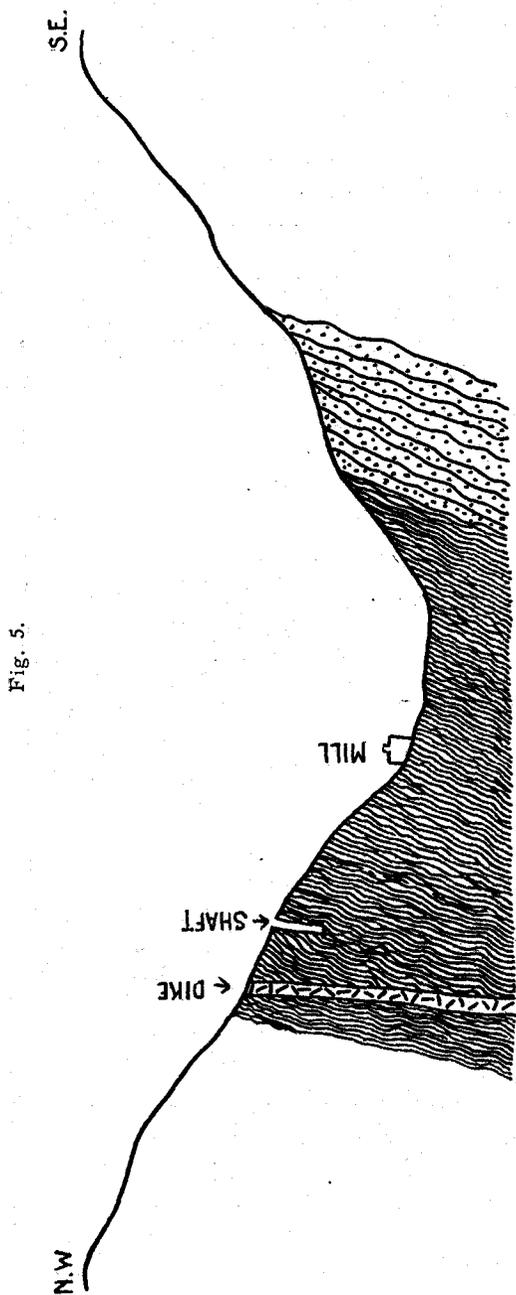
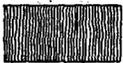
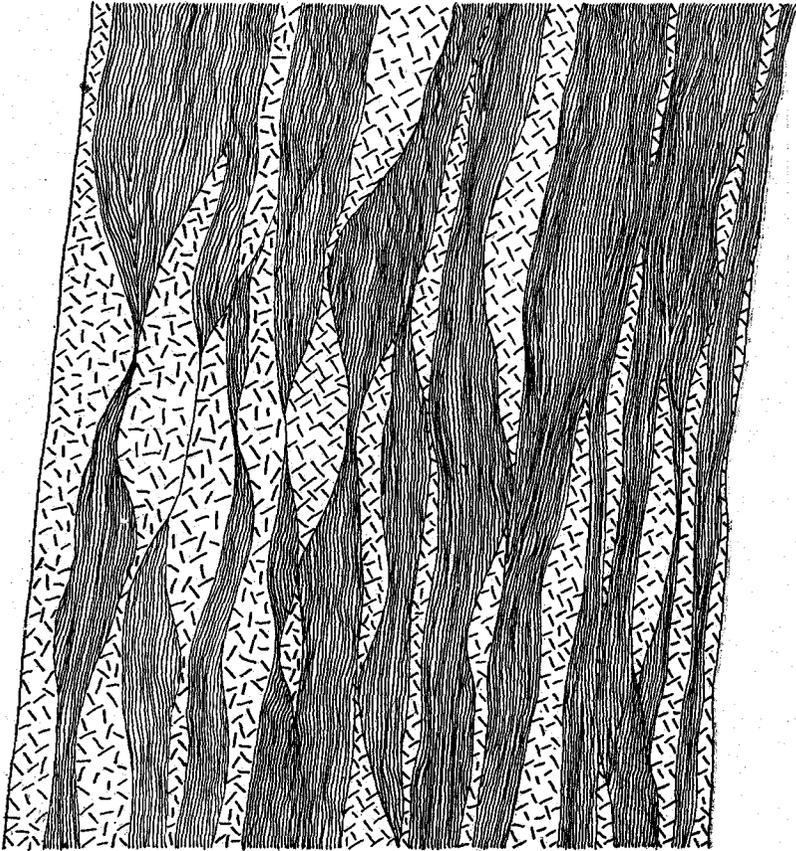


Fig. 5.

Section across Ravine at the Albemarle Zinc and Lead Mine. Albemarle County, Virginia.

extended and detailed work over the Virginia Piedmont area is done can we hope to definitely settle the age of the rocks in question.

Fig. 6.



SCHIST



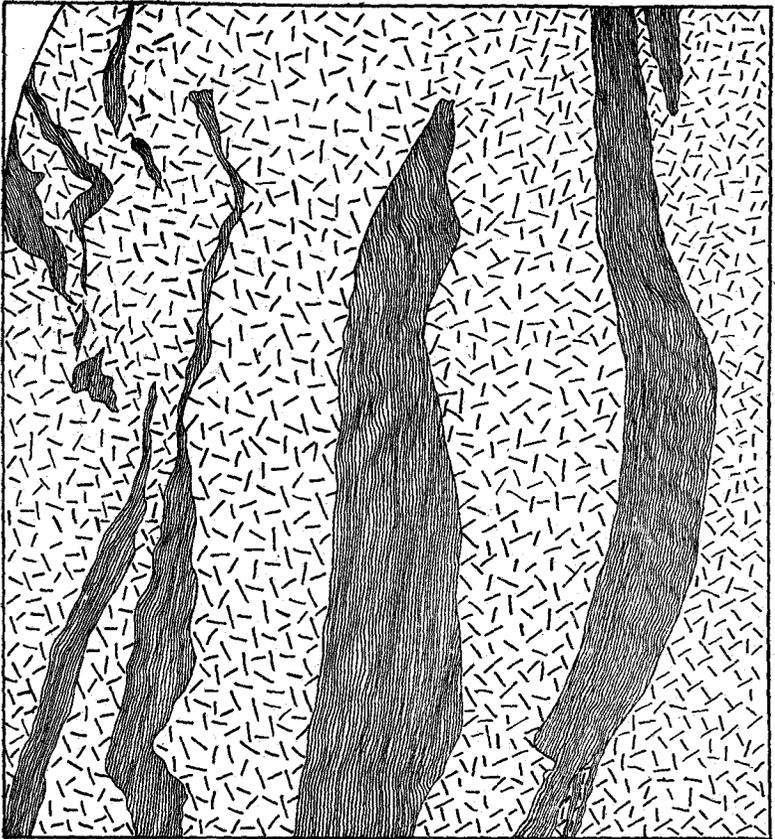
FLUOR SPAR
AND
QUARTZ

Diagram illustrating the type of fissure vein formed at the Albemarle Zinc and Lead Mine, Albemarle County, Virginia.

At Faber's station on the east side of the railroad is a nearly continuous exposure in the form of boulders for several miles of a diabase dike. Under the microscope thin sections of the rock show the typical diabase texture and normal composition. From this

point eastward to the mine openings are observed numerous intrusions of diorite. One of the largest of these dikes is exposed within 25 paces northwest of the Poplar Tree shaft. As nearly as could

Fig. 7.



SCHIST STRINGERS



FLUOR SPAR
LITTLE QUARTZ

Fluorspar lens, Albemarle Zinc and Lead Company's Mine, near Faber. Shows included stringers of the schist. One-half natural size.

be determined the diorite dikes have observed trend of N. 45° E., which direction is parallel to that of the metalliferous vein. These dikes show considerable alteration of the minerals composing them.

The most abundant constituent is hornblende and its common alteration product, with quartz and some feldspar. The dike of diabase at the depot is entirely unaltered in fresh pieces of the rock. It is of the normal Mesozoic type and is probably younger than the series of diorite intrusions. Its trend is some different from that of the diorite, it being about N. 5°-10° E.

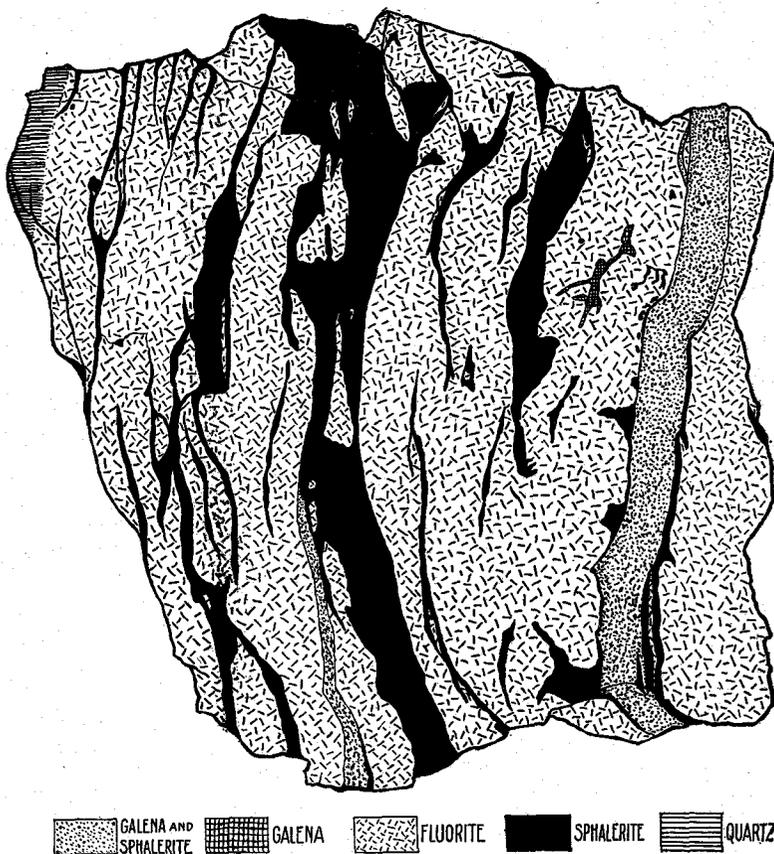
The vein is reported to have been traced for a distance of several miles on this and the adjoining properties. It varies in width, but will average about four feet; strike N. 45° E. exactly paralleling the diorite dike 25 feet away on the northwest side, and dips 80°-85° N. W. Where opened it is of the lenticular type, composed of bulbous or lenticular bodies of fluorspar admixed with some quartz through which the ore, blende and galena, is distributed. The fluorspar-quartz lenses vary much in size, and are often connected by a mere film or plate of fluorspar-quartz, which in other instances may be lacking altogether, giving the appearance to the vein in such cases, of having given out. A marked banded structure is frequently indicated, particularly near the walls, which is due to included plates of the schist. These films are often characterized by some impregnation of ore. The relations of the fluorspar-quartz lenses to the enclosing schist are well shown in figure 6.

The ore, consisting of blende and galena, occurs principally 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. Figure 8, which is a sketch of a large mass broken from one of the lenses, shows both of these occurrences. On working out the ore the two walls are perfectly smooth and solid. Enough work has probably not yet been done to indicate the relations of the two ores, blende and galena, but so far as developments extend there seems to be some tendency shown in the galena to follow or occur close to the foot-wall and the blende the hanging-wall. This relation may probably not continue on depth. It is the common belief that the fluorspar and blende increase on depth and that the quartz and galena decrease. The operations, however, have not yet advanced beyond the prospecting stage, and sufficient depth has not been reached nor enough work done, to establish any definite relationship in the ores to each other, and to the gangue.

Specimens of the blende collected by the writer gave Mr. J. H. Gibboney the following results on analysis:

	Per Cent.	
Zinc (Zn).....	62.11	} Equivalent to 92.70 per cent. of zinc sulphide, sphalerite, or blende.
Iron (Fe).....	3.44	
Sulphur (S).....	34.45	
Lime (CaO).....	.05	
Silica (SiO ₂).....	.26	
Total.....	100.31	

Fig. 8.



Specimen of fluorite lens, showing distribution of the sulphide minerals, sphalerite and galenite. Albemarle Zinc and Lead Company's Mine, near Faber. About one-third natural size.

In addition to the principal ores, blende and galena, some chalcopyrite occurs, and some smithsonite, cerussite and azurite were reported some years ago from the dumps, by W. H. Seamon. The galena is argentiferous. Both arsenic and antimony are reported in very small quantity. Fluorspar composes by far the bulk of the gangue with more or less admixed quartz. In addition to fluorspar and quartz, a little calcite occurs and feldspar has been reported. The fluorspar is mostly white, but quite a sprinkling of the amethyst shade occurs at times.

The following analysis was made by W. H. Seamon on a sample of the ore collected by him and believed to represent an average of the vein at that time:³⁴

	Per Cent.
Zinc.....	32.00
Lead.....	4.02
Calcium.....	9.09
Iron.....	1.86
Insoluble residue.....	25.24
Silver, per ton.....	2 to 3 oz.
Copper.....	trace
Arsenic.....	trace

Recalculated in another form the ingredients are:

	Per Cent.
Zinc sulphide, calculated from zinc.....	48.22
Lead sulphide, calculated from lead.....	4.65
Calcium fluoride, calculated from calcium....	17.75
Ferrous sulphide, calculated from iron.....	2.92
Insoluble residue.....	25.24
Total.....	98.78

The very close association of the vein with dikes of igneous rocks makes it reasonably certain that the ores are genetically related to the igneous intrusions. The evidence of such relationship is strengthened when the composition of the gangue and the metallic contents is considered. The principal and abundant gangue mineral, fluorite, and the metallic sulphide, argentiferous galena, with traces of both arsenic and antimony, constitute an association of minerals, such as can best be explained on the supposition only of highly heated conditions. Such could only have been deposited

³⁴Seamon, W. H., *The Virginias*, 1885, Vol. VI, p. 47.

from waters of deep-seated origin, or from waters whose source of heat was derived from intruded igneous masses.

As to the age of the deposits it can only be said that in case the ores are genetically related to the dikes of igneous rocks, which seems probable, the deposit could not be older than the diorite dikes. These dikes, however, are found to be altered in every case and are presumably older than the dike of diabase found east of Faber station, which can without much doubt be assigned to Mesozoic age. The deposits, therefore, can not be younger than the diabase intrusion and are probably not older than the period of dioritic intrusion, the exact age of which has not yet been fixed.

Equipment and Treatment.—The equipment includes a concentrating mill of 80 tons capacity per 24 hours, recently completed; eight sets of dry jigs; crusher, dryer, rolls and screens; and steam power of sufficient horse-power for operating the entire plant, including hoist, tram-cars and cable for conveying the ore from the shaft to the mill. Compressed air drills are used in the underground mining. The water used is conveyed through pipes pumped from ponded springs about 300 feet north of the property.

The dry process is employed in milling for separating the ore. The problem is principally one of separating the blende from the fluorspar, and of freeing the zinc concentrates from lead and the lead concentrates from zinc. The ore is crushed and sized to pass a 16 mesh screen. All ore above this size is passed back to the rolls and crushed until properly sized. Thence the ore goes to 4-roughened jigs and from here to 4-finishing jigs. By this process it is claimed that the tailings are practically free from all ore. If not, the jigs can be so regulated as to make a nearly complete separation. The important factor involved is that of time required in regulating and running the jigs. The trials so far made at the mill required the jiggling process to be repeated several times on the same ore before a clean concentrate was obtained. In other words a single jiggling was not sufficient and it was found necessary to pass the so-called concentrates through the jigs at least twice and better still, a third time.

Through the kindness of Mr. Wilkins U. Greene, Mining Engineer, in charge of the plant, several bags of the lead and zinc concen-

trates were sent to the writer, and separately analyzed with the following results:

	I	II
Lead (Pb).....	63.05	6.02
Zinc (Zn).....	12.12	47.88
Iron (Fe).....	3.16	7.26
Copper (Cu).....	trace	.94
Sulphur (S).....	19.32	29.52
Calcium fluoride (CaF ₂).....	1.31	4.74
Insoluble residue.....	1.08	2.90
Total.....	100.04	99.26

I. Lead concentrates from the Albemarle Zinc and Lead Mines, Albemarle county, Virginia. J. R. Eoff, Jr., analyst.

II. Zinc concentrates from the Albemarle Zinc and Lead Mines, Albemarle county, Virginia. J. R. Eoff, Jr., analyst.

Mr. Greene has kindly furnished the following analyses made in Philadelphia on the lead and zinc concentrates mined and milled at the Albemarle plant.

	Lead Concentrates Per Cent.	Zinc Concentrates Per Cent.
Lead (Pb).....	76.49	4.42
Equivalent to galena.....	88.31	5.11
Zinc (Zn).....	4.60	55.02
Equivalent to blende.....	6.90	82.10

It is claimed from the tests made on the concentrates from this mill that the following results represent fairly well the average of their composition:

Zinc concentrates: Zinc 55 pr. ct., lead 4 pr. ct. }	Copper about .05 pr. ct.
Lead concentrates: Lead 85 pr. ct., zinc 4 pr. ct. }	Iron about 3 pr. ct.

The dry process employed at the Albemarle county mill for separating the ore differs essentially from the wet in the form of jig used. The Crum jig is used at the Albemarle plant, which is made of screens of different size meshes, substituting air for water. These can be set to 700 puffs per minute of air. The ore passes off the jig over the back or rear and the refuse or tailings over the front.

THE VALLEY REGION OF SOUTHWEST VIRGINIA

General Statement

The production of lead and zinc ores in the State has been almost exclusively from the Valley region of Southwest Virginia. The ores have been worked in the following counties of the Valley region: Botetourt, Roanoke, Montgomery, Pulaski, Wythe, Smyth and Russell. Of these Wythe has been the important producing county. Work in the other counties has been largely in the nature of prospecting. Both lead and zinc are found in other counties of the Valley region, but so far as can be determined they do not occur in workable quantity.

The rocks of the Valley region of Southwest Virginia comprise a vast thickness of Paleozoic sediments, ranging in age from Cambrian to Carboniferous, inclusive. They include limestones, quartzites, sandstones, conglomerates and shales. Igneous rocks are not known to occur within the limits of the region. A résumé of the geology of the Valley region is given on pages 23-31 of this report and need not be repeated here.

The lead and zinc deposits are limited to a single formation, the Shenandoah limestone of Cambro-Ordovician age.

Historical

Lead mining in Virginia dates back more than 150 years, when lead ores were first discovered and worked at Austinville in Wythe county, Virginia. Finding lead ore in the outcropping, partially decayed limestone at the surface led to the discovery. Colonel Chiswell, a native of Wales and one of the earlier adventurers in Southwest Virginia, was the first one to work the Austinville mine. His operations at Austinville commenced in 1750 and closed in 1776. Mining on this property by Chiswell was for lead only and it consisted almost wholly of open work. However, an attempt was made by Chiswell to reach the "vein" at a lower depth, and he began driving a tunnel into the limestone hill from the edge of the river under a high cliff below the mouth of Bald Hill spring branch. The tunnel was driven through hard limestone for a distance of 20 feet and abandoned, it being now known as Chiswell's hole (see map, figure 11.) The ores were washed at the Bald Hill spring branch near the mining of them, and they were smelted on the hill southeast of the Long Hole shaft.

The remains of Colonel Chiswell's smelting plant indicates that it was a common air furnace, the hearth and roof having been built of fire-brick, which probably came from England. Among the remains was found the bottom of a small cupel furnace impregnated with oxide of lead, indicating that it was probably used for refining and the "trial to extract silver from lead," which probably started the tradition prevalent in the vicinity that Chiswell had made silver from lead, and had buried a pot of coined silver somewhere about the place.

Chiswell's career ended after the commencement of the first Revolutionary War (1774-1776). He is reported to have been a Tory and died in jail at Cumberland C. H., Virginia, about 1776. He being an alien, his property reverted to the State of Virginia, and it was sold between the dates of 1780-1800 to Stephen and Moses Austin, who continued the manufacture of lead at the mines. From this time down to the date of acquisition by the Bertha Mineral Company (August, 1902), the property passed through many hands, and was worked for lead until the Civil War.

From 1838-1848 the Wythe Lead Mines Company acquired and worked the property. During this period Scottish furnaces were built which were called smelt mills. Shot-making was commenced by them in 1843. Slag furnaces for smelting the slag which had accumulated for some time, were later built on the site of the old Scottish furnaces. During the period of 1838-1846, the amount of lead made on this property was 6,511,450 pounds, valued at \$146,577.07.

From 1848-1858 the property was worked by the Wythe Union Lead Mine Company which, it is claimed, produced 7,613,334 pounds of lead, valued at \$241,178.72. In 1851⁸⁵, 8,244 bags of shot were made between July 3, 1851, and March 31, 1852. Shot was manufactured for the Confederate Government up to December 17, 1864, when the works were burned by raiding Unionists. The damage was repaired at the close of the war. The Union Lead Mining Company was incorporated March 8, 1860, for the purpose of mining and manufacturing lead and shot, at \$400,000 capital. The amount of lead made from February 17, 1858, to April 1, 1868, was 6,813,662 pounds, valued at \$513,507.89.

The Wythe Lead and Zinc Mining Company later acquired the

⁸⁵ Higgins, E. Jr., *Eng. and Mng. Jour.*, 1905, Vol. 79, p. 610.

property and sold it to the Bertha Mineral Company in August, 1902. The Bertha Company is now actively engaged in exploring and developing underground the large bodies of sulphide ores, lead and zinc, in the hard limestone. During the very long period of working this property, the zinc ores seem not to have been recognized until about the time of the Civil War, all mining having been exclusively for lead ores up to this time.

Zinc ores seem to have been recognized first at the Austinville mines, some time during the Civil War, when at the request of the War Department of the Confederate States,³⁶ several tons of the ore were sent by the owners to the smelting works at Petersburg, Virginia. Soon after the close of the Civil War contracts were made for the shipment of zinc ores to the Lehigh Zinc Works, at Bethlehem, Pennsylvania, and the Mercer Zinc Works at Trenton, New Jersey.

Zinc ores were discovered at Bertha in 1866 by David S. Forney³⁷, who, it is claimed, was a pioneer in the active development of this part of the Virginia mineral region. Case says that the zinc ore was discovered at Bertha by Forney "not from any visible outcrop or float, but in the amateur pursuit of mineralogical and geological investigations, suggested by the favorable appearance of the region to which he came from Pennsylvania to pursue his profession of landscape artist."³⁸

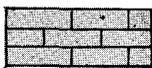
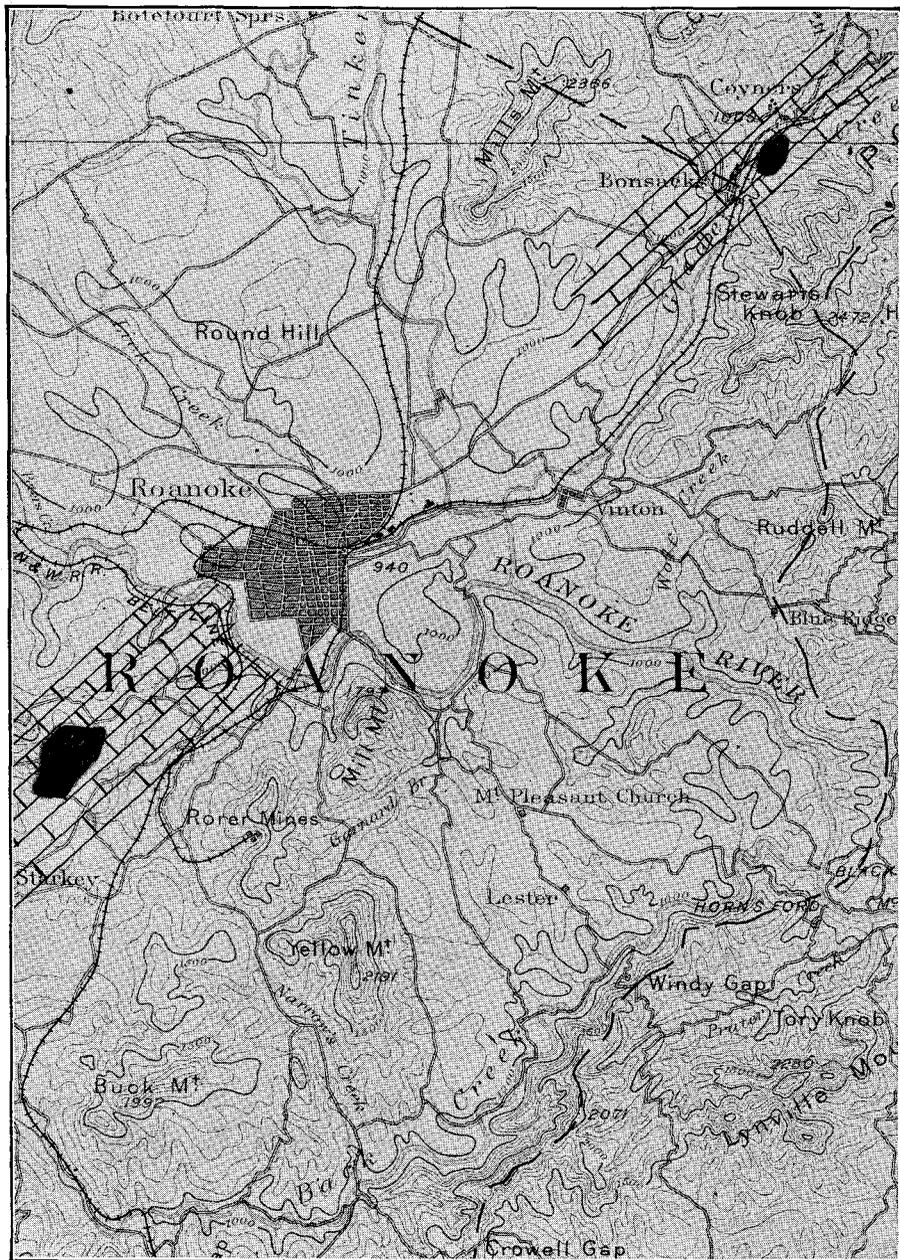
Mining of zinc ores in Virginia properly dates from the opening of the mine at Bertha in the southeast corner of Wythe county, in 1879, when a small shipment of ore was made to Providence, Rhode Island. The results of this shipment of ore proved so promising that mining was commenced at once and was continued until 1898, when the property was leased in 1898 to the Pulaski Iron Company, for the purpose of mining brown iron ore, limonite. At the time of leasing the property, it was hoped that by removing the cover of iron ore, more zinc ore would be found. The writer feels convinced, however, that the encouragement for such hope of finding workable bodies of either the oxidized (soft), or sulphide ores, is slight. However, the property is now producing large quantities of the iron ore.

The metal obtained from the zinc ores shipped from Bertha,

³⁶ Higgins, E. Jr., *Eng. and Mng. Jour.*, 1905, Vol. 79, p. 610.

³⁷ Case, Wm. H., *Trans. Amer. Inst. Min. Engrs.*, Chicago Meeting, Aug. 1893, Author's Edition, p. 26.

³⁸ *Ibid.*, p. 26.

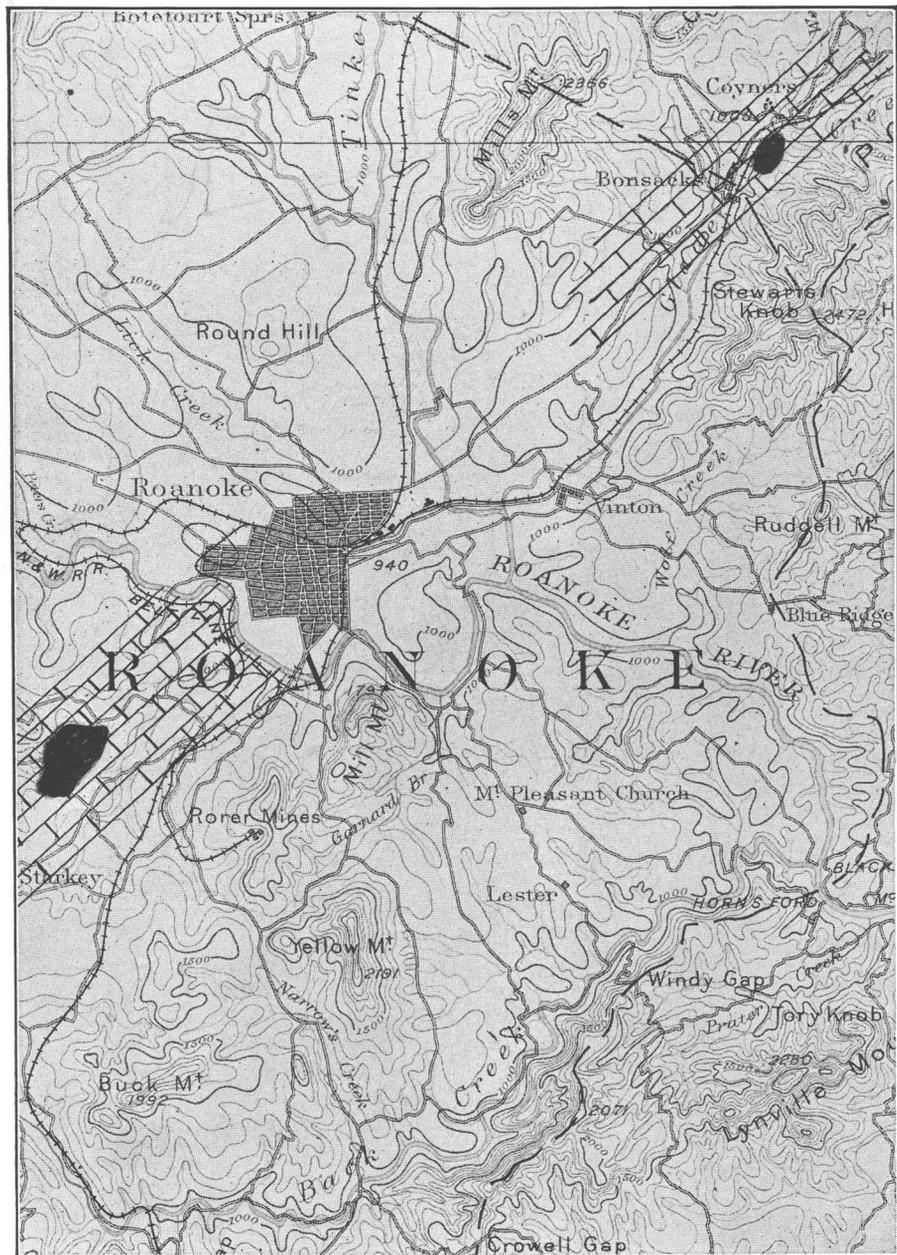


Shenandoah Limestone



Lead and Zinc Deposits

Map of the Lead and Zinc Deposits in the vicinity of Roanoke, Virginia. Based on the Roanoke Sheet, U. S. G. S. Geology by Thomas L. Watson. Scale $\frac{1}{2}$ inch = 1 mile. Contour Interval 100 feet.



Shenandoah
Limestone



Lead and Zinc
Deposits

Map of the Lead and Zinc Deposits in the vicinity of Roanoke, Virginia.
Based on the Roanoke Sheet, U. S. G. S. Geology by Thomas L. Watson.
Scale $\frac{1}{2}$ inch = 1 mile. Contour Interval 100 feet.

Virginia, to Providence, Rhode Island, proved to be of such rare purity that attention was at once directed to the ores, and a small smelting plant was built at Pulaski, Virginia.³⁹ This plant was later remodeled and enlarged. It is owned by the Bertha Mineral Company, and a full description of the plant is given on pages 140-148 of this report. This commenced the manufacture of high grade Bertha spelter which has grown into an enterprise of considerable economic importance, and which has a world-wide reputation.

ROANOKE AND BOTETOURT COUNTIES

Ores of zinc and lead have been opened at two places in the vicinity of Roanoke city; one on the Martin property, $2\frac{3}{4}$ miles southwest of Roanoke city, in Roanoke county; the other just across the county line in Botetourt county, $\frac{1}{2}$ mile northeast of Bonsack, a station on the Norfolk and Western railroad. While some ore is reported to have been shipped from the Martin property many years ago, the work at each place is to be regarded entirely in the nature of prospect openings.

The location of the ore deposits and the topography of the region are shown on the accompanying map, plate II. At each place, the ore occurs in the dark gray, crushed, crystalline magnesian limestone of Cambro-Ordovician age.

The Martin Prospect.—The openings made for lead and zinc ores on the Martin property are located $2\frac{3}{4}$ miles southwest of Roanoke city. The work done comprises some half-dozen small openings in limestone, scattered over an area of about three acres in extent. These are further grouped along a small stream which has carved a moderate valley out of the limestone. The deepest opening will not exceed 25 feet in depth, and its surface is only a few feet above the stream level.

A little prospecting is reported to have been done at this place prior to 1840, but the principal work was done in 1885 and shortly after, when some ore is said to have been shipped to several different points. Very little could be seen at the time of my visit, as the dump-piles had been cleaned up rather thoroughly of ore and the openings were filled with water. A careful examination of the dumps showed the occurrence of the sulphides of lead, zinc and iron, in the form of the minerals galenite, sphalerite and pyrite,

³⁹ Moxham, E. C., *Eng. and Mng. Journ.*, 1893, Vol. 56, p. 544.

in close association. No ore was seen in place. Much oxidation of the pyrite was indicated over the dumps in the presence of a white coating of iron sulphate. So far as could be determined, the conditions apparently indicate that very little, if any, workable ore will be found at this place.

As shown in the analysis below, the ore-bearing rock is a magnesian limestone. It is dark gray, nearly black in color, finely crystalline, and has been much crushed and recemented by films and stringers of white calcite or dolomite. It is further interbedded in places with a thinly laminated, purplish red shale, which also bears distinct evidence of crushing in its crumbling on the outcrops into very small fragments. A partial analysis of this shale is given below. Good exposures of the limestone and shale are found on the Wertz place, a short distance southeast of the openings on the Martin place, where reliable measurements of the dip and joints were obtained. The limestone and shale are conformable, showing an average dip of 30° S. E. The shale shows jointing in two directions, namely, N. 55° E. and N. 20° W. In the limestone, similar jointing was observed, their directions, where measured, being N. 20° E. and N. 10° W. The shales at this point are closely jointed and joint spaces filled in places with white calcite or dolomite.

	I	II
Insoluble residue.....	2.90 ⁴⁰	—
Silica (SiO ₂).....	trace	54.95
Titanium oxide (TiO ₂).....	none	0.48
Alumina (Al ₂ O ₃).....	0.43	21.41
Iron oxide (Fe ₂ O ₃).....	0.94	5.00
Manganese oxide (MnO).....	none	0.21
Lime (CaO).....	30.06	0.23
Magnesia (MgO).....	18.41	
Potash (K ₂ O).....	0.24	
Soda (Na ₂ O).....	0.21	
Water, total (H ₂ O)....	3.30	
Carbon dioxide (CO ₂).....	43.98	
Total.....	100.47	

- I. Massive, grayish-black limestone from the Martin property, two and three-fourth miles southwest of Roanoke city. Dr. W. E. Barlow, analyst.
- II. Thinly laminated purplish-red shale, from the Wertz property, two and three-fourth miles S. 55° W. of Roanoke city. Thomas L. Watson, analyst.

⁴⁰The residue consisted of 1.39 per cent. of sand and clay; and 1.51 per cent. of matter lost on ignition, apparently carbon.

The Bonsack Prospect.—A single opening in the form of a shaft has been made in the limestone on the edge of a small cut along the Norfolk and Western railroad, about $\frac{1}{2}$ mile N. 30° E. from Bonsack, and about $6\frac{1}{2}$ miles northeast of Roanoke city. This is a test-opening and probably did not penetrate the limestone exceeding 50 feet in depth, and presumably much less. The dump showed some pyrite, a little chalcopyrite and sphalerite, the former greatly predominating. No galenite or lead ore was noted. Here, as at the Martin openings southwest of Roanoke, the pyrite shows much oxidation. Judging from the dump sphalerite, or zinc blende, is very sparingly present, and the prospect shows little or no encouragement, so far as lead and zinc ores are concerned.

The only evidence of ore in place was observed in the limestone, exposed in the small cut made by the Norfolk and Western railroad, just below the shaft. This consisted mostly of pyrite, more or less oxidized, concentrated in irregular stringer fashion in the limestone. The limestone is entirely similar to that on the Martin place described above. It is a grayish-black, crystalline limestone which has been much crushed and recemented by the white calcite or dolomite. Just above the shaft and back a few paces on the hill-slope, is an exposure of the reddish shales in which a well defined system of joints trending N. 45° - 50° W. is developed.

MONTGOMERY COUNTY

More or less prospecting for zinc and lead ores has been done in a number of places in Montgomery county, but as yet no productive areas of the ores have been found. The localities at which prospecting has been done are as follows: In the extreme southwestern part of the county, on Bony's creek, $2\frac{1}{2}$ miles southeast of Shawsville, on the Langhorn estate and the adjoining property owned by Wills; on the Walker and Vaughn properties south of the Norfolk and Western railroad, between Shawsville and Big Tunnel; and about two miles south of Christiansburg. Zinc ore has been reported as occurring on the Cloyd property located on New river, about 8 miles southwest of Blacksburg.

A small part of the work has been done recently, but most of it is of long standing, dating back 20 years and longer. The strongest indications of ore on any of the places examined could hardly be called more than a trace. Samples have been shipped

from time to time, but nothing that approached even a workable grade of ore has been discovered.

The most extensive prospecting done was on the Langhorn estate, located in the southwestern part of Poor Mountain, about 2½ miles southeast of Shawsville. The area rises 2,000 to 2,500 feet above sea-level and it presents a roughened and much dissected topography. The rock is magnesian limestone, dark gray in color and crystalline, and is interbedded with narrow bands of purplish red and occasional black shales, the average strike of the series being N. 30° E., and dipping 65°-70° S. E. In places the limestone is exceedingly porous and spongy, but as a rule it is compact and finely crystalline in texture.

Because of long standing the openings had so caved-in that a satisfactory examination was not possible at the time of my visit. However, a careful examination of the openings and of the dumps failed to indicate more than slight traces of ore. Very recently several minor openings have been made on the adjoining property owned by Wills, in one of the shaley bands of the limestone, showing very thin stringers of lead sulphide, galenite. The shale has been crushed and brecciated and the galenite is deposited in very thin stringer fashion between the broken fragments of shale. At the other places mentioned above the openings have been made in the magnesian limestone.

The general composition of the Shenandoah limestone in Montgomery county is shown in the following partial analyses made of specimens collected by the writer:

	I	II	III
Calcium carbonate (CaCO ₃).....	66.43	87.35	46.46
Magnesium carbonate (MgCO ₃).....	24.21	7.35	37.38
Iron and Alumina (Fe ₂ O ₃ +Al ₂ O ₃).....	.88	.38	1.33
Insoluble residue.....	8.18	6.24	14.93

- I. Limestone from the Bell quarry, three miles southwest of Blacksburg, Montgomery county, Virginia. J. R. Eoff, Jr., analyst.
- II. Limestone from the Plunkett quarry, near the Bell quarry, two and one-half miles southwest of Blacksburg, Montgomery county, Virginia. J. R. Eoff, Jr., analyst.
- III. Limestone from the Davidson farm, one mile east of Blacksburg, Montgomery county, Virginia. J. R. Eoff, Jr., analyst.

At no place examined in Montgomery county can workable deposits of either lead or zinc be counted on.

PULASKI COUNTY

The known occurrence of zinc ores in Pulaski county is limited to the extreme southwestern part of the county near the Wythe county line and in the vicinity of Allisonia and Delton, along New river. The ore consists of the original sulphide, zinc blende, occurring in the unaltered magnesian limestone, and the oxidized or soft ores, calamine and smithsonite, concentrated near the bottom of the residual clay derived from the limestone and the irregular weathered surface of the hard rock. Openings have been made at three places, only one of which has produced ore in sufficient quantity to be workable. The other two openings were made in the hard limestone dug in testing for zinc blende.

The Delton Mines.—These mines are located on the Clark property, about one mile south of Delton and about the same distance west of New river, where crossed by the Cripple Creek branch of the Norfolk and Western railroad. They are further located about 12 miles southwest of Pulaski City. The mines were opened by the Bertha Mineral Company, May, 1902, and were continuously worked until December, 1903, when it is claimed the ore pinched out, about 8,000 tons of ore having been mined.

Two connecting open-pits of large size and roughly circular in outline were worked. These were aligned in a northwest-southeast direction and were worked to a depth of about from 80 to 100 feet. Ore was also mined from shafts and drifts run in different directions from the sides and bottom of the pits. The limestone pillars, or chimneys, are not so strikingly developed here as in the open-work at Bertha and Austinville. The soft or oxidized ores, including zinc silicate, calamine; and zinc carbonate, smithsonite, were the ores mined. A little lead, galenite, and some iron, limonite, were found in association with the zinc ores. The occurrence of the workable ores was similar to that described at Bertha and Austinville.

The residual clays overlying the ores were red and yellow ferruginous clays, in which the percentage of iron was sufficiently large to warrant their being mined for iron. As such the property has yielded much iron ore, which was mined from the same openings from which the zinc ores were formerly removed.

Lead and iron were the only impurities in the zinc ores. After concentration the product contained 40 per cent. metallic zinc, 0.5

per cent. lead, and 5 per cent. iron. When the mines were first opened, it is reported that about four tons of run-of-mine ore produced one ton of concentrates, but toward the close of operations the ratio was higher, ranging as high as six to one.

Mining for zinc was stopped for the reason that the bodies of soft ore were exhausted. Drillings were made in the fresh unaltered limestone, below the covering of the residual clays, to test the presence of original sulphide ores. These proved the scant presence of sulphides in the limestone but not sufficiently concentrated to be workable.

The rock containing the original sulphide ores which yielded on weathering the workable soft ores, calamine and smithsonite, is a medium to dark gray magnesian limestone. It is thin bedded and much crushed, but not so coarsely crystalline as at Austinville. The crushed rock is recemented with white calcite or dolomite, in the form of films and stringers. Less than half a mile north from the mine openings, exposures of the interbedded thin banded purplish red shale and limestone are seen along the tram track between the mines and the mill. Several bands of the shale are repeated with the limestone at this point. Both the shale and the limestone are cut by well defined joints in two directions. Measurements of the joints cutting the shale in the exposure just north of the mines, gave N. 65° E. and N. 45° W., with minor jointing in at least two other directions. Measurements of the joints in the limestone $\frac{1}{2}$ mile southeast of Delton and on the Allisonia road, gave N. 40° E. and N. 50° W. Dip of the limestone measured here and in the mine openings was 40°-45° southwest.

A partial chemical analysis made by the writer on specimens of the red shale collected from this point gave the following results:

	Per Cent.
Silica (SiO ₂).....	69.29
Titanium oxide (TiO ₂)	1.19
Alumina (Al ₂ O ₃).....	17.35
Iron oxide (Fe ₂ O ₃).....	4.78
Manganese oxide (MnO).....	0.13
Magnesia (MgO).....	0.92
Lime (CaO).....	0.34

A separating and concentrating mill was built at Delton, the railway station, about one mile from the mines, where the zinc ores were treated before shipping to the furnaces at Pulaski for smelt-

ing. This mill was being dismantled and the machinery moved to Austinville for use, during the spring of 1905. A tram road was built and operated between the mill and the mines.

The Forney Test Openings.—Two openings were made in the limestone several years ago by Mr. D. S. Forney, on the opposite sides of New river from each other and about one mile northeast of Allisonia. The first opening, a shaft sunk to an unknown but not great depth in the limestone and located on the south and same side of New river as Allisonia, is reported to have penetrated the rock containing some sulphide ore. Judging from the dump, which was carefully examined, the ore was not sufficiently concentrated in the limestone at the depth reached by the shaft to be workable. A little zinc blende and some galenite, lead sulphide, were observed in the rock taken from the shaft. The rock taken from the shaft shows a well crushed and brecciated, dark-colored, crystalline magnesian limestone, cemented by crystallized white calcite or dolomite.

On the opposite and north side of the river, a tunnel was driven into the limestone slope at an elevation of 250 to 300 feet above the river level and about 300 yards distant therefrom. The tunnel was driven into moderately thick-bedded, dark, crystalline magnesian limestone, dipping 45° - 50° southwest. The work was done about five years ago and a little ore is reported to have been shipped. A careful examination of the dump showed some beautiful light yellow blende distributed through the dark limestone in small grains and to some extent as moderately large cleaveable masses. Some finely disseminated grains of lead sulphide, galenite, were noted in the rock associated with the zinc blende.

The limestone seemed to be less crushed here than at the shaft across the river, although more ore was observed. Purplish red shales outcrop lower down the slope, about half way between the tunnels and Allisonia, dipping slightly east of south 45° - 50° .

The construction of a coffer-dam across the river, at a position nearly between the shaft and tunnel on the two sides, showed the presence of zinc ore in the limestone forming the river bed.

WYTHE COUNTY

General Statement.—Wythe county has been and is now the main producing county of lead and zinc ores in Virginia. Indeed it can be safely stated that nine-tenths of the lead and zinc ores produced

in Virginia has been from the mines in this county. The mines at Bertha and Austinville in the extreme southeastern corner of Wythe county have produced practically the entire output in these ores. It was here that the first mining of lead and zinc ores in the State was done, which dates back, in the case of lead, more than 150 years. The ores mined up to the present time included only the soft or oxidized forms, concentrated at only slight depths below the surface. Recent exploitation below this level has developed the presence of large bodies of original sulphide ores in the fresh rock. Also prospecting now in progress at Cedar Springs, 22 miles west of Austinville, in the southwest corner of Wythe county, is very promising in that beautiful blende is being exposed which apparently promises well both in quality and in quantity.

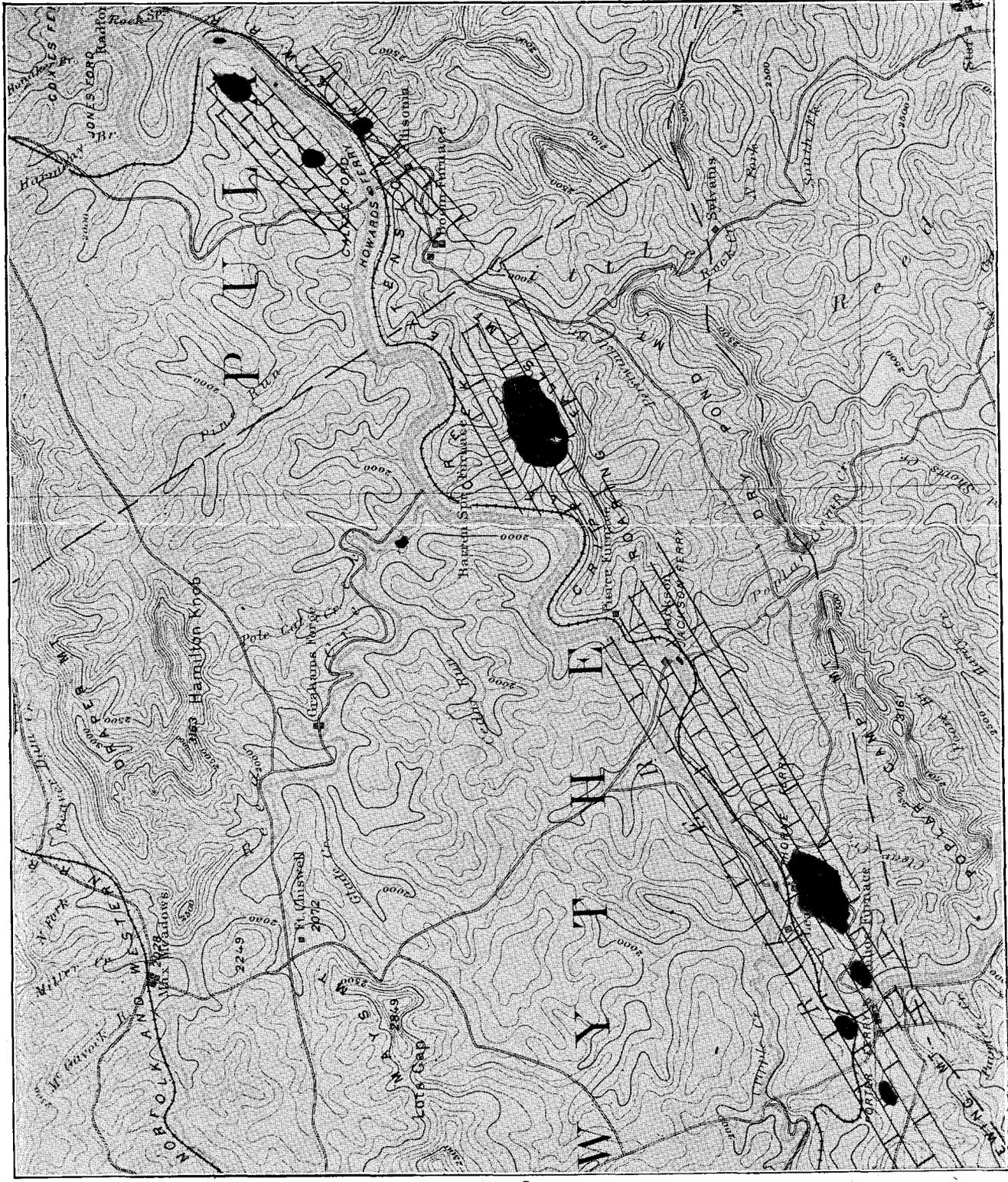
The ores of zinc include the silicate, calamine; the carbonate, smithsonite; and the sulphide, sphalerite. Those of lead are mainly the sulphide, galenite; and the carbonate, cerussite. The lead ores are principally limited to the mines at Austinville. Pyrite, sulphide of iron, occurs in some of the mines in the fresh limestone associated with the sphalerite and galenite, but at no point is it in quantity sufficiently large to be harmful to the ores of lead and zinc.

The occurrence and association of the ores, and their character and development, are described in detail below under the individual properties.

The Bertha Zinc Mines

These mines are located in the extreme southeast corner of Wythe county, 20 miles southwest of Pulaski and about one mile south of the North Carolina extension of the Norfolk and Western railroad. As stated above, zinc ores were first discovered at Bertha in 1866 and the mines were regularly opened in 1879 when the first shipment of ore was made to Providence, Rhode Island. This marked the beginning in systematic mining of zinc ores in Virginia.

The mines are further located about one mile south of New river on a plateau of magnesian limestone whose average elevation is 290 feet above the river. This forms the eroded portion of the northeast limb of the anticline cut through by New river at Austinville. The limestone is light to dark gray in color. It is finer grained, less crystalline and much less fractured than at Austinville. These differences in the general character of the limestone

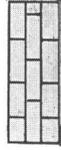
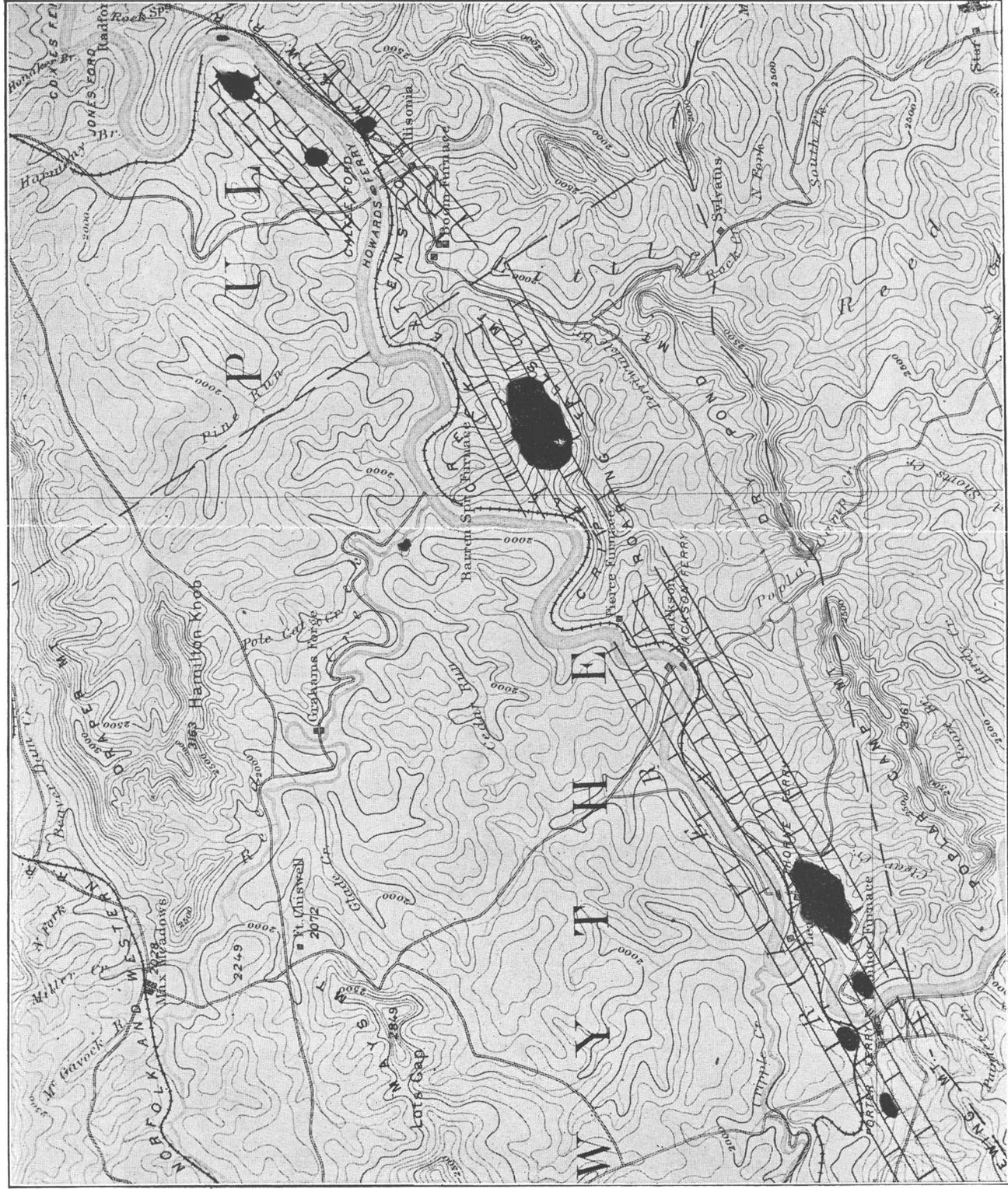


Shendoah
Limestone



Zinc and Lead
Deposits

Map of the Austinville and Bertha Lead and Zinc Deposits. Based on the Hillsville Sheet, U. S. G. S. Geology by Thomas L. Watson.
Scale $\frac{1}{2}$ inch = 1 mile. Contour interval 100 feet.



Shenandoah
Limestone



Zinc and Lead
Deposits

Map of the Austinville and Bertha Lead and Zinc Deposits. Based on the Hillsville Sheet, U. S. G. S. Geology by Thomas L. Watson.
Scale $\frac{1}{4}$ inch = 1 mile. Contour Interval 100 feet.

S.E.

ZINC MINES

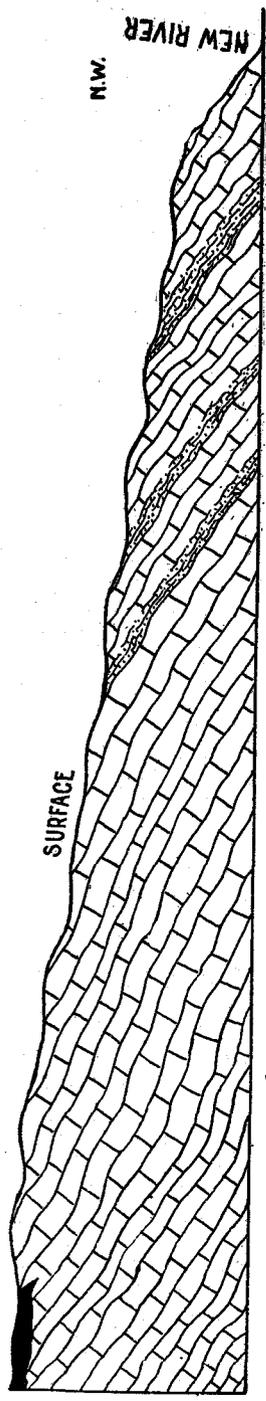


Fig. 9.

Geological section along a northwest direction from the Bertha Zinc Mines to New River at Bertha Depot, Wythe County, Virginia. Length of section 1 mile. 1. Magnesian limestone. 2. Thin bands of reddish sandstone and sandy shales.

noted at Austinville and Bertha seem to be characteristic of the rock on the two limbs of this fold. The dip is much flatter at Bertha than at Austinville. Numerous measurements made on the limestone beds in the mines and on the outcrops between the mines and the river gave 25° N. W.; strike N. 75° E. Between the river and the mines several thin bands, one to six feet wide, of reddish sandstone and sandy shales, are interbedded with the limestone at short intervals. Figure 9 is a structure section made from the mines to the river at Bertha depot, which shows the position and relation of the thin bands of sandstone and shale to the limestone.

The composition of the limestone is shown in the partial analysis given below, made by Mr. J. R. Eoff, Jr., on specimens collected by the writer from an outcrop between the mines and Bertha depot.

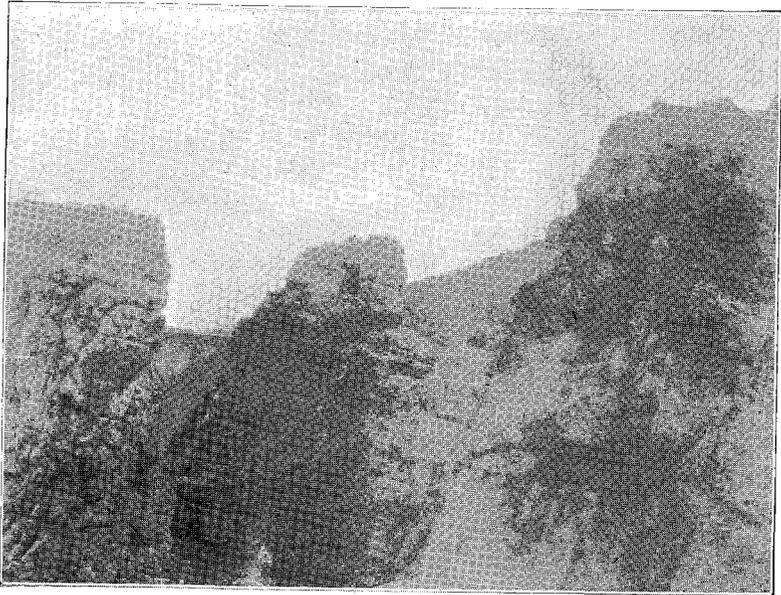
	Per Cent.
Calcium carbonate (CaCO_3).....	93.28
Magnesium carbonate (MgCO_3).....	1.55
Iron and Alumina ($\text{Fe}_2\text{O}_3 + \text{Al}_2\text{O}_3$).....	.36
Insoluble residue.....	2.06

The character of the ore mined at Bertha was of the soft oxidized type, concentrated at the bottom of the residual clays on the irregular surface of the limestone. These relations are shown in figure 10, which is a section through a part of the mines. The limestone has weathered very irregularly producing, when the clay is removed, a pinnacled surface, consequently the ore concentration has been correspondingly irregular as to depth, not exceeding at any point a depth of more than 80 or 90 feet. The "chimneys" or pinnacles of limestone are roughly circular in outline and show much variation in size. Some reach to the surface, others are buried at variable depths below the clay. Further variation is from fairly sharp crests to flat tops and steep sides, as shown in plates IV and V. For winning the ore the method of open cut mining, stripping, was largely employed, although in later years the form of mining consisted of shaft and tunnel work in the loose clays, as shown in figure 26. This form of mining the zinc ores has been confined to a surface belt or strip 1,500 feet wide extending across the tract in the direction of the strike of the limestone, south 35° to 40° west. Plates IV and V are views taken in some of the large open pits, which show their general character.

The ores mined on this property were the silicate and carbonate



A



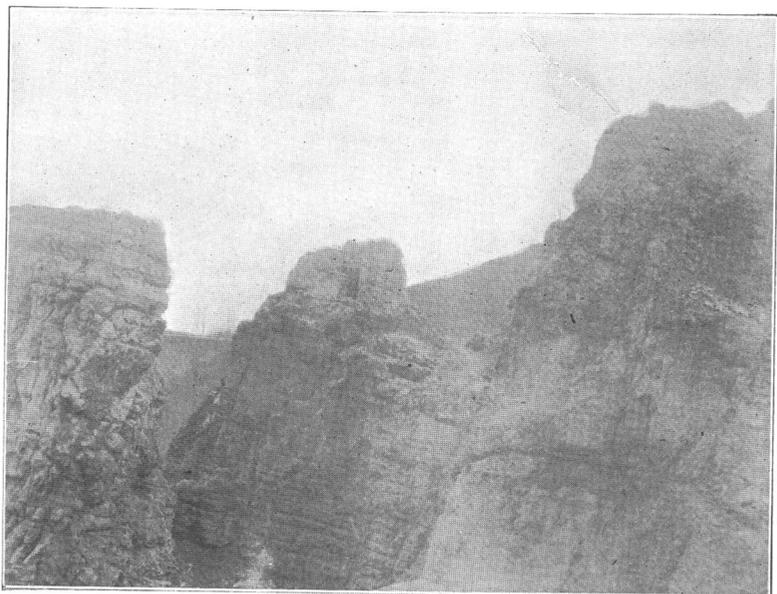
B

A. View in quarry of crystalline schists at Faber, Nelson County, showing schistosity and contact of crinkled schist on left with conglomerate schist. Same rocks in which the Albemarle Zinc and Lead Mines vein occurs.

B. View of limestone "chimneys" at Bertha Zinc Mines, Wythe County, Virginia.



A

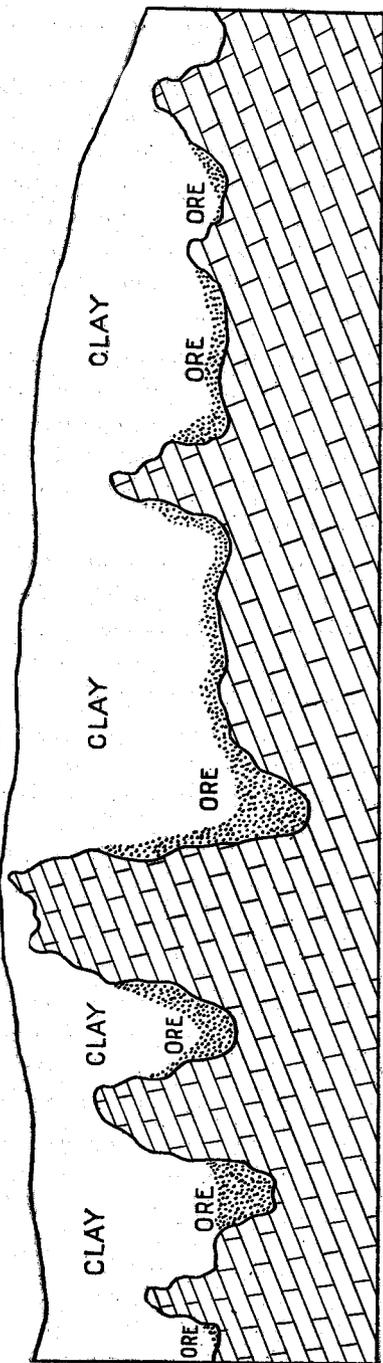


B

A. View in quarry of crystalline schists at Faber, Nelson County, showing schistosity and contact of crinkled schist on left with conglomerate schist. Same rocks in which the Albemarle Zinc and Lead Mines vein occurs.

B. View of limestone "chimneys" at Bertha Zinc Mines, Wythe County, Virginia.

Fig. 10.
SURFACE



Section in open cut at the Bertha Zinc Mines, showing the relations of the soft ore to the limestone "chimneys" and the residual clay. Bertha, Wythe County, Virginia. Blocked area is limestone.

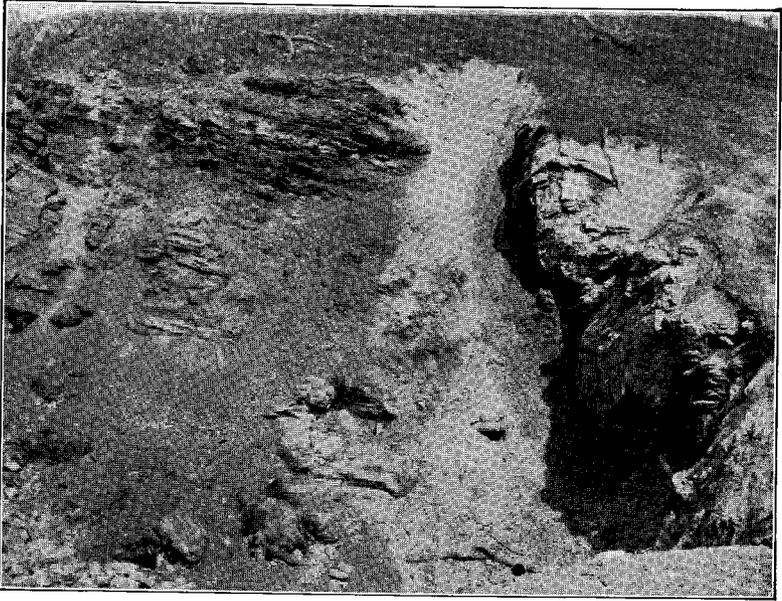
of zinc, calamine and smithsonite, intimately admixed. Drillings made in the fresh limestone beneath the clay covering in many places over the property, revealed the presence of rather sparsely disseminated blende. At no point, however, did the drillings show the blende to be sufficiently concentrated to be workable. Little or no galena, lead sulphide, has been found on the Bertha property. Several very large masses of pyrite, iron sulphide, were observed by the writer in one of the open pits.

The ores mined at Bertha were the result of extensive residual accumulation or concentration of the altered or oxidized zinc ores, calamine and smithsonite, derived from very large areas of sparsely disseminated zinc blende in the original fresh limestone. Some crystallized barite is found in the smaller openings made on the southwest end of the property.

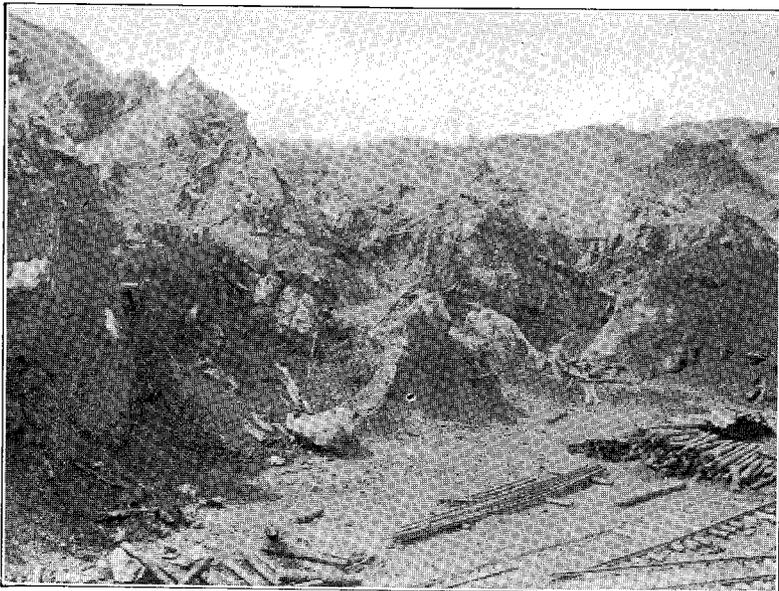
The residual clay covering of the open pits and cuts is intensely red in color, and at present it is being mined and washed by the Pulaski Iron Company for iron ore. This company leased the property in 1898 for the purpose of mining the clays for iron ore, when the mining of zinc ores was stopped. Mining of the zinc ores was suspended for the reason that they were practically exhausted, but it was hoped that by removing the ferruginous clay covering other bodies of zinc ore would be found. There seems but slight prospect for this, however, and unless zinc ores are found by careful testing other parts of the property not yet worked, it must be abandoned as a zinc property.

Very little zinc ore has thus far been found in working the pit for iron. The few pieces seen by the writer were porous masses of calamine highly stained with iron oxide from the admixed red clay. Some black oxide of manganese, in the form of nodules and staining is distributed through the clays in places, but it is not present in sufficient quantity to warrant the saving of it.

The Bertha mine has been the largest producer of soft ores in the State. The ore as mined is claimed to have averaged about 26 per cent. metallic zinc. When producing it yielded 12,000 to 15,000 tons of unwashed ore to the acre, and the ground was being worked over at the rate of $3\frac{1}{2}$ to 4 acres per annum. The output was 200 tons of ore per day, hoisted from 17 shafts, with a working force of about 300 men. The yield is reported to have been approximately

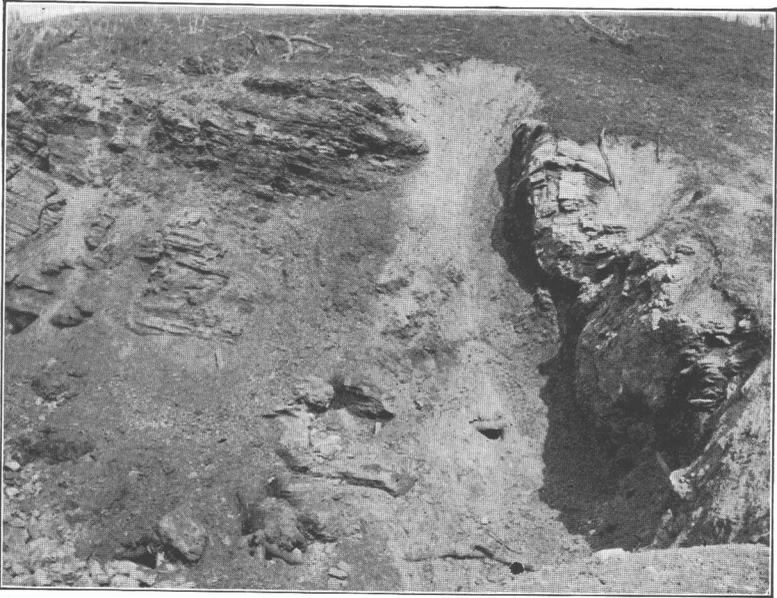


A

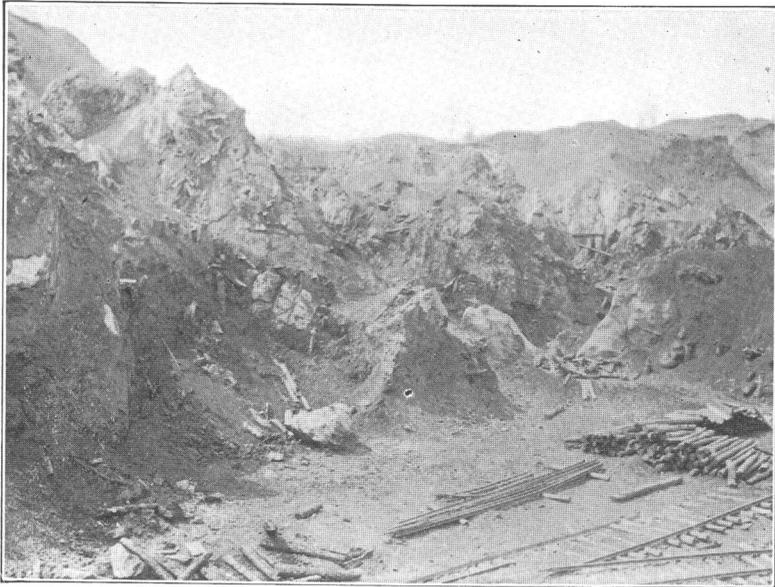


B

Views showing character of limestone weathering in open cuts of Bertha Zinc Mines. A. Weathered limestone surface showing dip of beds. B. General view in open cut showing limestone "chimneys."



A



B

Views showing character of limestone weathering in open cuts of Bertha Zinc Mines. A. Weathered limestone surface showing dip of beds. B. General view in open cut showing limestone "chimneys."

one-third of the crude ore treated and the product gave the following average analysis when dried at 212° F.⁴¹

	Per Cent.
Metallic zinc.....	38.08
Equivalent in zinc oxide (ZnO).....	47.61
Silica (SiO ₂).....	29.37
Iron and Alumina (Fe ₂ O ₃ +Al ₂ O ₃).....	9.23
Calcium carbonate (CaCO ₃).....	4.54
Magnesium carbonate (MgCO ₃).....	2.07
Water, combined (H ₂ O).....	8.23
Lead.....	trace
Total.....	101.52

An extensive and thoroughly up-to-date equipment for hauling and milling the ore was installed and operated near Bertha depot at the river and less than a mile from the mines. Tram-cars were operated between the mines and the mill. The plant was partly destroyed by fire some years ago, and the remaining machinery has recently been moved to Austinville for use at the Austinville plant. The method practiced in the treatment of the ores at the Bertha plant is described on page 137 of this report. A washer for cleansing the iron ores mined at the old Bertha Zinc Mines is still being operated near the site of the old zinc plant near the depot.

The Austinville Zinc and Lead Mines

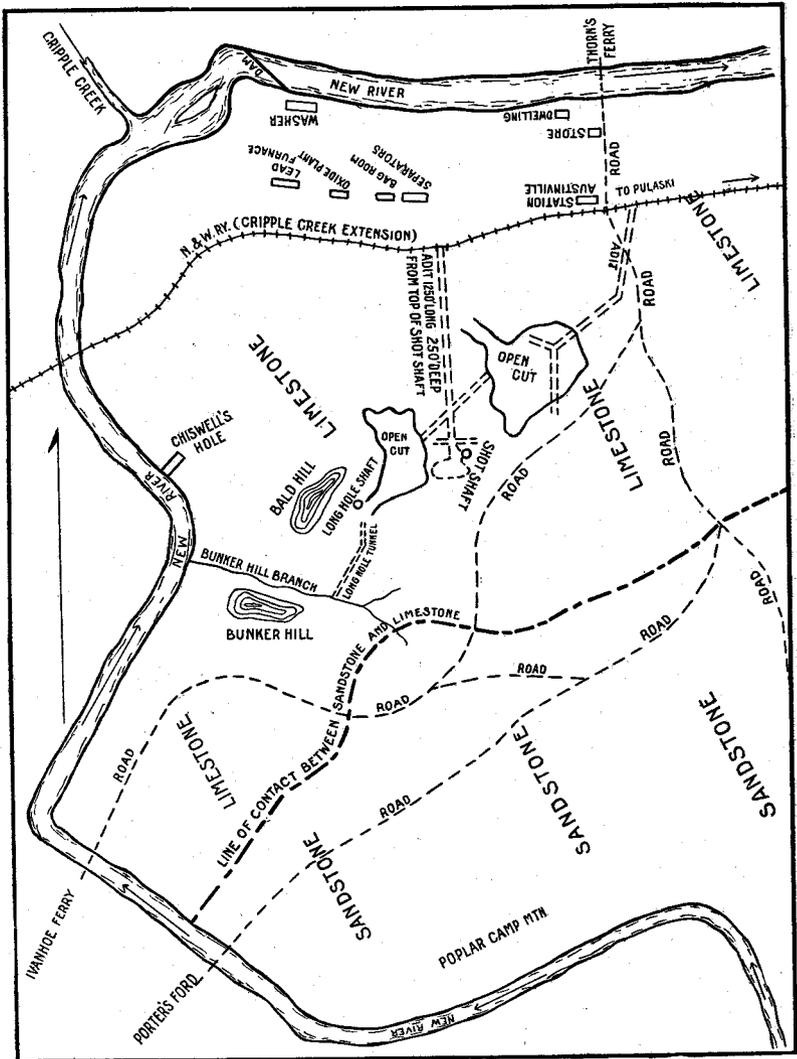
The Austinville Zinc and Lead Mines, owned by the Bertha Mineral Company, are located in the southeast corner of Wythe county, twenty-nine miles southwest of Pulaski by rail, and ten miles west of the Bertha mines described above. The mines are further located about a quarter of a mile south of New river on a plateau of magnesian limestone at an average elevation of 290 feet above the river level. The North Carolina extension of the Norfolk and Western railroad passes between the river and the mines, as indicated on map, figure 11. As stated above these mines were first worked more than 150 years ago, when lead ores were mined by Colonel Chiswell in 1750.*

The ores occur in an intensely metamorphosed zone along the southeast limb of an anticline which trends northeast-southwest, and is cut through by New river at this point. Along this zone the

⁴¹ Moxham, E. C., *Engr. and Mng. Jour.* 1893, Vol. 56, Nov. 25, p. 544.

* For a detailed historical summary see pp. 68-71.

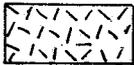
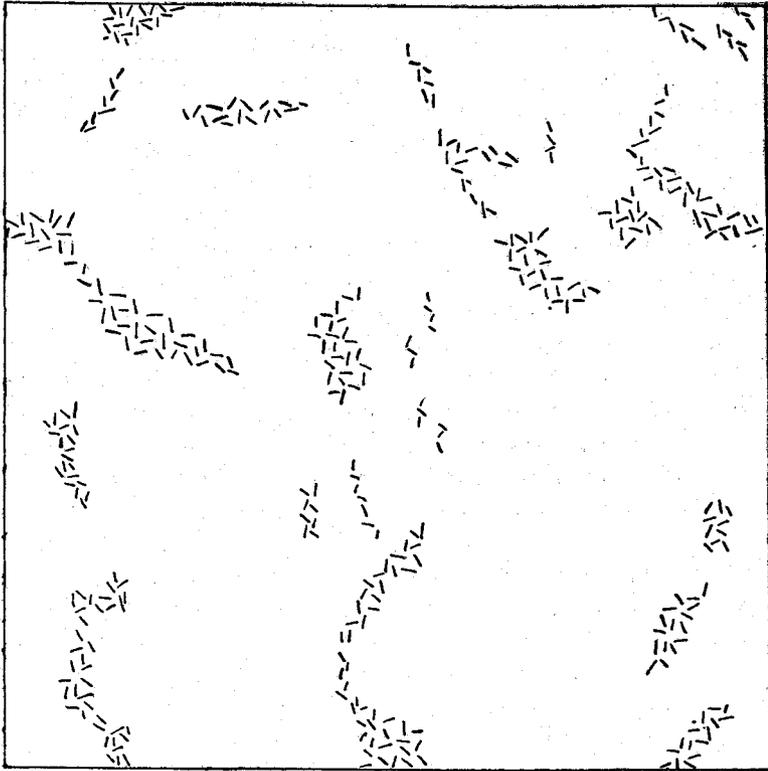
Fig. 11.



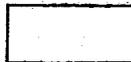
Sketch map of the Austinville Lead and Zinc Mines. Shows position and general character of workings, and line of contact between sandstone and limestone.

limestone has been intensely crushed and broken and cemented, and in many places almost entirely recrystallized. Only scattered and very small pieces of the original dark-colored rock are shown in

Fig. 12.



LIMESTONE FRAGMENTS



CALCITE
AND DOLOMITE

Breccia from Austinville Lead and Zinc Mines. Limestone largely recrystallized forming calcite and dolomite, with scattered "eyes" of original limestone through the crystalline calcite-dolomite matrix. Natural size.

the recrystallized limestone of light gray, nearly white color. This relation of the small proportion of original dark-colored rock resembling "eyes," to the bulk of the rock, now recrystallized light colored matrix, is well shown in figure 12. The recrystallized limestone may be either medium or coarse and even granular in texture, and may or may not contain "eyes" of the original dark-

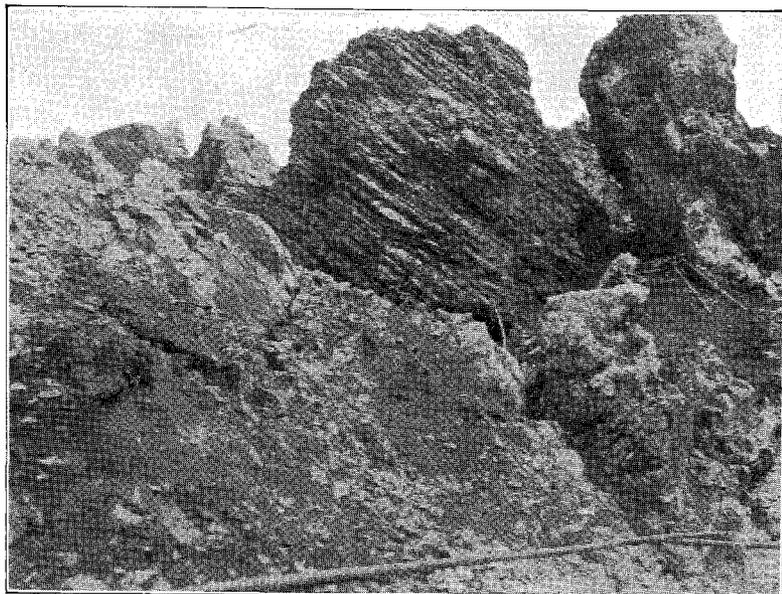
colored rock. In many places the extreme crushing and recrystallization have nearly, if not entirely, obscured the original bedding. Over most of the area, however, the bedding planes are very clearly and sharply defined, dipping on an average of 45° S. E.

As a rule, jointing is rather strongly emphasized in the limestone at the mine openings. The principal sets of joints correspond to the directions N. 50° - 70° E., and N. 65° - 85° W., with nearly all variations noted in minor jointing. The workings underground show in places pronounced lines of breakage in the limestone in three directions which are referred to faulting. These are N.-S., E.-W., and N.E.-S.W.

A number of complete chemical analyses have been made from carefully collected samples of both the fresh and the partially decayed limestone. These are given on pages 29, 97 and 98, and they indicate a dolomite in composition.

Until recently, the ores mined at Austinville were of the soft or oxidized type concentrated for the most part at the bottom of the residual clays on the irregular weathered surface of the limestone. These relations are shown in figure 16, which is a section through a part of one of the open cuts at Austinville. The weathering of the limestone here into pinnacled surfaces and the depth and character of the residual decay covering the limestone are, in every respect, similar to that described above at Bertha. Plate VI represents views of the pinnacles showing the dip of the limestone beds, and of the weathered limestone surface in the Austinville mines. The soft ores mined included calamine, hydrous zinc silicate; smithsonite, zinc carbonate; and cerussite, lead carbonate. Much galena, lead sulphide, was associated with the oxidized ores. Only the lead ores were mined from the beginning of mining in 1750 until after the close of the Civil War when the zinc ores first gained recognition. For winning the ore the method of open cut mining, stripping, was largely employed. The lead ores were then followed down by stoping whenever found, the zinc ores, in the early mining, being discarded and thrown to one side.

Considerable underground work has been done in the fresh limestone, and the Bertha Mineral Company has been largely engaged during the past year or more in exploring and developing the original sulphide ores in the fresh rock. Enough work has been done to indicate the occurrence of the sulphide ores in the form

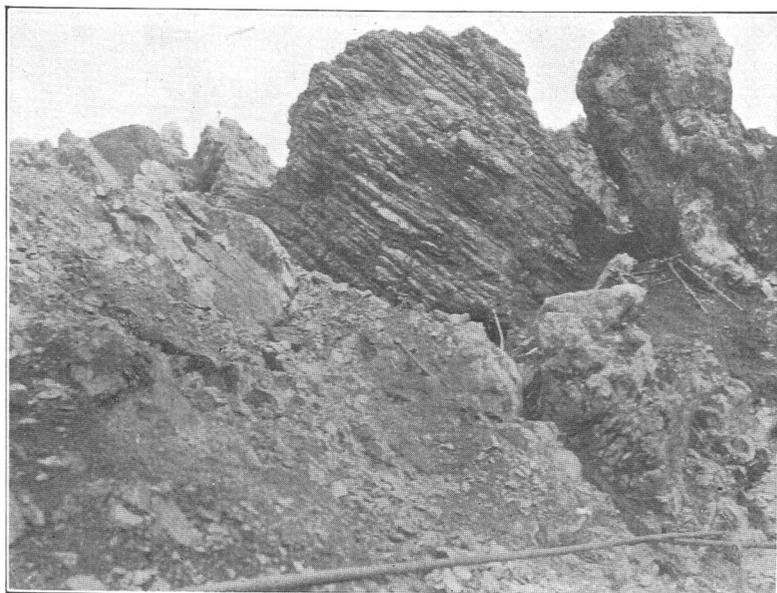


A



B

Views showing character of limestone weathering in open cuts of Austinville Zinc and Lead Mines. A. Limestone 'chimneys,' showing dip of beds. B. Weathered limestone surface; bedding obliterated by recrystallization of limestone.



A

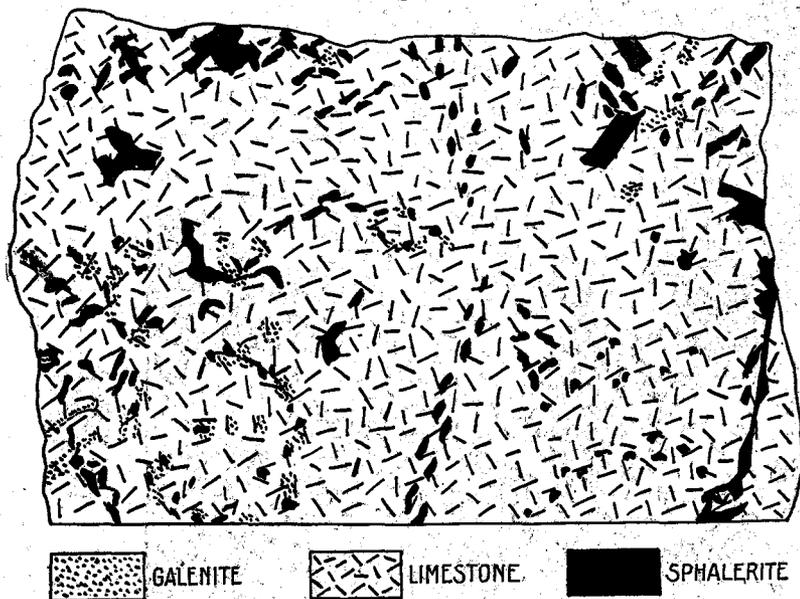


B

Views showing character of limestone weathering in open cuts of Austinville Zinc and Lead Mines. A. Limestone 'chimneys,' showing dip of beds. B. Weathered limestone surface; bedding obliterated by recrystallization of limestone.

of fairly well defined ore-shoots, as shown in figure 15. The ore bodies are apparently very large; one of these recently developed in the deep opening measured about 260 feet by 16 feet. A second one worked out was apparently much larger. The sulphide ores include zinc blende, galenite, lead sulphide, and some pyrite, all more or less closely associated. In places, however, large areas of the limestone show a predominance of zinc blende, with a little

Fig 13.



Specimen of lean ore from Austinville Lead and Zinc Mines. Shows relations of sphalerite and galenite to each other and to the limestone. Two-thirds natural size.

galena and less pyrite; while other areas show a predominance of galena, with but little blende and pyrite. Nearly all gradations in association of the sulphides between these two are observed. The association of blende and galena in the limestone is brought out in figures 13, and 14, which are drawings, made from hand specimens of the lean and average sulphide ores.

Pyrite as a rule, is not abundantly distributed through the limestone, but is rather limited in occurrence, and is not in quantity sufficiently large to be harmful to the ores of zinc and lead.

Fig. 14.



 GALENITE

 SPHALERITE

 LIMESTONE

Specimen or typical ore from Austinville, Lead and Zinc Mines, showing relations of sphalerite and galenite to each other and to the limestone. Natural size.

The general character of the ore is well shown in the following chemical analysis made by Dr. W. E. Barlow, on a carefully collected sample by the writer from an average face of ore underground.

	Per Cent.
Zinc oxide (ZnO)	39.02
Lead oxide (PbO)	1.205
Cadmium oxide (CdO)	0.22
Iron oxide (Fe ₂ O ₃)	4.395
Alumina (Al ₂ O ₃)	4.23
Lime (CaO)	12.23
Magnesia (MgO)	9.16
¹ Carbon dioxide (CO ₂)	18.71
² Sulphur (S)	19.05
Potash (K ₂ O)	0.41
Soda (Na ₂ O)	0.09
Silica (SiO ₂)	0.32
Manganese oxide (MnO)	trace
Water (H ₂ O)	0.10
Titanium oxide (TiO ₂)	
Barium oxide (BaO)	
Strontium oxide (SrO)	
Copper (Cu)	none
Arsenic (As)	
Antimony (Sb)	
Total	<u>109.14</u>
Less O=S	9.07
	<u>100.07</u>
Zinc sulphide (ZnS)	46.75
Lead sulphide (PbS)	1.286
Cadmium sulphide (CdS)	0.275
Iron disulphide (FeS ₂)	6.369

The purity of the zinc blende at the Austinville mines is indicated in the following analysis made by Mr. J. H. Gibboney on selected pieces collected by the writer.

¹ The 19.05 per cent. of sulphur found was recalculated first to PbS, ZnS and CdS. The remaining sulphur was calculated to FeS₂, and the remaining iron was expressed as Fe₂O₃.

² The amount of CO₂ theoretically corresponding to the amounts found of CaO and MgO is 19.67 per cent. This would make the sum of the analysis 101.039. The low result for CO₂ is probably due to the fact that the "sweeping out" of the apparatus, after the determination, was stopped too soon, because of the risk of absorbing some H₂S.

	Per Cent.
Zinc (Zn).....	65.01
Sulphur (S).....	31.93
Iron (Fe).....	1.94
Lime (CaO).....	.08
Magnesia (MgO).....	none
Silica (SiO ₂).....	.33
Total	99.29
Zinc sulphide (ZnS)	96.94

Specimens collected by the writer of the white recrystallized limestone in which the sulphide ores occur yielded Mr. J. R. Eoff, Jr., the following results:

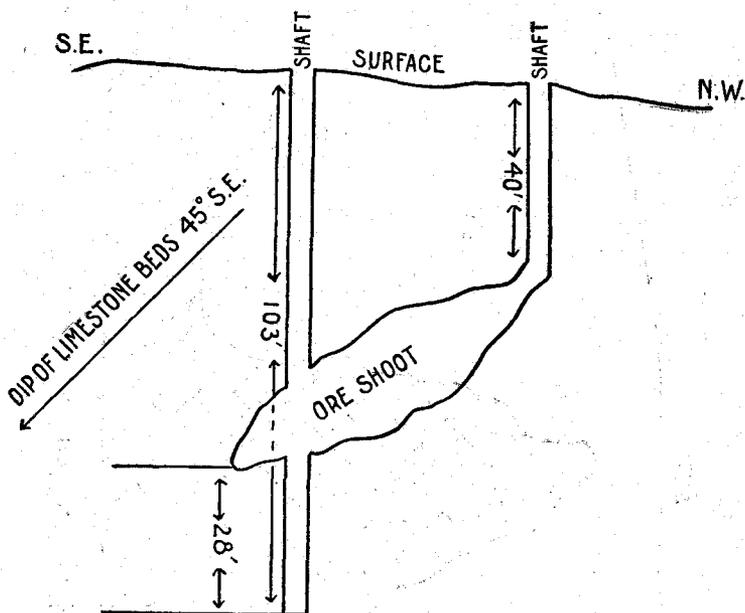
	Per Cent.
Calcium carbonate (CaCO ₃).....	54.85
Magnesium carbonate (MgCO ₃).....	44.58
Iron oxide (Fe ₂ O ₃}) } .....	.48
Alumina (Al ₂ O ₃) }	
Silica (SiO ₂).....	.22
Total	100.13

As the analysis indicates the rock is a dolomite, the ratio of calcium to magnesium being 1 : 1 the ratio of normal dolomite.

As discussed elsewhere in this report there appears no field evidence in support of secondary sulphide enrichment either at Austinville or elsewhere over the Virginia district; but the metallic sulphides are regarded as a product of primary deposition. At Austinville the formation of the sulphide ores in their present localized condition has been largely one of a replacement process, in which the limestone substance has been replaced by the metallic sulphides. Concentration of and replacement by the sulphide ores have gone forward along the bedding and joint planes; largely where the two intersect. Microscopic study of thin sections of the ore indicates that the process began first by the filling of fine cracks in the limestone, then extending into and replacing the grains of the magnesian limestone frequently as in the case of the galena, along some crystalligraphic direction in the limestone grains. See plates VIII, IX and X. Moreover, as elsewhere stated, it is believed that the conditions at Austinville favored the introduction and deposition of the metallic sulphides as such, and not as in Rye Valley in the form of sulphates, and the sulphates afterwards deposited as sulphides by reduction from the organic matter contained in certain layers of the limestone.

As shown in figure 11 which is a sketch map of the Austinville mines, mining of the ores has been by open cuts, shafts and tunnels. The ores have been worked on three principal levels at the following depths below the surface: 90, 180 and 238 feet. The main adit level has been run at an elevation of 45 feet above the river level, and the "water hole" is 110 feet below the adit level, or 55 feet below the river level. The lower limit of oxidation is

Fig. 15.

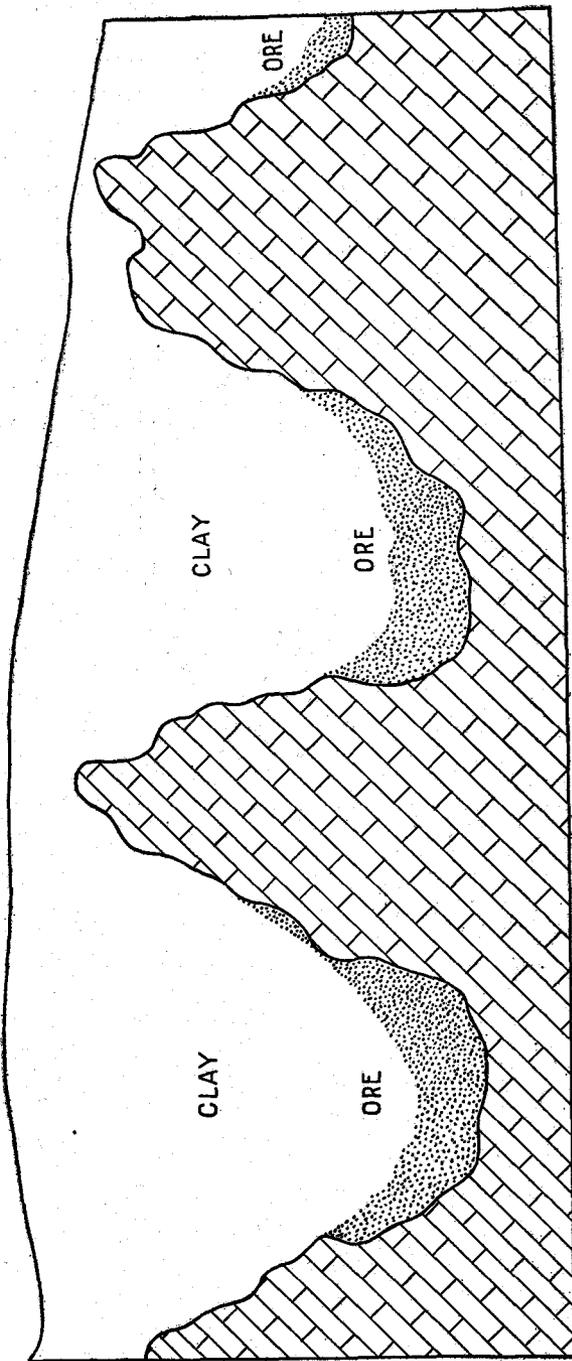


Plan of the Bunker Hill openings at the Austinville Lead and Zinc Mines, Wythe County, Virginia.

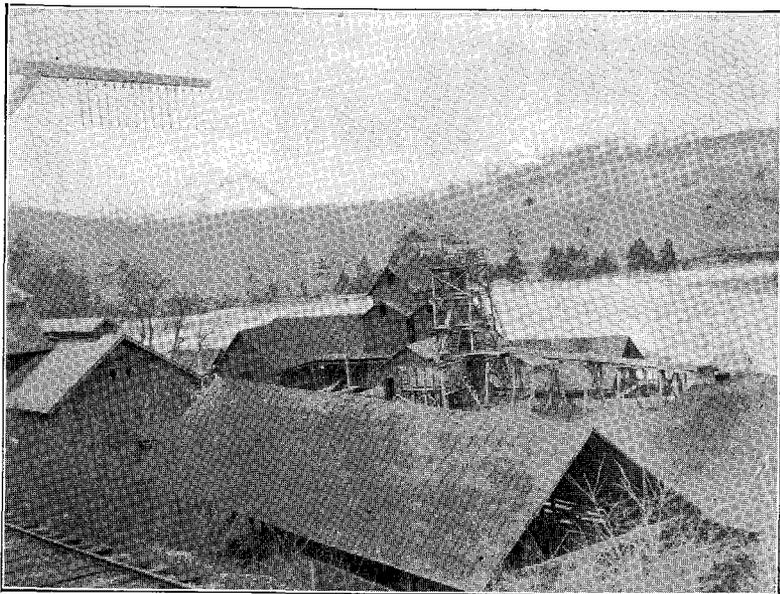
found between the two upper levels, 90 and 180 feet. Below the 180-foot level oxidation has not been observed.

Treatment of the Austinville ores from the time they are mined until they are ready for the smelter is described in full on pages 138 and 139. As shown in this treatment of the ores the Austinville plant is extensively and thoroughly equipped for handling and milling the ores. In addition to the elaborate concentrating mill, oxide furnaces have recently been built and are operated, which utilize all tailings and low grade ores that formerly were claimed not to be usable and hence were discarded.

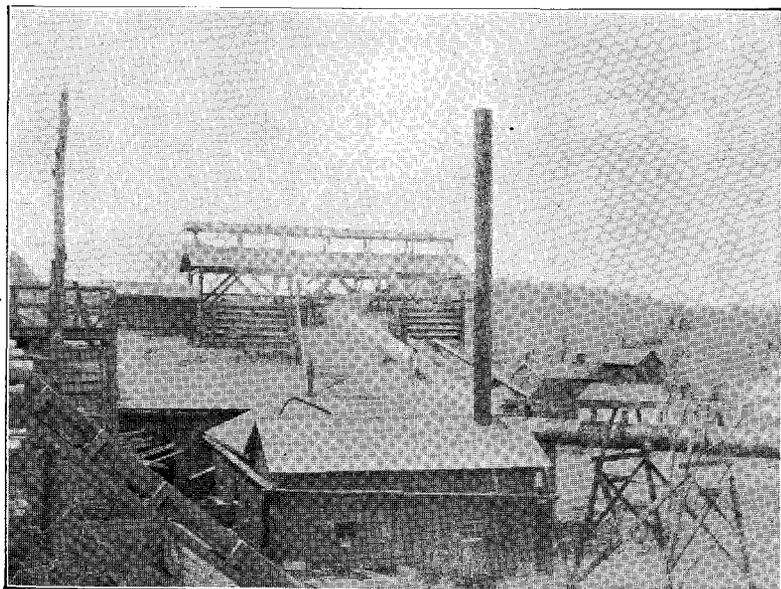
Fig. 16.
SURFACE



Section in open cut at the Austinville Lead and Zinc Mines, showing the relations of the soft ore to the limestone "chimneys" and the residual clay. Austinville, Wythe County, Virginia. Blocked area is limestone.

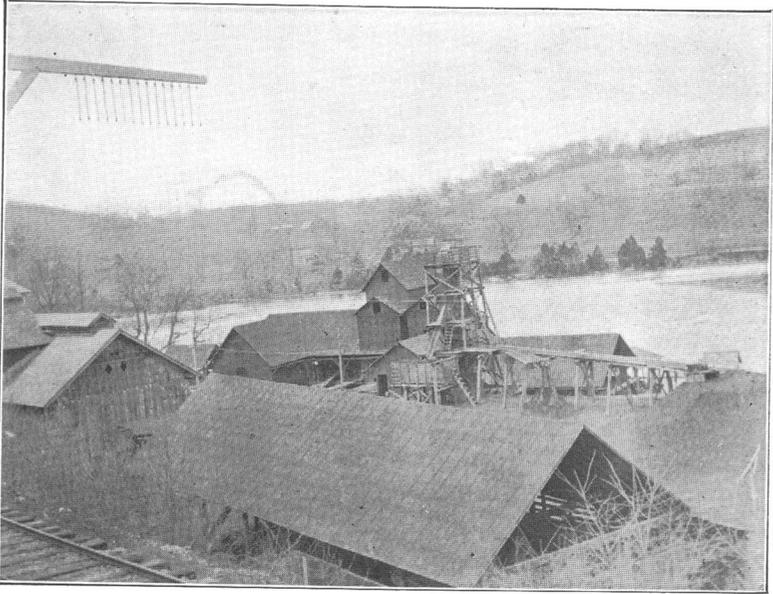


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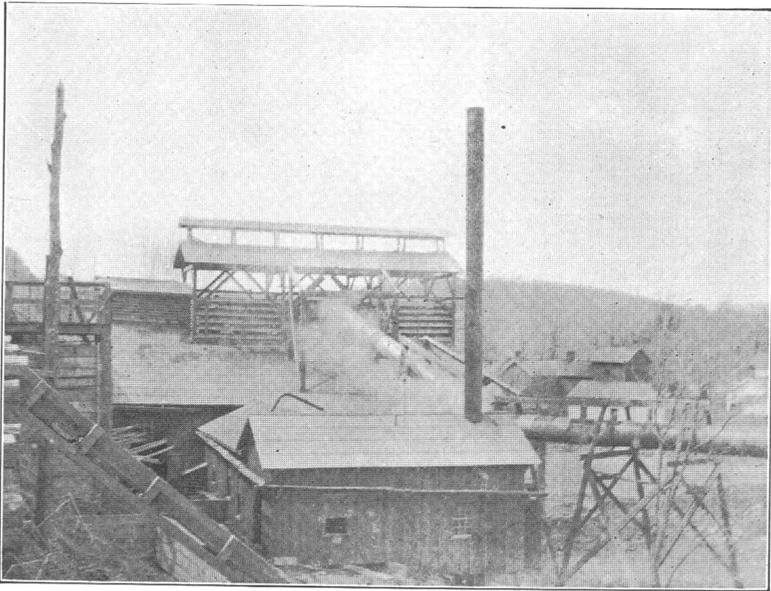


B

Austinville Zinc and Lead Mines Plant.
A. General view of the Plant. B. Oxide Furnaces.



A



B

Austinville Zinc and Lead Mines Plant.
A. General view of the Plant. B. Oxide Furnaces.

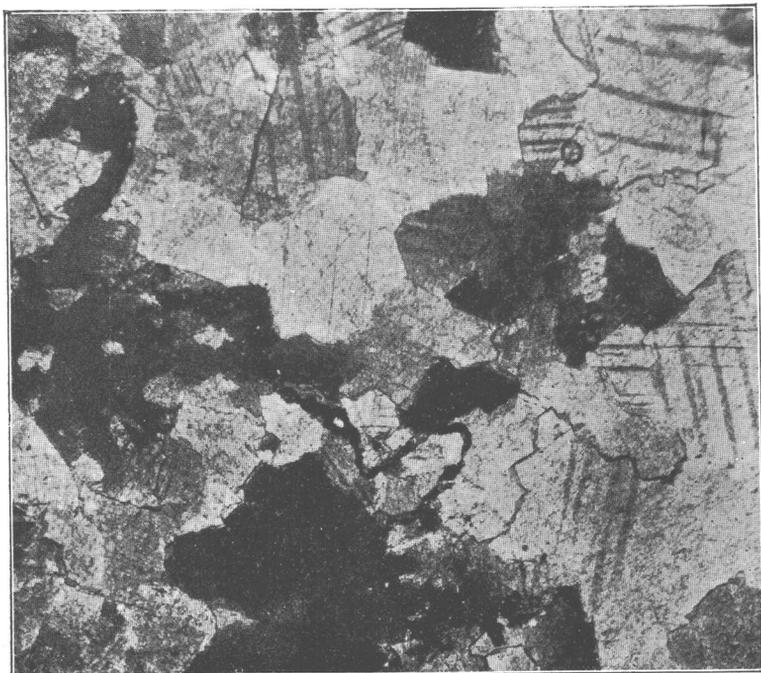


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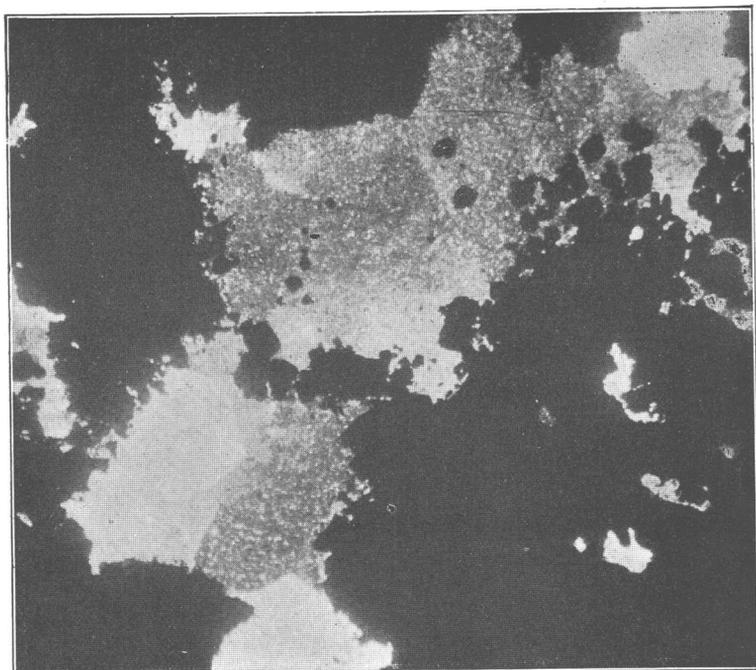


B

Photomicrographs of thin sections of sulphide ore from Austinville Mines, Wythe County. Magnified 50 diameters; cross nicols. Black areas represent sulphide minerals. A. Shows crystalline character of limestone, filling of fine cracks and some replacement by sulphides. B. Shows advance stage in replacement process.



A



B

Photomicrographs of thin sections of sulphide ore from Austinville Mines, Wythe County. Magnified 50 diameters; cross nicols. Black areas represent sulphide minerals. A. Shows crystalline character of limestone, filling of fine cracks and some replacement by sulphides. B. Shows advance stage in replacement process.

The oxide furnaces supply a zinc oxide which averages from 70 to 80 per cent. zinc used for charging in the smelting furnaces at Pulaski for making spelter. A system of trolley- and tram-cars is operated between the mines and washer for handling the ore.

At the Austinville mines not only the zinc and lead ores are mined, but the waste is washed for iron and the ore shipped to the furnaces, and the limestone of the "chimneys" or pinnacles of the open cuts is quarried and used for fluxing, thus practically utilizing everything.

Structure Section

This section was made in order to determine (a) the structural relations of the limestone formation, and (b) the stratigraphic relations of the limestone to the quartzite which forms a series of ridges topographically above the limestone on the southeast, known as Poplar Camp mountain. The section begins at Thorn's ferry on New river at Austinville and continues S. 70° E. (magnetic) for a part of the distance up the slope of Poplar Camp mountain, a total distance of something over two miles.

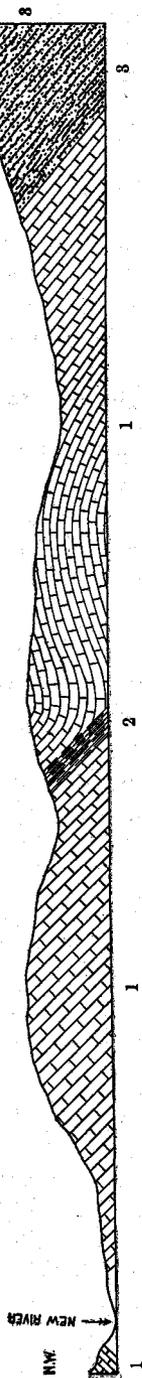
The important facts developed in this section may be briefly summarized as follows:

(1) Between Austinville and the quartzite contact with the limestone on the southeast, several reversals in dip of the limestone are shown, the significance of which is made clear by reference to the section.

(2) The limestone is variable in color and texture, and in the amount of chert it contains. About 3,600 feet S. 70° E. from the depot at Austinville is found 250 feet in thickness of purplish and olive colored shales interbedded with the limestone. A thin band of limestone occurs in the shale 175 feet above the bottom of the shale.

(3) About 2,000 feet S. 70° E. from the upper shale contact occurs a limestone conglomerate composed of long fragments of the limestone bound together by a calcareous cement, which is apparently more siliceous than the rock fragments. The larger limestone fragments are slightly bent or curved and in some cases are broken across by cracks at sharp angles to the longer axis of the fragments, and the cracks filled in with the matrix. The limestone fragments are roughly arranged in finger-like fashion. The evi-

Fig. 17.



Geological section along a S. 70° E. direction, from Thorn's Ferry across New River to Poplar Camp Mountain. Austinville, Wythe County, Virginia. Length of section about two miles.
1. Magnesian limestone. 2. Purplish to olive colored calcareous shales, 250' thick. 3. Quartzite, conglomeratic and shaly in places.

dence favors original deposition for this conglomerate band in the limestone.

(4) In its basal portion the quartzite is composed of thin banded sandy shales grading upward into heavier bedded quartzite with a conglomeratic facies in places. The quartzite is conformable with the limestone and at this point it appears to be stratigraphically above the limestone.

When certain structural details are considered, such as ripple marks and mud cracks which are found in the sandy shales in places, the rocks appear to be right side up. Yet when the section is extended further east into the crystallines, the stratigraphic relations seem difficult of interpretation unless we assume overthrust faulting or folding.

Petrography

In the hand specimens the limestone is completely crystalline, varying from fine to moderately coarse granular, and is light gray to nearly white in color. Brecciation is shown in small irregular "eyes" of the less metamorphosed original limestone of dark color, distributed through the more metamorphosed light-colored crystalline rock. In the more completely metamorphosed zone of the limestone the bedding is frequently nearly entirely obscured. In other places the bedding is very sharply defined. The rock contains 45.10 per cent. of magnesian carbonate.

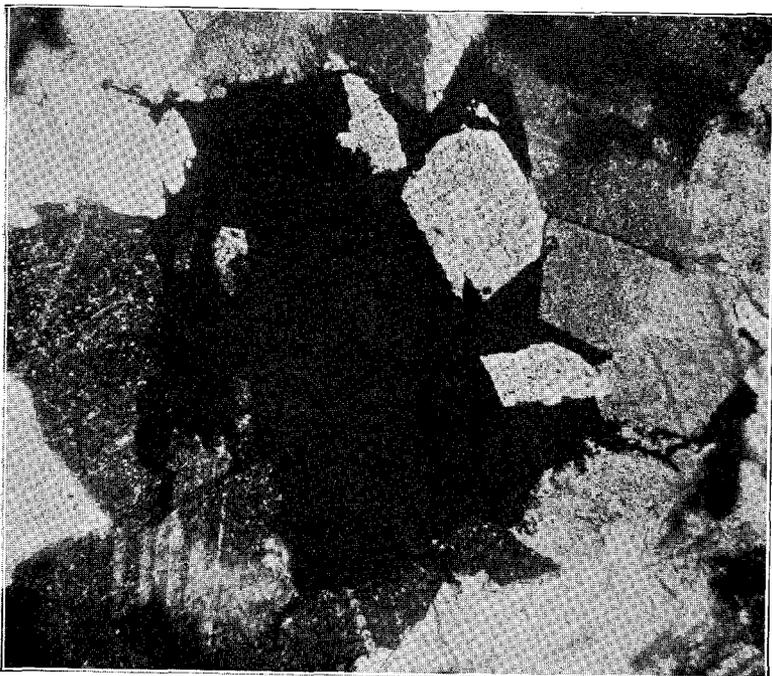
In thin sections under the microscope the rock is evenly granular and wholly crystalline, with no admixture of other mineral than dolomite and the ores. The dolomite exhibits both the characteristic cleavage and twinning as shown in plates VIII and IX. The crystalline grains are filled more or less with minute inclusions usually of an indeterminable nature. Some of these are of a dark brown and a reddish brown color and are certainly iron oxide. Frequently these have accumulated along the sutures between the grains and extend outward into the substance of the grains, rendering those parts opaque and nearly black to polarized light. Parts of some sections show an opaque yellowish color due to discoloration from iron oxide staining. In some sections the iron oxide fills the irregular thread-like cracks and has been derived from pyrite by oxidation.

Areas of fresh pyrite are distributed through some of the sections, which show characteristic replacement borders. The peripheries of the pyrite areas are characterized by re-entrant angles which correspond to the cleavage angles in the dolomite grains. In some instances a partial cavity is left filled with dark amorphous matter, resembling iron oxide, suggesting oxidation of the original pyrite. Galenite shows equally well the evidence of formation by replacement of the dolomite substance along the cleavage directions. The border portions of the large irregular areas show perfectly straight and sharply defined edges bounding re-entrant angles which correspond to the cleavage angles of the dolomite grains. From the margins are given off irregular long thread-like stringers which ramify outward into the dolomite substance in spider-like fashion. Some of these fill in part the sutures between the dolomite grains, rimming the grains for considerable distances; others fill irregular microscopic fractures in the dolomite grains. This phenomena is typically shown in plates VIII, IX and X, which are photomicrographs of thin sections of the ore from the Austinville mines in Wythe county.

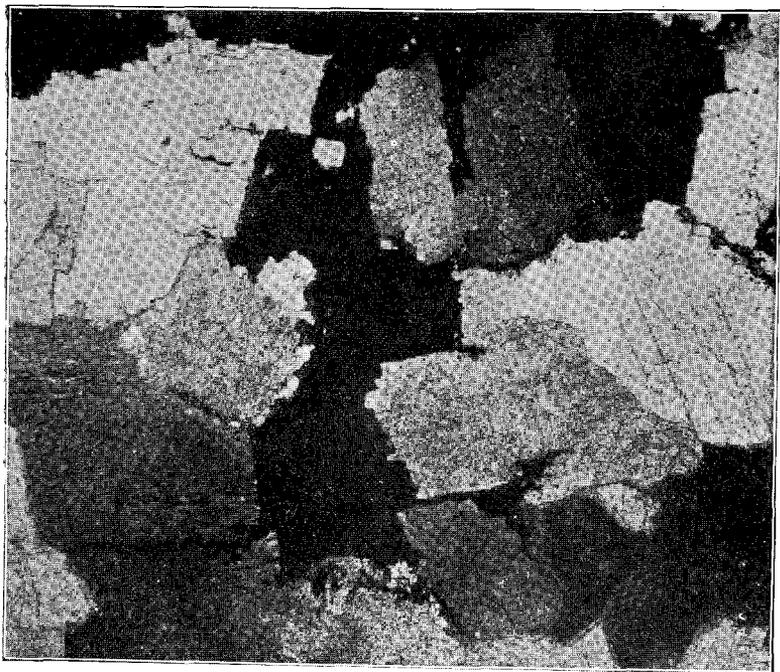
Weathering

As stated elsewhere in this report, the mining of zinc and lead in Southwest Virginia has been limited in the past to the oxidized ores, derived by weathering from the original sulphide ores, in the belt of weathering. The country rock, limestone, containing the original sulphide ores, likewise has been weathered for a considerable depth below the surface, and the insoluble parts of it concentrated in place as an irregular mantle or covering of residual red clay, in and near the bottom of which the altered ores have been concentrated.

In order to indicate the changes which the rock has undergone in the process of weathering, carefully selected specimens of the fresh limestone and its corresponding partial decay, were collected from different places in the Austinville mines, and analyzed in the chemical laboratory. The results of these analyses are given below in tabular form.

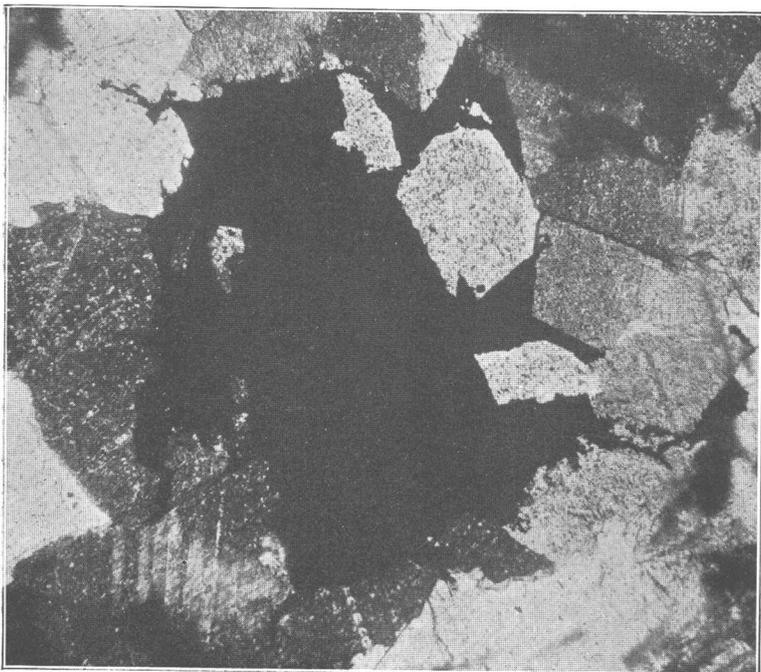


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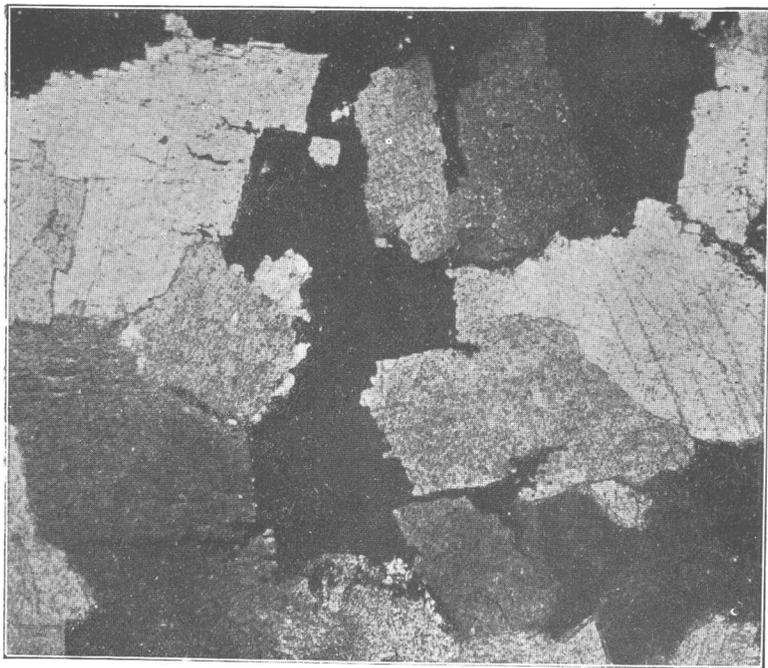


B

Photomicrographs of thin sections of sulphide ore from Austinville Mines, Wythe County. Magnified 50 diameters; cross nicols. Shows crystalline granular dolomitic limestone, and the filling of fine cracks accompanied by replacement of limestone grains along crystallographic directions by the sulphides. Very dark irregular areas in center represent sulphides. Reentrant angles along margins of the sulphides and the spider-like arrangement of the sulphide areas as a whole are well shown.

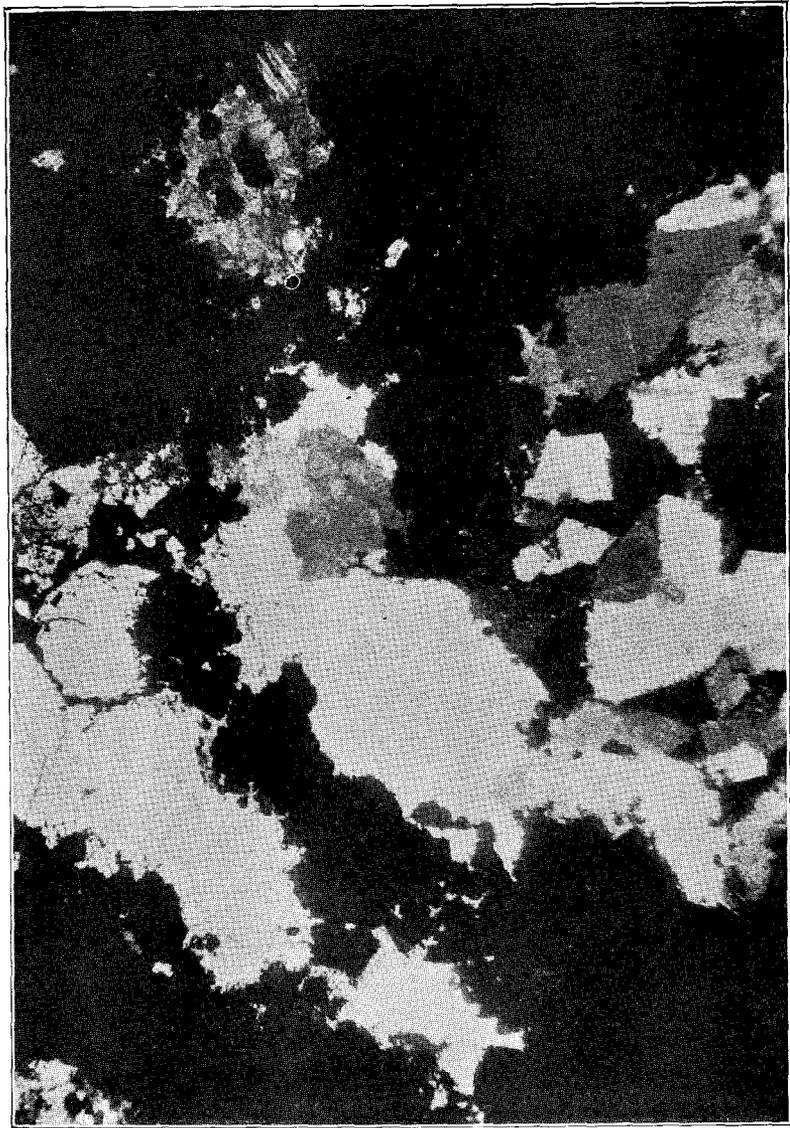


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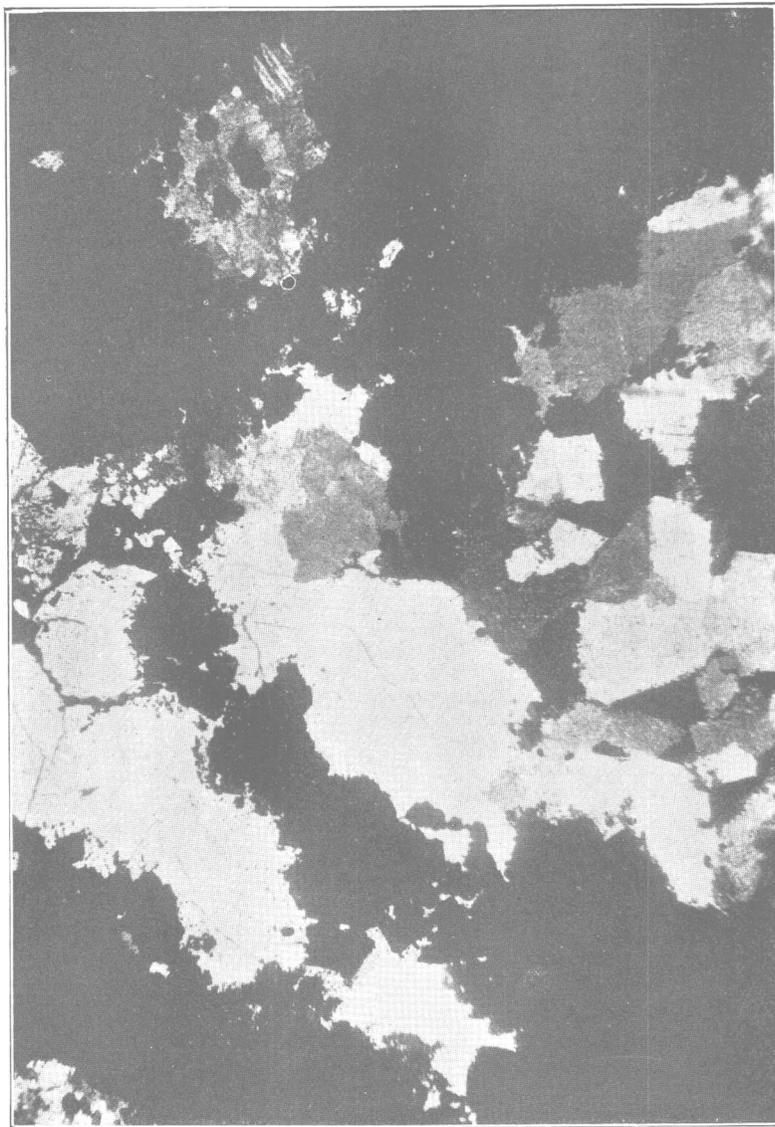


B

Photomicrographs of thin sections of sulphide ore from Austinville Mines, Wythe County. Magnified 50 diameters; cross nicols. Shows crystalline granular dolomitic limestone, and the filling of fine cracks accompanied by replacement of limestone grains along crystallographic directions by the sulphides. Very dark irregular areas in center represent sulphides. Reentrant angles along margins of the sulphides and the spider-like arrangement of the sulphide areas as a whole are well shown.



Photomicrograph of thin section of sulphide ore from Austinville Mines, Wylthe County. Magnified 50 diameters; cross nicols. Shows filling of fine cracks by sulphides, and advance stage in replacement process. Black areas represent sulphide minerals.



Photomicrograph of thin section of sulphide ore from Austinville Mines, Wythe County. Magnified 50 diameters; cross nicols. Shows filling of fine cracks by sulphides, and advance stage in replacement process. Black areas represent sulphide minerals.

Analyses of the Fresh and Partially Decayed Limestone from the Austinville Mines

	Fresh Limestone			Partially Decayed Limestone		
	I	II	III	IV	V	VI
Insoluble residue.	.594	.452	.20	.51	1.41	.48
CaO.....	29.085	29.50	30.71	30.41	29.22	29.95
MgO.....	20.54	19.93	21.56	20.78	20.12	21.15
Al ₂ O ₃.....	.344	.242	.37	.21	2.23	.38
Fe ₂ O ₃.....	.19	.17	.22	.21	.64	.30
MnO.....	.193	.378	trace	.11	.29	.20
ZnO.....	—	—	—	trace	.47	.91
Na ₂ O.....	.38	1.02	.10	.15	.22	.16
K ₂ O.....	.22	.56	.12	.05	.05	.04
CO ₂	45.40	44.01	43.88	43.80	41.34	42.51
H ₂ O.....	2.58	3.73	3.92	3.78	3.84	4.57
Total.....	99.52	99.99	101.08	100.01	99.83	100.65

- I. Grayish white and moderately coarse crystalline fresh limestone. Specimens taken from the 190-foot level in the Austinville Zinc and Lead Mines, Wythe county, Virginia. Dr. W. E. Barlow, analyst.
- II. White coarsely crystalline and crushed limestone. Specimens taken from the 80-foot level, bottom of open cut, in the Austinville Zinc and Lead Mines, Wythe county, Virginia. Dr. W. E. Barlow, analyst.
- III. White and medium textured crystalline limestone. Specimens taken from the 80-foot level, bottom of open cut, in the Austinville Zinc and Lead Mines, Wythe county, Virginia. Dr. W. E. Barlow, analyst.
- IV. Partially decayed limestone. Specimens of decay scraped from the sides of open cut between the shop and the fill across ravine to Bunker Hill, fifteen feet below the surface. The fresh rock at this point was slightly impregnated with galena. Austinville Zinc and Lead Mines, Wythe county, Virginia. J. R. Eoff, Jr., analyst.
- V. Partially decayed limestone. Specimens of decay scraped from the surface of one of the limestone "chimneys," Bald Hill, at a depth of about twenty feet below the surface. The outer surface of the decay was colored a deep red from iron oxide. The ore mined at this point was calamine, with a little galena. Austinville Zinc and Lead Mines, Wythe county, Virginia. J. R. Eoff, Jr., analyst.
- VI. Partially decayed limestone from the Austinville Zinc and Lead Mines, Wythe county, Virginia. Specimens consisted of a fine grained limestone sand, of grayish brown or light rusty color, collected from out-crop along road leading from the depot to the mines near the top of the hill and only a few rods below the mines. J. R. Eoff, Jr., analyst.

In order to indicate more clearly the changes involved in the transformation of the fresh to the partially decayed rock, as represented in the analyses above, an average of the three analyses of

the fresh limestone in columns I, II, and III, is given below in column A; and a similar average of IV, V and VI is given in column B. In column C is given an analysis of a carefully sampled portion of the residual red clay from one of the large open pits.

	A	B	C
Insoluble matter in dil. HCl...	.42	.80	SiO ₂ 48.96
Lime (CaO).....	29.77	29.86	.24
Magnesia (MgO).....	20.69	20.68	1.02
Alumina (Al ₂ O ₃).....	.22	.94	26.27
Iron oxide (Fe ₂ O ₃).....	.19	.38	10.53
Manganese oxide (MnO).....	.19	.20	none
Zinc oxide (ZnO).....	none	.46	none
Soda (Na ₂ O).....	.50	.18	}undet.
Potash (K ₂ O).....	.30	.05	
Carbon dioxide (CO ₂).....	44.43	42.55	} H ₂ O above 110°C. 2.06 } H ₂ O at 110°C. 7.41
Water (H ₂ O).....	3.41	4.06	
Total	100.21	100.16	98.22

On comparing these analyses essentially no difference is shown in the principal ingredients in A and B, which clearly indicates that the early stage in the weathering of this limestone is purely a physical one and is unaccompanied by any appreciable chemical action. In the next or final stage of the decay, shown in C, the results are markedly different, the more refractory constituents which are present in the fresh rock in barely more than traces, are retained as the principal ingredients composing the residual clay. The carbonates of lime and magnesia which practically make up the fresh rock have suffered most from solution and removal, and are only present in the residual clay in very small amounts.

The fresh rock composing the zone within which the lead and zinc ores are found is a recrystallized magnesian limestone. The first and early stage of weathering is a physical crumbling of the crystalline rock into a dolomitic sand varying from a light to brownish red color, in which only slight oxidation is shown. A characteristic feature of the weathered surface of the uncovered limestone "chimneys" is a pronounced irregular pitted aspect. A close examination of the limestone surface, shows this peculiar form of weathering to be due to solution and etching along the irregular fracture lines in the rock. The weathering of the limestone surface into the characteristic pinnacled or "chimneyed" surface is controlled largely by the jointing of the rock.

This form of weathering is characteristic of the openings at Bertha, Austinville and Ivanhoe, and in some of the openings made for mining brown iron ore. The location of each of these is along the zone of folded and crushed recrystallized limestone.

The New River Mineral Company's Property

The mines of this company are located near Ivanhoe and they have been extensively worked for limonite. Mining on the property dates back prior to 1874. The openings are made on the anticline which extends southwestward from Austinville and the limestone has suffered the same changes and is of the same character as that described at Austinville. It has been extensively shattered and recrystallized and when the residual decay has been stripped for iron ore, the underlying limestone presents a perfectly pinnacled surface similar to that at Austinville and Bertha. The pinnacles of limestone are closer together and are sharper crested here than at Austinville and Bertha. The limestone dips about 35° N. W.

On the north side of the openings nearest to and west of Ivanhoe much zinc ore is reported to have been mined. The ore comprised the secondary forms, calamine and smithsonite, and considerable unaltered galenite. Examination of the limestone pinnacles shows some disseminated sulphides, spalerite, galenite and pyrite. Differential weathering has emphasized the galenite at the surface of the pinnacles. The small bunches of the mineral stand out from the limestone surface as irregular black lusterless masses. Crusts of cerussite are frequently observed on the galenite. The three sulphides, sphalerite, galenite, and pyrite, are closely associated and occur with abundant masses of cavernous barite. In several instances the sphalerite and galenite were observed to be entirely enclosed by the barite. Quartz is very abundant both in the form of chert and as druses of perfect crystals and grains lining cavities in the limestone and the masses of limonite ore. Small perfect rhombs of calcite are often seen filling the smaller cavities in the limestone.

A similar occurrence of the sulphides is noted in the Simmerman iron ore pits nearby. Some fluorspar is associated with the sulphide ores in these pits in addition to the other nonmetallic minerals mentioned in the pits of the New River Mineral Company.

The zinc ores mined on this property are reported to have been shipped to Trenton, New Jersey.

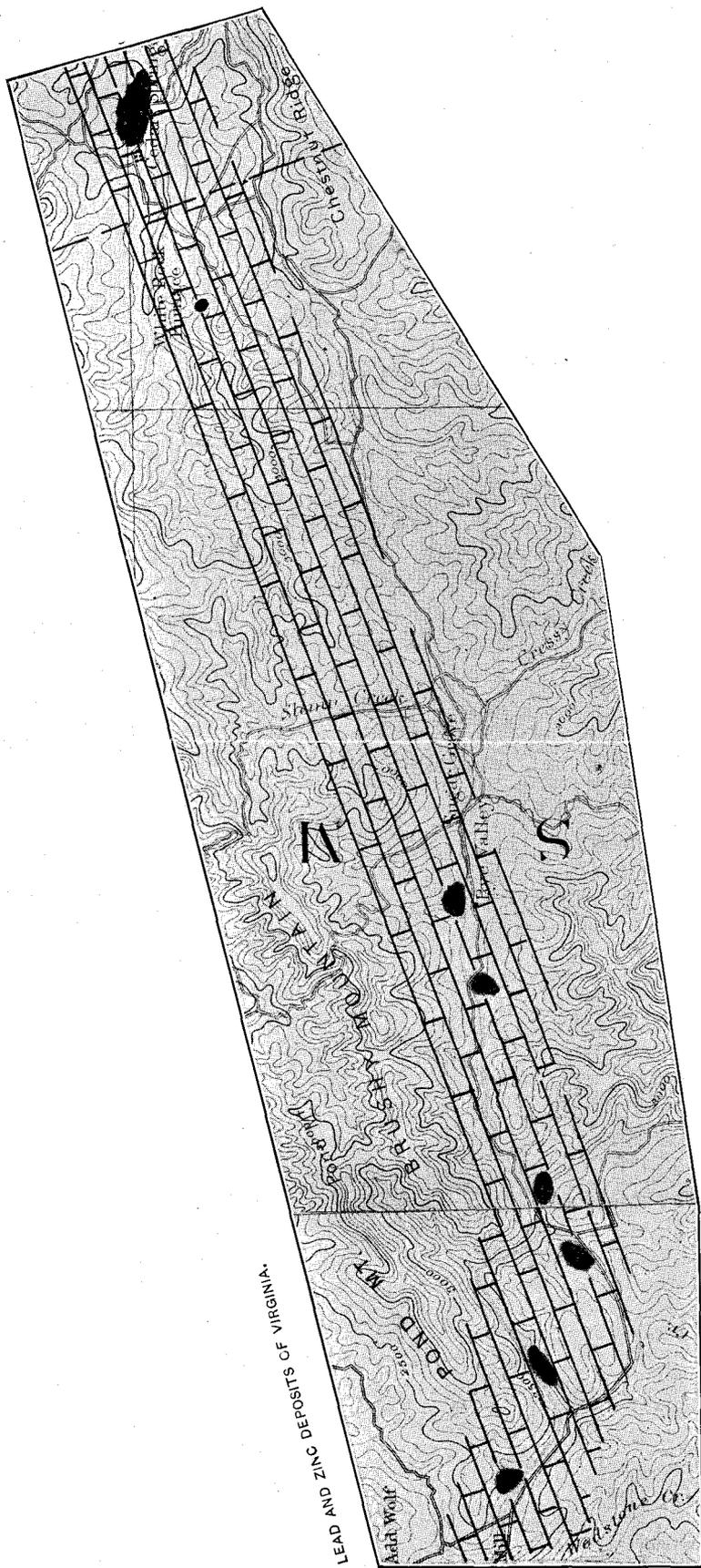
The Price Property

In the rear of the hotel at Ivanhoe zinc carbonate and silicate are reported to have been mined in 1874-75. The main opening was about 75 feet long, 6 feet wide and 30 feet deep and is now nearly completely filled in. The writer is reliably informed that 49 tons of the soft ores were shipped from this opening to Trenton, New Jersey.

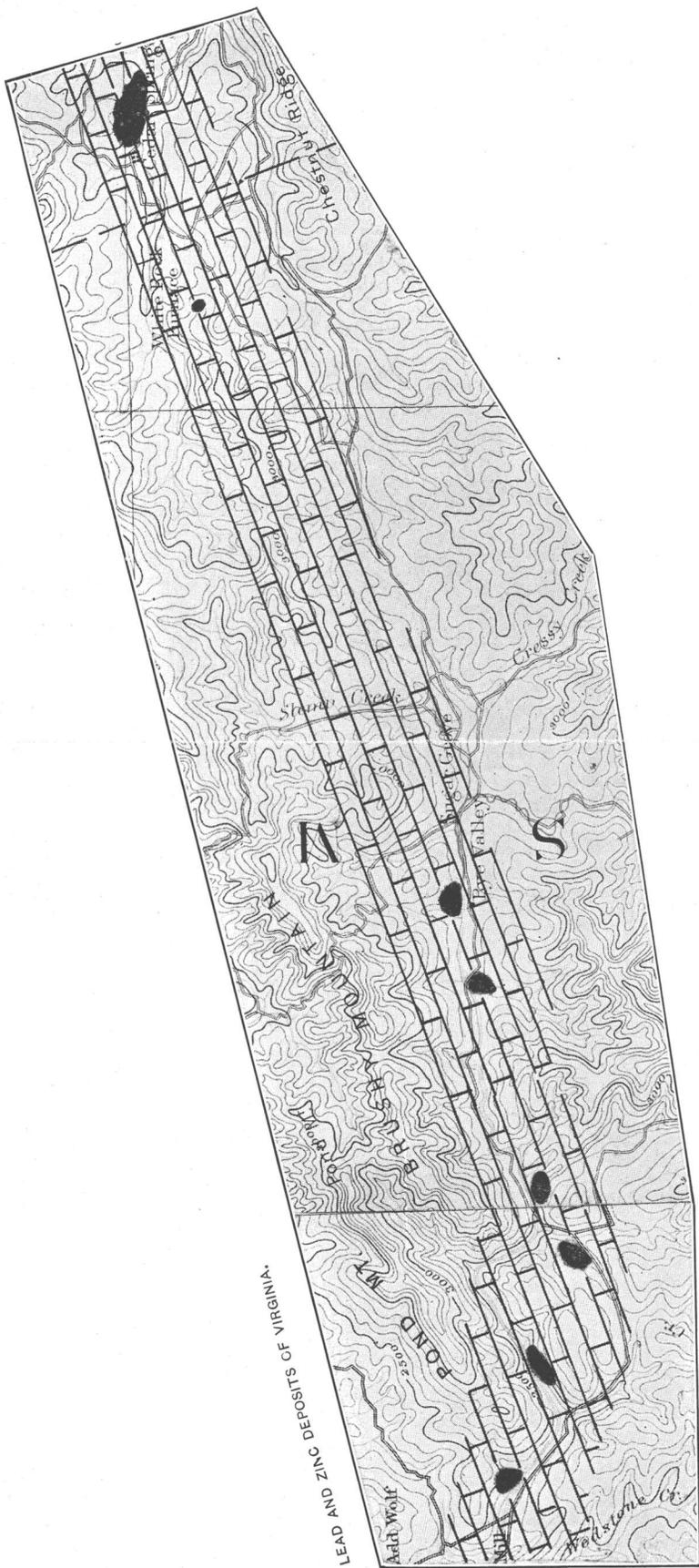
The Cedar Springs Zinc Mining and Development Company's Property

The general offices of this company are located in Columbus, Ohio. William Bucher of Columbus, Ohio, is President. The property comprises 387 acres of land located in the extreme southwest corner of Wythe county, about $5\frac{1}{2}$ miles south of Rural Retreat and 20 miles west of Austinville. It was first prospected some years ago by the Bertha Mineral Company. For the past few months extensive prospecting has been in progress by the Cedar Springs Company. The openings were made on the north side and along the head-waters of Cripple creek, extending from Cedar Springs eastward for a distance of a mile or more. The principal and large openings are grouped reasonably close together, and are only a short distance east of Cedar Springs. These comprise open-cuts, shafts and tunnels. The largest of these is an open-cut 250 feet long, 8 to 25 feet wide, and from 5 to 23 feet deep. Several shafts, sunk at different points, have reached a depth of 50 feet. In addition to open work some drilling has been done, the deepest of which reached a depth of 250 feet. The openings are made on and along the base of the limestone slope which bounds the stream on the north side and in elevation ranging only a few feet above stream level up to 50 and 75 feet. Several openings are reported to have reached depths of from 8 to 10 feet below stream level. The prospected zone, which parallels the stream in an east-west direction will not exceed 1000 to 1200 feet in width.

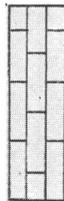
The topography of the area is shown on the accompanying map, plate XI. The rock in which the openings were made is a dolomitic limestone, as shown in the analysis below, of compact and finely crystalline texture. It is moderately dark in color and much crushed and broken and the fragments recemented by well crystallized calcite and dolomite, forming a typical breccia in the pro-



Map of the Cedar Springs and Rye Valley Zinc Deposits. Based on the Wytheville Sheet, U. S. G. S. Geology by Thomas L. Watson. Scale $\frac{1}{2}$ inch = 1 mile. Contour Interval 100 feet.



LEAD AND ZINC DEPOSITS OF VIRGINIA.



Shenandoah
Limestone



Zinc Deposits

Map of the Cedar Springs and Rye Valley Zinc Deposits. Based on the Wytheville Sheet, U. S. G. S. Geology by Thomas L. Watson.
Scale $\frac{1}{2}$ inch = 1 mile. Contour Interval 100 feet.

spected zone. Careful measurements made at some of the openings gave a dip of 80° N. W., and a strike of N. 80° E. These are not constant, however, but abrupt and sudden changes were noted in them, probably indicating that the zone is located on or very near the crest of a faulted anticline. The 250-foot open-cut shows the development of an east-west zone of slickensides in the limestone, which, so far as evidence indicates, probably point to localized movement at the time of brecciation and folding. Chert is distributed quite abundantly through the limestone in places but seems not to occur in the rock at the openings.

Between Rural Retreat and Cedar Springs the principal rock is the Cambro-Ordovician limestone and some shales. Pronounced reversal in the dip of the rock is shown in several places, accompanied by the arching of both the limestone and shale. The shales are purplish-red and olive in color, and are much fractured and folded. The limestone is similar to that described above at the opening, except chert is quite freely distributed through it. A chemical analysis made of specimens of the limestone collected by the writer from the openings near Cedar Springs gave Mr. J. H. Gibboney the following results:

	Per Cent.
Silica (SiO ₂).....	2.44
Organic matter.....	0.62
Iron oxide (Fe ₂ O ₃).....	} 1.18
Alumina (Al ₂ O ₃).....	
Lime (CaO).....	29.74
Magnesia (MgO).....	20.11
Calcium carbonate (CaCO ₃).....	53.11
Magnesium carbonate (MgCO ₃).....	42.80

The ore is of the breccia type composed of blende, zinc sulphide, practically without galenite, lead sulphide, and pyrite, iron sulphide. However, a little galenite has been reported from the extreme eastern prospect openings. Oxidized ores, calamine and smithsonite, are essentially absent, although the occurrence of very small amounts of smithsonite, zinc carbonate, is reported. The blende is found in large and small irregular crystalline masses, which show as a rule good cleavage development. It is light yellow in color and of exceptional purity as shown in the analysis given below made by Mr. J. R. Eoff, Jr., of pieces collected by the writer.

	Per Cent.	
Zinc (metallic).....	66.76	} Equivalent to 99.63 per cent. of zinc blende, ZnS.
Sulphur (S).....	33.44	
Iron (Fe) metallic.....	.50	
Insoluble matter.....		
Calcium carbonate (CaCO ₃)...	} trace	
Magnesium carbonate (MgCO ₃)		
Water (H ₂ O) at 110°C.....		
Cadmium (Cd).....	} none	
Lead (Pb).....		
Total.....	100.70	

Fig. 18.



SPHALERITE



LIMESTONE

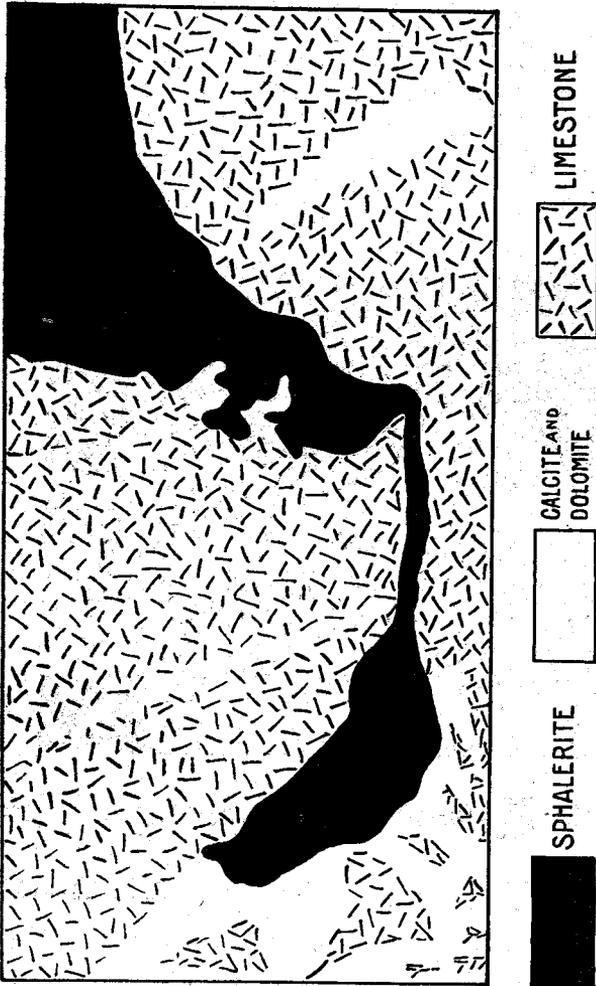
CALCITE
AND DOLomite

Breccia from Cedar Springs, Wythe County, showing relations of sphalerite to calcite-dolomite filling and to the limestone. Some replacement of the limestone by sphalerite is clearly shown. Natural size.

Partial replacement of the limestone fragments composing the breccia by the blende is shown, though not so emphasized as elsewhere. The bulk of the blende is distributed through the filling

of the white crystallized dolomite and calcite which cement the limestone fragments. It appears that the blende and the associated minerals, dolomite and calcite, were introduced and de-

Fig. 19.



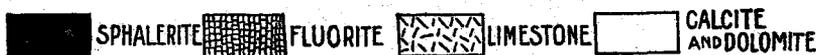
Breccia from the Cedar Springs Zinc Mining and Developing Company's openings, showing angular fragments of limestone cemented with sphaalerite, calcite and dolomite. Natural size. Cedar Springs, Wythe County, Virginia.

posited together. The relations of the blende to the limestone and to the associated minerals, dolomite and calcite, are shown in figures 18 and 19. Much of the filling between the limestone fragments is in large cleavable masses of the rhombohedral type.

Carefully selected portions of the filling were analyzed by Mr. J. R. Eoff, Jr., with the results given below, which indicate that it is composed of the minerals dolomite and calcite.

	I	II
Calcium carbonate (CaCO_3).....	54.75	98.89
Magnesium carbonate (MgCO_3).....	45.11	0.78
Iron oxide (Fe_2O_3).....	} 0.66	0.10
Alumina (Al_2O_3).....		
Insoluble matter.....	0.22	0.34
Total.....	100.74	100.11
Sp. Gr.....	2.97	2.66

Fig. 20.



Limestone breccia from the Cedar Springs Zinc Mining and Development Company's openings, showing the relations of fluorspar to sphalerite, and to the calcite-dolomite filling. Natural size. Cedar Springs, Wythe County, Virginia.

Quite a sprinkling of purple fluorspar, calcium fluoride, occurs in places. Green fluorspar is reported from one of the openings but the writer did not see any of it. The fluorspar is distributed through and is enclosed by both the blende and the filling of dolomite and calcite, as illustrated in figure 20. In other words, fluorspar is enclosed by masses of blende without calcite and dolomite, and is enclosed also by the latter minerals from which blende is

absent. These relations certainly suggest contemporaneity in deposition of the fluorspar with both the blende and the dolomite and calcite. The occurrence of fluorspar has been noted at only three places in Southwest Virginia as an associated mineral with the zinc and lead ores, namely, Cedar Springs, Wythe county, and on the McCarter place in Rye Valley, Smyth county. It also occurs in the Simmerman iron ore pits near Ivanhoe in association with lean sulphide ores of lead and zinc.

So far as developments have gone, the Cedar Springs property must be considered a promising one, and it affords strong indications of large quantities of blende of excellent quality being present. It should prove to be an easy milling proposition, since the ore, blende, is distributed through the brecciated rock in fairly coarse and massive form. The largest dump of ore, taken from the 250-foot open-cut, will probably average as it stands 10 to 15 per cent. of blende, zinc sulphide. A sample of the ore analyzed by O. S. Marckworth in the Ohio Testing Laboratory, and reported in the prospectus of the Cedar Springs Zinc Mining and Development Company, gave the following results:

	Per Cent.
Zinc sulphide (ZnS).....	43.86
Calcium carbonate (CaCO ₃).....	53.19
Iron (Fe ₂ O ₃).....	} 1.29
Alumina (Al ₂ O ₃).....	
Organic matter.....	0.50
Moisture (H ₂ O) at 100°C.....	1.14
Total.....	99.98

SMYTH COUNTY

General Statement.—Within the last few months considerable interest has been manifested over the probable occurrence of workable bodies of zinc ore in the south-central portion of Smyth county, in Rye Valley. Prospecting was being actively engaged in during the spring by several different companies and as many private parties, representing mostly Ohio capital. Operations were entirely confined along the South Fork of the Holston river, in Rye Valley, extending in a general east-west direction. About 10 miles east of Rye Valley, in the extreme southwest corner of Wythe county, very promising bodies of zinc blende are being exploited at Cedar

Springs. The location of these deposits is shown on the accompanying map, plate XI.

Rye Valley is formed from a narrow east-west strip of limestone enclosed between nearly parallel high and more or less broken quartzite ridges. The principal drainage of the region, South Fork of the Holston river, has been established on the weaker rock, limestone, which accounts in some measure for the valley, although folding and faulting have probably been important factors. The topography of this area is represented on the map, plate XI. The area between Marion and Rye Valley is composed of limestone, sandstone or quartzite, and shale. These preserve a general north-east strike and dip to the southeast, though reversals in dip are noted. The more resistant sandstone or quartzite is ridge-forming and the weaker limestone and shale are valley-making.

The Rye Valley district is 6 or 8 miles distant in an air-line from the nearest point on the main line of the Norfolk & Western railroad. However, a branch line, known as the Marion and Rye Valley railroad, is in operation between Marion on the main line, and Rye Valley, which offers good facilities for marketing the ore.

INDIVIDUAL OPENINGS

The Rye Valley Mining Company

The Rye Valley Company, composed of Baltimore capitalists, contains $18\frac{1}{2}$ acres of land, located one-quarter of a mile north of Sugar Grove, and 200 yards from and on the north side of the South Fork of the Holston river. The property was worked for two and a half years about eight years ago. About twenty-five carloads of the ore are reported to have been shipped. The ore was hand-picked before shipping, there being no concentrating mill on the property. The dumps are quite large, and they contain some good ore.

The openings comprise two main shafts, and a number of small test-pits. These are made on the strike of the rock along a N. 80° E. course. The two shafts are reported to have reached depths of 100 and 200 feet respectively, following on the dip of the rock, 60° S. E. They are spaced 225 feet apart and are connected underground by a drift at the 100-foot level.

Mineralization is along a distinct brecciated zone of variable width, which averages about two feet across in the shafts. The limestone breccia is apparently included between a compact and

fine-textured limestone of light gray and brown color, and a finely banded white and dark "birds eye" limestone. The fragments of the breccia are cemented by thin films of white crystallized calcite and dolomite. The limestone is of Cambro-Ordovician age and is much folded, broken and crushed. The surface exposures of the limestone at the mine openings show distinct bedding. The beds dip 60° S. E., and strike N. 80° E.

The ore is chiefly galenite, lead sulphide, of very fine-granular massive form. Only in the bottom of the 200-foot shaft has zinc blende been found. Here it is in fine-granular form of yellow color and intimately associated with the galenite. Specimens show blende enclosed by galenite, and galenite enclosed by blende. The ore penetrates and fills innumerable irregular strain cracks and fractures in the rock and, to some extent, it replaces the substance of the limestone fragments. Pyrite has not been observed in the openings, but it is found in places in the limestone in the railroad cuts near by.

Quite a sprinkling of violet fluorspar occurs intimately associated with the calcite and dolomite, and with the metallic sulphides. The fluorspar likewise fills fractures in the rock and in some instances encloses the metallic sulphides and in others, the fluorspar is enclosed by the sulphides. It further occurs with the calcite and dolomite as a thin coating on parting planes and slickenside surfaces, as well as filling small irregular cavities in the limestone.

Galenite, sulphide of lead, is reported from a number of other places in the vicinity of Sugar Grove, especially on R. N. Ward's place near the depot on the southside of the South Fork of the Holston river. A shaft was sunk to a depth of 82 feet encountering ore at depths of 78 and 82 feet.

The Calhoun Prospect.—Several openings were worked just above the Calhoun dwelling house by the Virginia Lead and Zinc Company during the spring and summer of 1904. The openings include a shaft and two open-pits dug on the top of a limestone knoll, 2 miles west of Sugar Grove P. O. These are made at an elevation of from 30 to 50 feet above the level of a small stream, which flows at the base of the knoll.

The rock is a semicrystalline limestone of Cambro-Ordovician age. It is dark gray in color, much crushed and broken and the fragments recemented by white crystallized calcite or dolomite,

forming a true limestone breccia. Measurements made in the openings gave for the limestone a dip of 65° S. E. and a strike of N. 60° E. The rock is of the same general character and the conditions quite similar as at Cedar Springs in Wythe county.

Very little ore was visible on either the dumps or in the openings. It comprises irregular masses of yellow, crystallized blende similar to that occurring at Cedar Springs, and some calamine. Galenite, lead sulphide, does not occur.

The Virginia Lead and Zinc Company

This company is composed of Ohio capital with offices in Columbus. In addition to the work done on the Calhoun place, prospecting was in progress by this company on the Scott and Livesay places at the time of my visit. The test openings made on these two places are separately described below.

The Scott Prospect.—The work comprises an open-cut and shaft dug during December, 1904, and January, 1905, at an elevation of from 10 to 15 feet above the level of the South Fork of the Holston river, on the south side and distant therefrom about 100 yards. It is located about one mile S. 80° W. from the Calhoun openings. The shaft was sunk to a depth of 53 feet on the dip of the rock. It was almost entirely filled with water at the time of my examination.

The rock is a very dark, nearly black, carbonaceous limestone, some layers of which part readily into very thin plates along the direction parallel to the bedding. It has been much crushed and broken and the fragments recemented by a filling of white crystalline dolomite. Slickensides are developed on the foot-wall in the open cut, indicating subsequent movement in the rocks. The rock dips 48° S. E. and strikes N. 75° E. The composition of the rock is shown in the following chemical analysis made by Mr. J. H. Gibboney of specimens collected by the writer from the openings on the Scott place.

	Per Cent.
Silica (SiO ₂).....	3.46
Organic matter.....	0.26
Iron oxide (Fe ₂ O ₃).....	} 0.58
Alumina (Al ₂ O ₃).....	
Lime (CaO).....	30.08
Magnesia (MgO).....	19.80
Calcium carbonate (CaCO ₃).....	53.71
Magnesium carbonate (MgCO ₃).....	42.14

So far as is shown by the openings, the only mineralogical form of ore found is blende, zinc sulphide. It occurs in massive crystalline form, having perfect cleavage development, and replacing in part the limestone substance, but more often it has been deposited with the dolomite or calcite in the once open spaces between the crushed fragments of the limestone, forming a typical breccia ore. Neither galenite, lead sulphide, nor the oxidized forms of zinc ore, carbonate or silicate, has been observed.

The blende is remarkably clean and pure, and is of a dull sulphur yellow color. An analysis of selected pieces of the ore gave Mr. J. H. Gibboney the following results:

	Per Cent.	
Silica (SiO ₂).....	.08	
Metallic zinc (Zn).....	66.94	} Equivalent to 99.86 per cent. zinc sulphide (ZnS).
Metallic iron (Fe).....	.30	
Sulphur (S).....	33.26	
Lime (CaO).....	trace	} Equivalent to 0.63 per cent. iron sulphide (FeS ₂).
Magnesia (MgO).....	trace	
Total.....	<u>100.58</u>	

The Livesay Prospect.—This prospect is located about 2½ miles S. 70° W. from the Scott openings. A shaft was being sunk in the hard limestone immediately on the edge of the South Fork of the Holston river, and approximately at the level of the stream, in April, 1905. Very little could be seen, as the shaft had penetrated only a few feet in depth.

The rock is a brecciated limestone closely resembling that on the Scott place. It is steeply inclined, maintaining a dip from measurements made in the shaft of 70° S. E. and a strike of N. 70° E.

Specimens of the limestone collected from the shaft by the writer yielded Mr. J. H. Gibboney on analysis the following results:

	Per Cent.
Silica (SiO ₂).....	4.10
Organic matter.....	0.66
Iron oxide (Fe ₂ O ₃).....	} 0.88
Alumina (Al ₂ O ₃).....	
Lime (CaO).....	29.46
Magnesia (MgO).....	19.68
Total.....	<u>54.78</u>
Calcium carbonate (CaCO ₃).....	52.16
Magnesium carbonate (MgCO ₃).....	41.88

A comparison of this analysis with that made of the limestone from the Scott openings indicates the practical identity of the limestone.

Both here and on the Scott place the ore is apparently confined to the darker and more carbonaceous layers of the limestone. If this association is found to continue on the further developing of these two properties, it would indicate that the ore was probably introduced in the form of sulphates and was precipitated as the sulphides by reduction from the organic matter contained in the limestone.

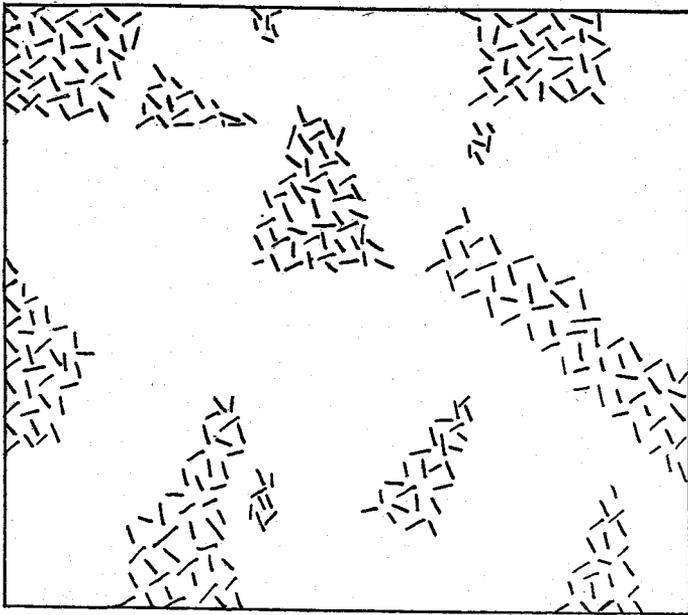
Enough work has not yet been done to state definitely whether workable quantities of ore will be found or not. The slight depth reached in the shaft shows some blende, similar in all respects to that described above on the Scott place, associated with as much or more galenite, lead sulphide.

The McCarter Prospect.—The place of prospecting on the McCarter property is located about $\frac{3}{4}$ mile southwest of the Eivesay prospect and from a quarter to a half mile south of the South Fork of Holston river. The work includes a single large shaft 40 feet deep and several small openings in progress at the time of my examination in April, 1905.

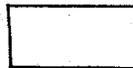
As shown in figure 21, the rock penetrated by the shaft is a true limestone breccia, the fragments of the limestone being cemented by white crystallized calcite and dolomite. It is semi-crystalline in texture and of much lighter color than the limestone described above from the Scott and Livesay prospects. A further unlikeness of the limestone occurring at this point from that described above is in the absence of organic matter in it. The same degree of strike is observed here, N. 70° E., but the dip is less steep, it being 45° S. E. Much chert is contained in the limestone in places. The rock has been faulted at the shaft, the fault-plane forming for a part of the depth the foot-wall of the shaft. As nearly as could be determined the strike of the fault is coincident with that of the limestone, S. 70° E., but the hade is steeper than the dip of the limestone, the former being 60° S. E., while the dip of the limestone is only 45° S. E. In other words, the fault intersects the limestone layers, making an angle of 15°. At present the shaft follows the dip of the limestone, but preparations were being made to cross-cut and follow the hade of the fault. Natur-

ally, mineralization of the rock would follow more or less closely the zone of crushing resulting from faulting, which would offer the most favorable conditions for the free circulation of the ore-bearing solutions and the precipitation and deposition of the metallic sulphides. Prospecting, therefore, should be directed along this line of breakage, as concentration of the ore would be more likely to take place here than elsewhere.

Fig. 21.



LIMESTONE FRAGMENTS

CALCITE AND
DOLOMITE

Breccia from McCarter place, Rye Valley, showing angular fragments of limestone cemented with calcite and dolomite. Natural size.

So far as the prospecting has developed, blende, zinc sulphide, is the only ore found. The oxidized zinc ores, carbonate and silicate, and galenite, lead sulphide, do not occur. Several pieces of pyrite, iron sulphide, are noted on the dump, but this mineral is very rare. The limestone is replaced in part by the blende, but probably the bulk of the blende is distributed through the white crystallized calcite and dolomite which, together with the blende,

are deposited in the spaces between the broken limestone fragments, forming the cementing material which binds together the rock fragments.

In addition to the filling of the spaces by blende, calcite and dolomite, quite a little sprinkling of deep violet colored fluorspar, calcium fluoride, occurs. The fluorspar occurs in masses large enough to show good cleavage development and in very small grains. At the shaft it is associated with the calcite or dolomite-filling of the brecciated limestone. About 1,000 feet northwest of the shaft a test opening made in the limestone reveals numerous small cavities or vugs filled in part with fluorspar and in part with calcite. Some of these show first a lining or filling of fine granular fluorspar next to the limestone and the rest of the cavity filled with white calcite. Others show intimately admixed fluorspar and calcite filling the entire cavity. Figure 1 represents these occurrences of the two minerals. In the former case it would appear that the fluorspar was introduced into the cavity in advance of the calcite; in the latter contemporaneous deposition of the two minerals seems probable. In some weathered fragments of the rock, it was noted that the deep violet color of the fresh fluorspar had faded or altered to a light wine red color.

The Martin Prospect.—The work includes six or eight openings made on the Martin place, located about 4 miles N. 80° W. of the McCarter property. The openings are made near the top and on a slope of a limestone knoll, about 500 feet north of the South Fork of the Holston river and at an elevation of from 50 to 100 feet above the stream level.

The rock is a light gray crystalline limestone, not brecciated, but has suffered considerable crushing. It resembles somewhat closely the fine grained dolomitic limestone at the Austinville mines in Wythe county, except that the Austinville rock shows brecciation quite distinctly in places which is not indicated at all in the rock at the Martin opening.

Careful examination reveals very little ore. A little blende, zinc sulphide, darker in color than the blende described above from the other openings in Rye Valley, but of the massive crystalline type, occurs. A little galenite, lead sulphide, is associated with the blende. The indications as disclosed by the developments thus far

made are by no means encouraging for the finding of workable ores.

The VanHoy Prospect.—About $1\frac{3}{4}$ miles to 2 miles S. 80° E. of the Martin place prospecting for ore had just begun on the VanHoy place at the time of my visit in April, 1905. Some blende, zinc sulphide, had been found, and the indications are reported to be encouraging.

RUSSELL COUNTY

General Statement.—Zinc ores are known at only one locality in Russell county, namely, on Copper creek about 7 miles south of Castlewood, a station on the Clinch Valley division of the Norfolk and Western railroad. Here the occurrence of the ore is in the Knox dolomite, magnesian limestone, of Cambro-Ordovician age, and is interbedded with thin bands of reddish and olive colored shales. Developments have been entirely confined to one place on Copper creek, although ore is reported on several adjoining properties.

The Osborn Zinc Mine.—This mine, so-called, is located on the George Osborn place, 7 miles south of Castlewood, a station on the Clinch Valley division of the Norfolk and Western railroad. It is further located on the south side of and a quarter of a mile from Copper creek, as shown on the accompanying map, plate XII.

The ore was first opened some 5 or 6 years ago by L. D. Crawford, who worked the property for a period of about six months, and afterwards optioned it to the Bertha Mineral Company. This company worked it for about the same period of time, and after making considerable developments, concluded it would be better to drop the option. Crawford again resumed mining on the property and shipped the ore to the furnaces at Pulaski. Considerable work has been done and apparently much money has been spent in developing the property. The principal hindrance to mining is the distance from the railroad and the rough mountainous area over which the ore must be hauled for shipping.

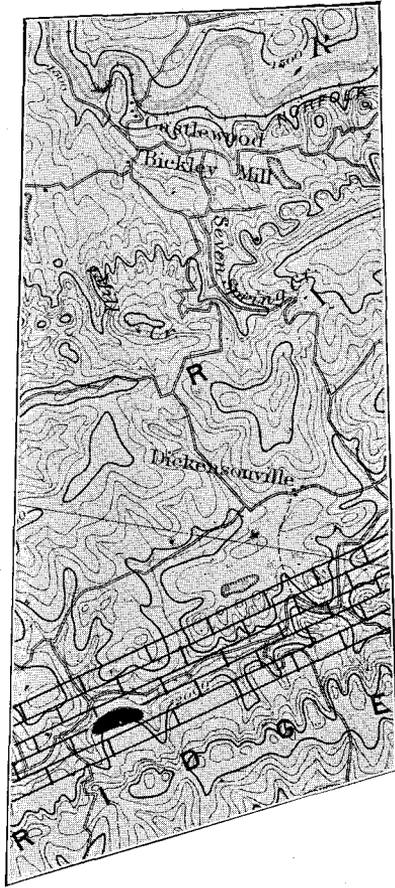
The openings, which include a main large open pit and numerous test-pits, are made on a north sloping shelf of a principal ridge paralleling Copper creek, and at an elevation of from 300 to 350 feet above the creek. Several tunnels and drifts were worked from the large pit, all of which were of shallow depth. The shelf was

evidently determined in part by an east-west strike fault which is exposed in the west end of the principal opening. Where observed in the opening, the fault has a steep dip, nearly vertical, to the south. The openings are made along and near the fault-plane, extending in a general east-west direction on both sides of the larger opening, and they are dug in the area on the downthrow side of the fault.

The topography of the area is shown on the accompanying map, plate XII. It is rough and typical of the mountainous district of Southwest Virginia. The rocks are folded and faulted and are deeply incised by stream cutting, giving a pronounced ridge-valley type of topography. The rock is magnesian limestone of Cambro-Ordovician age, having an average dip of 25°-30° S. E., and striking N. 70°-80° E. Thin banded, calcareous and argillaceous, olive-colored shales, much crushed, are interbedded with the limestone at the openings. The shales are repeated on both sides of the fault-plane. The rocks are further intersected by a well developed system of joints cutting approximately at right angles to the bedding and trending in a general northeast direction. Crushing effects of the limestone are much less apparent here than elsewhere and very little calcite, other than that contained in the limestone proper, is developed.

The limestone is almost continuously exposed along the road between Castlewood and the mines. Some crushing of the rock is in evidence, in places, and the fragments are recemented by white calcite or dolomite. The limestone is prevailing dark in color, finely crystalline, and is filled with irregular masses and nodules of black chert. No chert, however, was observed in the limestone at the openings. Elsewhere, the chert weathers white in color; is compact to spongy in texture, with fine quartz druses lining some of the cavities; and, in places, it thickly litters the surface as large and small masses. At several places along the road between Castlewood and the mines, the breaking off of fragments from the limestone ledges is accompanied by a distinct fetid odor, indicating the presence of more or less bituminous matter in the rock. About half way between the station and the mines, the limestone is interbedded with a considerable thickness, probably several hundred feet, of calcareous, olive shales.

Plate XII.



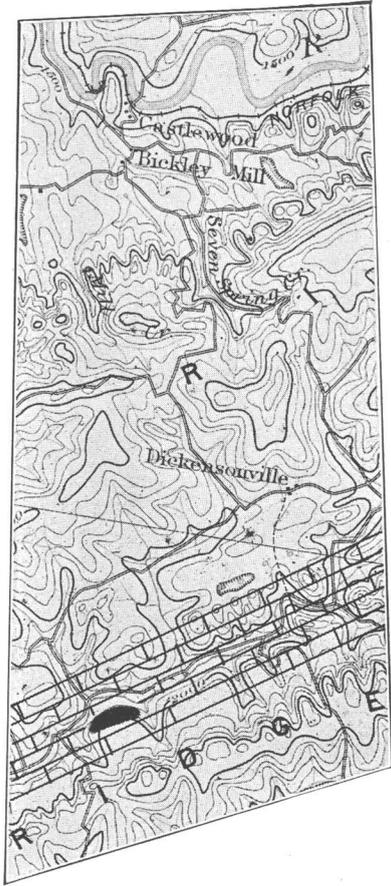
Shenandoah
Limestone



Lead and Zinc
Deposits

Map of the Russell County Lead and Zinc Deposits. Based on the Bristol Sheet, U. S. G. S. Geology by Thomas L. Watson. Scale $\frac{1}{2}$ inch=1 mile. Contour Interval 100 feet.

Plate XII.



Shenandoah
Limestone



Lead and Zinc
Deposits

Map of the Russell County Lead and Zinc Deposits. Based on the Bristol Sheet, U. S. G. S. Geology by Thomas L. Watson. Scale $\frac{1}{4}$ inch = 1 mile. Contour Interval 100 feet.

The composition of the limestone is shown in the following analyses:

	I	II
Silica (SiO_2).....	2.76	1.94
Organic matter.....	.80	none
Iron oxide (Fe_2O_3).....	.24	2.26
Alumina (Al_2O_3).....		
Lime (CaO).....	51.12	44.62
Magnesia (MgO).....	2.32	7.60
Calcium carbonate (CaCO_3).....	91.28	79.69
Magnesium carbonate (MgCO_3).....	4.96	16.17

I. Specimen of limestone collected five miles south of Castlewood. J. H. Gibboney, analyst.

II. Specimen of limestone collected at the zinc mine seven miles south of Castlewood. J. H. Gibboney, analyst.

The ores include zinc silicate, calamine, admixed with some galenite, lead sulphide, and zinc sulphide, sphalerite. Sphalerite occurs only in the unaltered limestone, disseminated through the rock as the result of a replacement process, elsewhere described. It is a dark yellowish gray in color, and is usually of the fine granular type. Calamine is entirely secondary and was derived from the original sulphide ore, sphalerite, by oxidation. It occurs associated with the residual decay of the limestone.

The usual gangue minerals, such as calcite, dolomite, etc., except in the form of the enclosing rock, limestone, are practically absent. While baryta, barium sulphate, has been mined further north and is reported as occurring over large areas in Russell county, it was not found as an associated mineral with the ores in any of the openings. Galenite, lead sulphide, was reported to be more abundant near the surface, but on depth it decreased and blende, zinc sulphide, increased in amount. Calamine was the principal ore shipped. The total shipment of ore from this property will probably exceed a dozen carloads. Similar ores are reported to occur on adjacent properties, along an east-west direction, but no openings have been made.

Not all the openings were accessible for examination at the time of my visit, but judging from the general conditions the ore is by no means exhausted. Further development, however, is needed to determine the general character, extent and quality, of the sulphide ores, which occur with fresh and unaltered limestone below

the belt of decay. Just at present the principal drawback to developing the property is its distance from the nearest railroad point, with a rough area intervening over which to haul the ore.

GENERAL OUTLINE OF THE GENESIS OF ORE DEPOSITS

Introductory

Metalliferous deposits may be divided into three general groups, namely: (1) those which are of direct igneous origin, as some bodies of magnetic iron ore; (2) those which are the direct result of the processes of sedimentation, such as placer gold deposits; and (3) those which are deposited by circulating underground waters. By far the majority of all known ore deposits belong to the third class, or those which owe their origin to circulating underground waters, either of meteoric or magmatic origin, or both. To the third class of deposits are referred the lead and zinc ores of Virginia. The method of formation of the third class of deposits with special reference to the lead and zinc deposits of Virginia is briefly outlined below. In presenting this outline of the modern theory of ore-deposits, the work of Professor Van Hise is followed, free use being made of the several excellent papers published by him on this subject.⁴⁰

Zones of the Earth's Crust

The outer part of the crust of the earth may be divided into three zones. These are, from the surface inward: (1) the zone of rock-fracture; (2) the zone of combined rock-fracture and rock-flowage; and (3) the zone of rock-flowage.

The first zone, or the zone of rock-fracture, is that near the surface. In this zone the rocks, when rapidly deformed, respond by fracturing. When this deformation is exceedingly slow—extending through a long time interval—the rocks, within certain limits, will bend rather than break. However, the so-called folds in rocks, which occur in the zone of fracture, are due chiefly to numerous parallel, small fractures or breaks. In this zone, then, the conditions are particularly favorable for the development of fissures or cavities in the rocks. The most important of these are known

⁴⁰Some Principles Controlling the Deposition of Ores. *Trans. Amer. Inst. Mng. Engrs.*, 1901, Vol. 30, pp. 27-177.

Ibid. *Journal of Geology*, 1900, Vol. 8, pp. 730-770.

A Treatise on Metamorphism. U. S. Geol. Survey, Monograph XLVII, 1904, 1286 pages.

as fault-planes, joint-planes and planes of rupture due to the differential movement of one bed or layer of rock upon another. The principal ore deposits occur within this zone because the conditions are more favorable for a free circulation of water. The lead and zinc deposits of Virginia belong to the zone of fracture and the large cavities which occur in the rocks in which the ores are found—the limestones—are fractures produced by deformation. In some cases the openings in the rocks have been enlarged by solution and refilled by the ores and their associated minerals.

Below the zone of fracture is another zone called the zone of combined fracture and flowage, where under deformation some of the rocks will flow while others will fracture. Moreover, certain rocks are deformed by flowage at a much less depth than are other rocks, because of the various factors involved. Chief among these are the varying strengths of rocks; the variation in the rapidity of deformation; the temperature at which the deformation occurs; and the amount of moisture present. Van Hise states as an instance of this a shale, which being a weak rock may be deformed by flowage at a much less depth than that of a strong rock like granite. It follows from this, then, that within the zone of combined fracture and flowage cavities will not exist in those rocks which are deformed by flowage, but will only exist in the more brittle ones or those which are deformed by fracture.

In the deepest of the three zones, or the zone of rock-flowage, the pressure is so great that, when the rocks are deformed, they respond by flowing rather than by breaking. There are no cavities of appreciable size within the zone of flowage, for as fast as they may be formed they are filled by the inflowing of the rock from the sides. It is believed that at a depth of about 10,000 meters and below, the strongest rocks are deformed by flowing. As stated above, certain rocks, especially the weaker ones like shale, respond to deformation by flowing at a much less depth than that of the zone of flowage.

The General Circulation of Water

Of the water which falls from the clouds upon the land, a part is evaporated and returned to the sky, a second part flows off the surface of the ground into the nearest water course and is subjected to evaporation, and the remainder sinks into the ground.

It is that part of the atmospheric water which sinks into the

ground, which is of the most importance in the formation of ore-deposits. A part of the water which sinks into the ground is soon returned by capillarity and vegetation and is of no importance in the formation of ore-deposits.

The water which enters the ground, forming the underground waters, flows through very circuitous and complicated channels, passing from areas of high pressure to those of lower pressure. This water is constantly in motion. On entering the ground at higher levels it emerges again at lower levels. The distance traveled between the two levels may be short or it may be long. The underground waters are returned again to the surface after a long or short journey, in the form of springs or wells; or it may enter the streams, lakes and oceans at or beneath their surface.

On entering the ground, the atmospheric or meteoric waters pass downward through the rocks until a point is reached below the surface where the rocks are saturated with water. This belt is known as the belt of saturation and the upper level of the belt of saturation is known as the level of ground water. A second or outer belt of underground circulation may be designated as an upper belt of underground water circulation, next above the belt of saturation, and extending from the surface of the ground to the level of ground water. The thickness of the outer belt of circulation or the depth from the surface to the level of ground water, varies greatly. In areas where the surface is but little higher than the adjacent bodies of water, such as streams, lakes and the oceans, the level of ground water may reach near or to the surface, thus affording either a very thin upper belt of circulation, or none. In regions whose topography is marked by slight elevations and irregularities the level of underground water may vary from 10 to 100 feet below the surface. In regions of greater elevation and stronger irregularities the level of ground water may be several hundred feet below the surface. It may be stated in general that for any given region the level of ground water is at the surface of the streams, and rises to higher levels under those land surfaces back from the streams. In other words the level of the underground water is not horizontal but is undulating, roughly following the topography of the land surface. This level will vary a few feet from season to season, for any given place, depending largely upon the amount of rainfall. In Southwest Virginia where the lead

and zinc deposits are found, the region as a whole is one of marked topographic irregularities, a ridge-valley type of topography—the ridges rising many hundred feet above the valley bottoms. The ground water level over this region will vary from zero at the streams to several hundred feet under the higher lands below the surface.

• The Openings in Rocks

In its passage downward from the surface through the rocks, the water flows through the openings in the rocks. These openings in rocks are of various sizes and shapes and include (1) those which are of great length and depth, as compared with their width; (2) those in which the dimensions of the cross-sections of the openings are approximately the same; and (3) irregular openings.

The openings of the first kind include faults, joints, fissility and bedding partings. These are likely to be continuous for considerable distances both laterally and vertically. This is true to the largest extent of the fault openings and to the least extent of the openings of fissility. These are very important openings in the flowage of underground waters, for the reason that they are frequently nearly vertical in position, traversing the rock-layers or beds at approximately right angles, and are usually continuous for considerable distances. To the second class of openings belong the spaces between the different grains of the rock which might be called the pore space. The pore space varies greatly for different rocks and for the same rocks under conditions of different size and shape and different degrees of cementation. Many sandstones contain a pore space amounting to as much as 10 to 20 per cent. of the total bulk of the rock. In the case of some fine grained shales and clays the percentage of pore space will amount to 30 or 40 per cent. It is necessary here to distinguish between porosity and permeability of rocks, or the difference between the amount of water absorbed by the rocks and the amount of water allowed to pass through them. Certain rocks, such as some sandstones, possess a high porosity and a high permeability, while other rocks like certain fine grained shales or clays will absorb more water than some sandstones, they will allow only very little water to pass through them. This is a very important principle in its bearing on the formation of ore-deposits, since in many areas, beds of impervious rocks in

their relations to more pervious ones have exercised a very important influence upon the circulation of underground waters.

Under the third class or that of irregular openings Van Hise includes those of the vesicular lavas and the irregular fractures of the rocks.

Openings belonging to either of the three classes designated above may be, and frequently are enlarged subsequently by solution. This is especially true of so easily soluble a rock, comparatively speaking, as limestone, and may be extended to all kinds of rocks, however resistant, under certain conditions. The circulation of water is, of course, freer in the larger openings, such as those designated under the first head, and it is along these openings that the trunk streams are formed and the ore most likely to be concentrated.

The Flowage of Underground Waters

It has already been stated that the movements of underground water were complex. These complex movements are resolved into

Fig. 22.

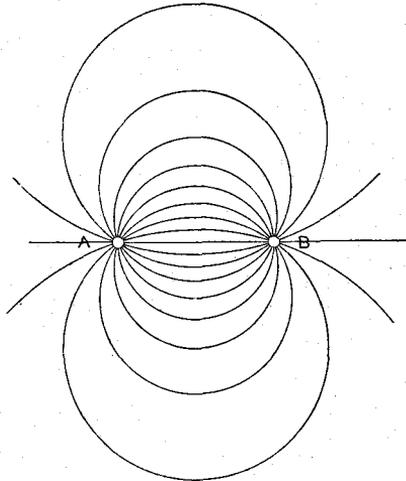


Diagram illustrating the horizontal routes taken by water in flowing from one well (B) to another (A). (After Van Hise.)

two components, horizontal or lateral movements and vertical movements. In general the horizontal component will probably greatly exceed the vertical component. Again it has been stated that the direction of flowage of underground waters is from areas of high pressure to areas of lower pressure. Waters entering the

ground at the surface, work their way downward through the rocks to lower levels by the force of gravity. They do not pass directly from the point of entrance to the point of emergence, however, but they travel by irregular and circuitous routes, so that, below the surface, the rock in the zone of fracture is traversed through the entire depth by the currents of water. The rate of movement of these circulating waters through the zone of fracture varies for different parts of the zone, being more rapid, as a rule, in the upper part of the zone than deeper down.

Some idea of the complexity of the circulating underground waters can be gained from the accompanying diagrams, which illus-

Fig. 23.

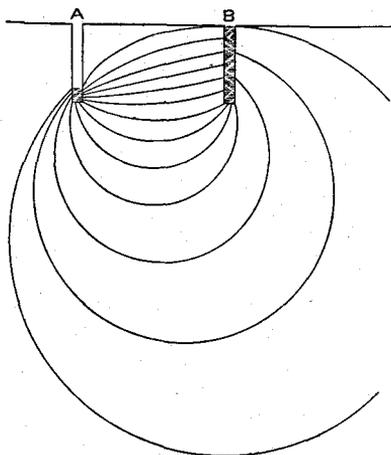


Diagram illustrating the vertical routes taken by water in flowing from one well (B) to another (A). (After Van Hise).

trate the paths by which the waters will pass from one opening to another. Figures 22 and 23 are diagrams which represent the horizontal and vertical circulations of the underground water, respectively, from one opening to another, such as between two wells. Figure 22, illustrating the horizontal circulation, represents two wells, A and B, separated by a homogeneous porous medium. If we assume that in the beginning well A contains no water, and water be poured into well B, it will flow from well B to well A through the porous medium. The paths of this flowage are represented by the curved lines. Some of the water travels in a nearly direct course, while another part takes a somewhat curved course.

Still other parts of the water follow a very indirect course, as represented by the longer curved lines. Figure 23 illustrates the vertical circulation between the two wells A and B. The water poured into well B passes into well A, following the course of the curved lines. A difference in head equal to the difference in the level of the water in the two wells causes a part of the water poured into B and passing through the porous medium to A, to penetrate to some depth, from which it rises and enters well A.

Figure 24 illustrates the circulation of underground waters from

Fig. 24.

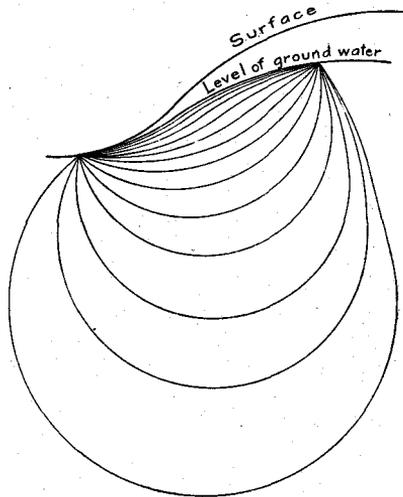


Diagram illustrating the routes taken by water which enters the ground at one point on a slope and emerges at a lower point. (After Van Hise.)

highland to lowland. This figure shows the shape of surface, the level of ground water, and the flowage of water from a high to a lower point. Below the level of ground water the rocks are saturated, all the openings in the rocks both large and small are filled with water. It is further assumed in the diagram that all the water enters at a single point A and issues at a single point B. The paths of the flowage of the water are shown in the curved lines.

Comparison of the three diagrams (figures 22, 23, 24) illustrate in a very clear manner the statements previously made that, (1) the route of the underground water in passing from the points of entrance to the point of emergence is very variable and complex; and (2) that practically all parts of the zone of fracture are trav-

ersed by the circulating waters. Moreover, the general circulation of underground waters which pass downward and laterally, is largely through the smaller openings or pore spaces in the rock. A strong tendency is shown in these waters to flow toward and concentrate in the larger openings, such as fault-planes, joint-planes, etc., where a mingling of the waters from the different sources takes place and the principal metallic deposits are frequently made. Reference to figure 25 makes clearer this idea. The figure represents a vertical section of the flow of water entering at a number of points on a slope, and passing to a valley below interrupted by two open vertical channels, one about midway down the slope, the other

Fig. 25.

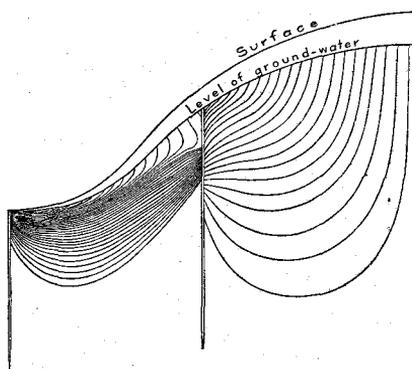


Diagram illustrating the waters descending below a slope and emerging into vertical openings where they become ascending waters. (After Grant.)

in the valley below. The water enters the rocks principally on the high area, passes downward and horizontally through the small openings and converges in the larger channel or fissure halfway down the slope. Of course a fissure located upon the middle of a slope will probably receive water from above and below as well as from the sides or laterally. The water received at the upper side of the fissure from the high area escapes laterally, at the lower side, and with that water entering the ground below the upper fissure, will make its way to the fissure below the valley. The level of ground water in the lower fissure, however, is at the surface, consequently, all the water entering this fissure will rise or ascend to the surface and issue as a spring. As noted later, these ascending currents are of much importance in the deposition of ores.

It was stated above that gravity was the principal cause of the

circulation of underground waters. While this is true, it must be borne in mind that in the deeper underground circulations temperature also probably plays an important role. Increased depth from the surface downward is accompanied by an increase in temperature. Also the increased temperature of the waters at these depths is accompanied by a decrease in the viscosity of the waters, which causes more rapid circulation of the waters for those depths. In the region of the Virginia lead and zinc deposits there seems no apparent reason for regarding them as having been formed from the circulating waters of great depth, hence gravity has been the cause of the underground circulations in this region.

The Work of Underground Waters

The circulation of underground waters having been described, it now remains to enquire into and discuss the work accomplished by these waters. So far as the work of underground waters relates to ore-deposits, the zone of fracture may be conveniently divided into two belts: (1) an upper belt of weathering, and (2) a lower belt of cementation. In the first belt are grouped all alterations or changes of rocks resulting from the action of physical and chemical agents, which tend to disintegrate and decompose the rocks. This belt or the belt of weathering extends from the surface to the level of ground water and for a short distance below this level, the depth of which varies for different areas. The second belt or the belt of cementation, extends from the bottom of the belt of weathering to the bottom of the zone of fracture. This belt is mainly characterized by cementation and induration, by hydration, by deposition, and by increase of volume of the rocks. The changes produced in this belt which are involved in the transfer or migration of mineral matter from one point to another are of the most importance in the present connection. The work of the underground circulating waters, which results in these changes, may be grouped under three heads: (1) solution, (2) transportation, and (3) deposition.

Solution.—The solvent action of water is probably one of the most widespread phenomena among the natural processes. Pure water is capable of dissolving very many substances in small amounts, but the meteoric waters both before and after entering the earth's crust are never pure. As the waters fall through the atmosphere, they take into solution certain gases, principally oxygen and carbon dioxide, and on entering the ground they take

into solution by virtue of the dissolved gases, more or less of the mineral substance of the rocks. Some substances are of course much more readily soluble than others. Among rocks, limestone is found to be one of the most soluble in water containing dissolved carbon dioxide and hence suffers the most from solution effect. Again in its passage through the rocks the waters, by continually dissolving mineral matter, are enabled chemically to extract certain other salts from the rocks because of the presence of those already in solution.

Furthermore increased temperature and increased pressure augment the dissolving power of waters. As the waters descend deeper into the earth the temperature and pressure are increased, so that the circulating waters in the deeper and lower portions of the zone of fracture have their dissolving power greatly increased. While the substances dissolved by the underground circulating waters in their journey through the rocks are numerous and complex, only those containing lead and zinc and iron are of the most importance in this connection. The minute quantities of the compounds of these metals which are scattered through the rocks are dissolved, either in part or in whole, by the underground circulating waters and are carried in solution by them.

Transportation.—It has already been shown, that practically all parts of the zone of fracture are traversed by the underground circulating waters, and that in their journey through the rocks of this zone they are continually dissolving a part, at least, of the mineral matter with which they come in contact. It is believed further that the solution of these substances by the circulating waters is accomplished largely by the descending currents. These dissolved substances then are transported downward and laterally through large areas of the rocks, mainly through the smaller openings, tending to emerge into the larger openings, where they join the ascending currents. In this way it is readily understood that large quantities of soluble mineral matter are carried or transported by the underground circulating waters from one place to another in the earth's crust.

Deposition.—It is necessary to consider the conditions under which precipitation or deposition of the mineral matter held in solution and transported by the underground circulating waters takes place. It is clear that the necessary condition for the pre-

precipitation or deposition of the mineral matter from solution is super-saturation. There are various ways in which precipitation from super-saturation may result. The following are regarded as the more important: (1) by decrease in pressure; (2) by decrease in temperature; and (3) by chemical reactions. Under the latter head are included numerous, varied and complex reactions only the simplest ones of which are as yet well understood.

It has been shown that the zone of fracture is divisible into an upper belt of weathering and into a lower belt of cementation. The upper belt, or the belt of weathering, is the belt in which solutions are mainly taking place. Below the belt of weathering is a second belt in which precipitation and consequently cementation take place, though some solution also takes place. It is within the larger cavities that the ore-bearing solutions are mainly concentrated and the ores and associated minerals are precipitated and deposited. The ascending currents in the larger cavities are likely to be depositing currents, because in them the pressure and temperature are constantly decreasing, two factors which are of first importance in causing precipitation. While decreasing temperature and pressure are important factors in causing precipitation, the mingling of the ore-bearing solutions with certain other solutions and the ore-bearing solutions coming in contact with the wall rock are likewise of extreme importance in producing precipitation. As will be pointed out elsewhere in this volume, the latter principle is regarded as having been the main factor which has caused precipitation of the lead and zinc from the ore-bearing solutions in the Virginia district, rather than decreased pressure and temperature. Apart from the mingling of solutions, certain of the Virginia deposits indicate that the organic matter contained in parts of the limestone, where the deposits of zinc are now found, was an important, if not the important, factor causing precipitation.

Returning to the case of mingling of solutions in causing precipitation it frequently happens that where two fissures cross the solutions traveling in one fissure may be different from those traveling in the other, enriched ore-deposits often occur, due to the difference in composition of the two solutions mingling at or near the crossing of the two fissures.

Deposition From Ascending and Descending Solutions

It has been pointed out that ascending waters, especially in the larger cavities are waters which tend to deposit mineral matter. Many of the ore-deposits of the world are due to waters moving in an upward direction. It is also true that under certain conditions descending waters become at times depositing waters. This can best be illustrated by the case of ore-bodies that have been brought partly within the belt of weathering from the processes of erosion. Those parts of the ore-bodies brought within the belt of weathering are being dissolved and their solutions are carried downward. These descending solutions from the belt of weathering meet other solutions which are traveling in other directions, either horizontally or, in some cases, upward, which may result in precipitation or deposition from the descending solution. Or precipitation may be caused by the descending solutions coming in contact with the materials of the surrounding rock.

In the Virginia lead and zinc district there seems no apparent reason for regarding any of the original sulphide ore-bodies as having been enriched by secondary deposition. On the other hand, the field conditions indicate that the sulphide ores all belong to a first or primary deposition. The evidence for this is discussed elsewhere in this volume. In many instances, however, notably at Bertha, as much of the first concentration of the ores in the form of sulphides that were subsequently brought within the belt of weathering or solution, have been oxidized and dissolved and reconcentrated in different mineral forms below the residual clays and close to the weathered surface of the original rock containing the sulphide ores.

GENESIS OF THE ORES

General Statement

Many general statements have been made as to the origin of the Virginia deposits, but so far as the writer is aware not a single hypothesis has been advanced and discussed to account for these deposits. In most cases where statements have been made of the origin of these deposits they seem so at variance with the facts in the field that they can be dismissed without further notice being taken of them. It is proposed here to briefly outline an hypothesis

to account for the origin of the Virginia deposits which is most in accord with the observed facts in the field. This hypothesis applies only to the zinc and lead deposits of Southwest Virginia or the Great Valley region and does not apply to the single deposit east of the Blue Ridge in Albemarle county. From the previous description of the ore-deposits in the two districts, the conditions are seen to be totally unlike. In the Albemarle county area, the deposits are found in crystalline schists and their genetic relation to igneous masses is fairly well established, while the deposits of the Valley region are as definitely shown not to have any relation whatever to igneous rocks.

Original Source of the Material

The ore-deposits of the Valley region of Southwest Virginia are not entirely unlike some of those of the Mississippi Valley region. On the contrary there are apparently strong points of resemblance in the Virginia deposits to certain ones of the Mississippi Valley region. For those of the latter region there seems to be pretty general agreement that for the source of the material from which the deposits were formed, the ocean in which the rocks themselves were formed must be looked to.

In the Virginia region evidence rather strongly points in the same direction as the original source of the material. During Cambrian and later time debris was received by the interior sea from the adjacent pre-Cambrian land area on the east, which forms the rocks composing the Virginia Valley region in which the lead and zinc ores are found. The rocks composing the Virginia pre-Cambrian land area on the east were in part at least of igneous origin. It was from these pre-Cambrian crystalline rocks that the lead and zinc were originally derived. Through the agents of weathering these rocks were decayed and broken down and the lead, zinc and associated minerals, including the lime and magnesia which compose the country-rock, were transferred and deposited.

There are, so far as known, at present no igneous intrusions found within the limits of the Valley region of Southwest Virginia with which to connect the ore-deposits. While it is true the ores are related to the pronounced folding and faulting of the region, there appears no good reason for regarding the ores as having been derived from profound depths within the interior of the earth and

later introduced into the limestone from such solutions. Indeed, the evidence is against this source of the material, for when ore deposits have been formed by such a process they are usually associated with a characteristic set of minerals, such as compounds of arsenic, antimony and silver, and frequently by fluorspar, etc., all of which, with the exception of barely more than a trace of fluorspar at three places, are entirely absent.

Omitting the question of original regularity or irregularity of the distribution of material, for which there has not yet been made out any definite evidence either for or against such distribution, the process of concentration and localization of the ores may be considered.

Process of Concentration

The presence of very small quantities of lead and zinc in the Shenandoah limestone away from the present localized deposits of these metals can only be inferred, for no direct tests have been made on the limestone to prove it. Even though the usual chemical tests were made and failed to show the presence of lead and zinc in the limestone it would not be safe to conclude that these metals were entirely absent. Assuming that all the lead and zinc localized in and distributed as at present through the Shenandoah limestone were uniformly distributed through this formation, it is safe to predict that the quantity of these metals would be so very small that the ordinary tests would probably not detect them. Grant⁴¹ quotes an estimate made of the entire quantity of ore, lead and zinc, taken from the Potosi district, in Wisconsin, where the ore was assumed to be uniformly distributed through the adjacent rock, Galena limestone, which gave a result of *only one fourteen hundredth of one per cent.*, or a little more than seven-millionths part of the rock.

In the absence of chemical proof there is some geological evidence to support the inference. As has already been pointed out, the Shenandoah limestone is the only formation in the district that is positively known to contain lead and zinc ores. Other limestones have good development over parts of the district, and apparently offered equally as good advantages for ore-deposition as the Shenandoah. In view of these facts there appears no real reason

⁴¹ Grant, U. S., Wisconsin Geol. and Nat. Hist. Survey. Bulletin No. IX, 1903, p. 79.

why the lead and zinc deposits should have been deposited in one formation and not in another, except that the source of the material was limited to the single formation in which they have been localized and are now found, the Shenandoah limestone. Moreover, it seems unnecessary to appeal to highly heated waters either from profound depths or from connection with igneous intrusions, as a source of the material since, as already stated, the field evidence is against such a process.

Assuming then the original source of the material to have been the Cambro-Ordovician limestone, the lead and zinc deposited probably as sulphides at the time of the formation of the limestone and sparsely disseminated through it, it remains to show how the present localization of the ores was accomplished. It is now a well established fact that these materials are capable of being taken into solution, transported and redeposited by the circulation underground waters. The general process would consist first, in the solution of the disseminated material, probably in the form of the sulphides, by means of certain constituents, oxygen and carbon dioxide, held in solution by the waters. Through the oxidation of the sulphides the metallic compounds would be transported by the underground waters as soluble sulphates and the redeposition of the sulphates as sulphides, either by the action of organic matter in the rocks or by the mingling with other currents of underground water. The prospecting thus far done in Rye Valley, Smyth county, points to an association of the blende with the more carbonaceous portions of the limestone, indicating that the materials were probably introduced as sulphates and were reduced by the organic matter present in the rock and deposited as sulphides. In addition to the sulphate cycle it seems probable that there was a second or sulphide cycle in which the metals were transported as soluble sulphides and deposited as such. This was probably the process of deposition at Austinville and in some of the other Virginia deposits. Excepting the Rye Valley deposits in Smyth county and the one south of Castlewood, in Russell county, analyses of the limestone collected from the other openings failed to show the presence of organic matter. In the case of the Austinville deposits, however, where the limestone has been so largely recrystallized, organic matter, if originally present, would hardly be expected now. In order that the metals be transported in the form

of sulphides it is necessary that they be in solution. In the presence of certain compounds, such as the alkaline carbonates and sulphides, it is found that the metallic sulphides are rendered soluble.⁴² Since the several complete analyses of the limestone from the Austinville mines show the presence of small amounts of both sodium and potassium, it is probable that the necessary compounds were present in the underground waters to cause the transportation of the metals in the form of soluble sulphides. It is probable, therefore, that the metals, lead and zinc, in the Southwest Virginia district were transported in the form of both sulphates and sulphides.

Causes of Precipitation

It has been pointed out that some of the Virginia deposits seemingly are associated with the more carbonaceous portions of the limestone. In such cases the underground waters which carry the sulphates of the metals in solution would on coming in contact with the organic matter of the country-rock be precipitated in the form of sulphides of zinc and lead. This is a simple reducing process whereby the organic matter withdraws the four oxygen molecules from the sulphate and precipitates the sulphides. Again the mingling of solutions of different compositions may result in the precipitation of the sulphates in the form of sulphides. Such mingling of solutions usually takes place along trunk channels and their presence in the Virginia district are pointed out below. The precipitation of metallic sulphides transported as such may result either from simple dilution of the compounds by decrease of temperature or pressure, or by both; or from the mingling of solutions and the reaction of the ore-bearing solutions on the wall rock, limestone. It has already been shown that the Virginia deposits are associated with the folding and faulting of the Shenandoah limestone, following rather closely, in other words, the brecciation of the rock produced by this deformation. This produced ready channels in the limestone for the free circulation of the underground water, and it was along these directions that the conditions were favorable to the precipitation and deposition of the metallic sulphides in the ways mentioned. The two processes may have acted together.

⁴² Van Hise, C. R., *A Treatise on Metamorphism*, U. S. Geol. Survey, Monograph XLVII, 1905 p. 1106 *et seq.*

Formation of the Altered Ores

The oxidized or altered ores, carbonates and silicates, have been described and explained at some length in a previous part of this report. It is only necessary here to again repeat that they have been formed within the belt of decay by the oxidation of the original sulphides, galena and sphalerite. They are in the strict sense of the term secondary or derived ores.

Replacement

By replacement is here meant the solution in part of the limestone and the substitution therefor of the metallic sulphides, lead and zinc. The process is one of molecular interchange. Careful microscopic study of thin sections of the original sulphide ores from the Austinville mines, conclusively points to replacement as having been a principal process in the formation of the ore-bodies. Here, as described on page 95, the process begun first by filling the fine cracks and then by the replacement of the dolomite anhedra (grains) along some crystallographic direction, as indicated in plates VIII, IX and X. Over much of the Southwest Virginia district more or less replacement of the limestone by the metallic sulphides is shown. In some instances, however, none of the evidences of replacement are shown, but instead the ores simply fill the spaces in the rock as introduced and precipitated from solution. In either case, it has been shown that secondary enrichment of the sulphides has not taken place, but that these ores are the result of a first or primary concentration.

General Conclusions Regarding the Ores

From the previous description and discussion the following conclusions seem to be warranted:

I. The zinc and lead of the Southwest Virginia district were originally deposited with the limestone in which they were subsequently localized and concentrated and are now found. Unlike the Southwest Virginia deposits the one in Albemarle county occurs in crystalline schists and was connected with igneous intrusions.

II. The district is one of intense deformation—folding, faulting and brecciation. The ores are closely associated with the faulting and folding, and are of the disseminated replacement breccia type.

III. The accumulation and concentration of the ores were by circulating underground waters. These were probably transported in the form of both sulphates and sulphides, and were precipitated and deposited in their present position partly by organic matter and partly by the mingling of solutions, and the reaction of the ore-bearing solutions on the wall-rock, limestone.

IV. From the character of the metallic sulphides and the associated minerals, neither a profoundly deep circulation of underground waters nor a circulation connected with igneous rock masses was responsible for the deposition of the ores.

V. The associated minerals, gangue, include dolomite and calcite in crystalline form as the principal ones, with a little fluorite and barite found in several places.

VI. Replacement has been an important process in the formation of the ores over most of the district. The common evidences of secondary sulphide enrichment are lacking and the sulphide ores are regarded as the products of a first or primary concentration.

VII. The soft or oxidized ores, carbonates and silicates, were produced by the alteration of the original sulphide ores, galena and sphalerite.

ECONOMIC CONSIDERATIONS

Methods of Mining

Until very recently, mining of lead and zinc ores in the Virginia district was limited wholly to the surface belt of weathering. The mode of occurrence and the character of the ores to be mined were such as to demand the employment of methods used in mining secondary concentrated ores. Accordingly a system similar to that practiced in mining brown iron ores was employed, with the necessary modifications and changes made in the method as the conditions demanded.

Oxidized or Soft Ores.—Up to the present time, practically all the ore mined over the Southwest Virginia district has been oxidized or soft ores, silicate, calamine; and carbonate, smithsonite, largely the former; which have been localized and concentrated at only slight depths below the surface. Because of the extreme irregularity with which the limestone weathers when stripped of the overlying residual clay, it presents a roughened surface of large and

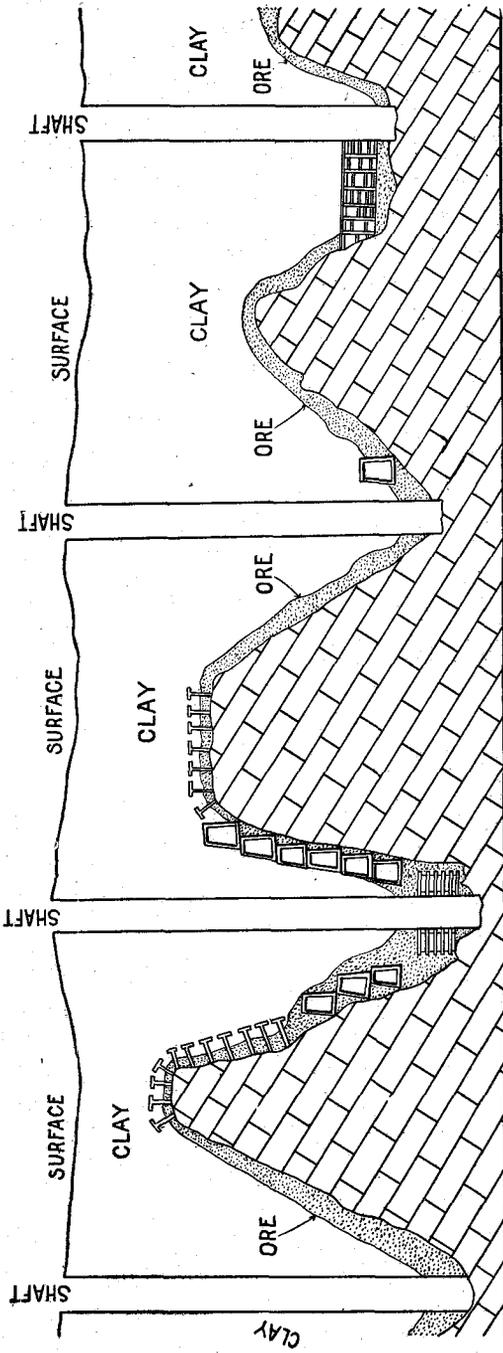
small irregular chimneys and pinnacles of the hard rock, as shown in figures 10 and 26. It is in the depressions between the pinnacles and extending some distance upward on their sides, occasionally passing entirely over the pinnacles from bottom to top, that the ores have been concentrated. The ores hug somewhat closely the irregular surface of the limestone and are overlaid ordinarily by the clay. In this mode of occurrence, the ore will range from 1 to 25 feet in thickness, and it will not exceed in depth below the surface 80 to 90 feet, usually much less.

Such an occurrence favored working of the ores in the beginning by the method of "open-cut" mining, the usual method practiced in the region for mining the brown (limonite) iron ores. The "open-cut" method of mining the zinc ores differs, however, from that of mining the iron ores, in that the former is one essentially of stripping, while in the latter the ores and enclosing clays are mined together and sent to the washer for separation.

At Bertha⁴³, the most systematically worked of the Virginia zinc mines for soft ores, the method of "open-cut" mining was followed until the fall of 1889, when a change in the method of mining the ore was made. The difficulties to the "open-cut" mining at Bertha were numerous and as the work progressed these, added to the increased cost of removing the clay, made a change in the method of mining necessary. The chief object, however, in making a change was mainly to secure a steady and sufficient output for the furnaces, as well as to lessen the cost of mining. Accordingly a system of underground mining was introduced, the ore being reached through shafts 31½ feet in diameter sunk in the clay. Inexpensive plank shafts 38 inches square, inside diameter, were also used. These were sunk to the limestone bottom at its deepest points. Timbered drifts were then driven in the ore, following it around the chimneys. When the chimneys were thus encircled at a given level, a second drift was established or run upon the ore below. In this way, one after another, drifts were carried around and over the chimney, until all the ore had been entirely removed from the chimney. See figure 26. The ore was wheeled to the shafts, where it was loaded into iron buckets and hoisted by steam power. It was then dumped into cars of about two tons

⁴³ For a detailed and complete description of the method employed in mining at Bertha, see paper by Wm. H. Case, entitled "The Bertha Zinc Mines, at Bertha, Virginia. Trans. Amer. Inst. Min. Engrs. Chicago Meeting, August, 1893."

Fig 26.



Section through the Bertha Zinc Mines, showing occurrence of zinc ore in relation to the limestone and clay, and the method of mining the ore. Blocked area is limestone.

capacity and carried by a locomotive to the dumps at the head of the water carriage. The ore as thus mined is reported to have contained about 26 per cent. metallic zinc.

On the Lead Mine tract at Austinville, 10 miles west of Bertha, lead and zinc ores above ground water level have been mined for more than 150 years. Large quantities of the ores have been removed, mined principally from "open-cut." Much underground mining was done above ground water level, consisting of shafts, drifts and stopes, reaching a maximum depth of 250 feet. Both the open-cut and the underground mining have been done without any apparent system. The soft lead ores were mined on this tract for a long period of years before any attention was given to the zinc ores, if indeed they were recognized at all.

The only method used in mining the lead ores seems to have been that of following the ore down from the surface through the clays, wherever found, by irregular underground openings. Ordinarily little or no timbering was done, regard being had only for the present in mining the ore.

The Sulphide Ores.—Practically no sulphide ores have been mined, and apart from some prospecting and a little development work, practically no underground mining in the hard rock, limestone, has been done in the Virginia region. This has been due not to a lack of the sulphide ore, blende, in the limestone, but to the fact that the soft or oxidized ores within the belt of weathering were adequate for the needs of the furnaces. Now that the known areas of soft ores seem very limited, considerable exploitation of the sulphide ore-bodies in the hard limestone is in progress over the Southwest Virginia district. The outlook seems encouraging, particularly at Austinville and Cedar Springs, in Wytthe county, and at places in Rye Valley in Smyth county.

Preparation and Treatment of the Ores

Washing and Milling.—The preparation and treatment of the ores can best be explained by describing the methods formerly used and at present practiced at the two largest worked and the most extensive mines in the Virginia district, namely, Bertha and Austinville. At Bertha, mining for zinc ores has been discontinued and the mines are now being worked for brown iron ore. However,

a description of the treatment of the Bertha zinc ores will be of interest.

The Bertha Ores.—Mining zinc ores at Bertha was stopped in 1898 when the property was leased to the Pulaski Iron Company for the purpose of mining iron ores. The hope exists, however, that more available zinc ore will be found when the covering of iron ore has been removed.

Two storage bins for receiving the ore as mined were built on the bluffs overlooking New river about $\frac{3}{4}$ mile from the mines. These were built on timbered trestles leading out from the hillside and were provided with V-shaped floors, down the center of which passed the water-trough made of cast iron 12 inches wide and 6 inches deep. The ore was hauled from the mines to the bins in tram-cars. The ore was fed into the water-trough and carried thence by a current of water to the dressing-house, 1,300 feet below. The water used was pumped into a large tank on the hilltop above the bins and there stored and fed as required. An inclined plane between the troughs was operated by steam-hoist, up which timbers and supplies were taken to the mines.

The dressing-house was a three story building, reported to have been well equipped with all the necessary automatic machinery for the concentration of both zinc and iron ores. The zinc ore was brought down the trough, falling upon a grizzly, through which the large lumps were broken, and passed into a single log-washer, where it was given a gentle sluicing, which served to free the ore from adhering clay.

Because of its porous structure and the contained gangue, clay, in the cavities, it was necessary to further treat the lump ore by passing it through a Blake crusher, and a pair of Cornish rolls. From the rolls the ore passed to conical, revolving screens, where it was sized; the large pieces dropped upon a steel-plate conveyor and were hand-picked. The small pieces passed down to four sets of Parson jigs, on which they were thoroughly concentrated. The tailings resulting from this treatment were passed through a spitzkasten, or classifier, and thence to two Harz jigs. The slimes were discharged into a slime pond, from which the muddy water was drained off into the river.

The capacity of the dressing-house is reported to have been 80 tons of concentrated zinc ore per day of 10 hours. The yield is

said to have been approximately one-third of the crude ore treated, and the product as having afforded the following average analysis when dried at 212°. ⁴⁴

	Per Cent.
Zinc, metallic (Zn).....	38.08
Zinc oxide (ZnO).....	47.61
Silica (SiO ₂).....	29.37
Iron oxide (Fe ₂ O ₃) }	9.23
Alumina (Al ₂ O ₃) }	
Calcium carbonate (CaCO ₃).....	4.54
Magnesium carbonate (MgCO ₃).....	2.07
Water, combined.....	8.23
Lead, metallic (Pb).....	trace
Total.....	101.05

A roasting plant, consisting of an 8-foot Taylor gas producer and a 30-foot cylindrical roaster, was operated for expelling the moisture from the ore.

The Austinville Ores.—The run-on-mine ore at Austinville is said to average in composition 28 to 30 per cent. metallic zinc, 8 to 10 per cent. metallic lead and 8 to 10 per cent. metallic iron. A brief outline is here given of the various operations practiced at Austinville in treating the ore from the time it is mined until ready for the furnaces at Pulaski.

The ore as mined is carried by trolley to tipples. From the tiple, the ore is carried by tram-cars to the mill and dumped on a 4-inch grizzly; thence to a log-washer through a 9 by 15-inch Blake crusher, set at 1½ inches, and then to 14 by 24-inch corrugated rolls, set at 6 mm. From the corrugated rolls, the ore is carried to a second log-washer; thence to elevator and sizing screens of 6 mm., 2 mm., and 1 mm. mesh, respectively.

The oversize from 6 mm. screen goes to smooth rolls, 12 by 18 inches, and is returned to the system or second log-washer. The undersize from 6 mm. on 2 mm. goes to 4-compartment Cooley jigs; 1st hutch and side-draw, making clean lead; 2nd hutch and side-draw, middling; recrushed and returned to the system or second log-washer; 3rd and 4th hutches, clean zinc. Tails are passed to settling boxes; heads of boxes, reworked. Lighter material goes to the oxide furnaces.

⁴⁴In the preparation of this summary of the treatment of the Bertha ores, the writer has made use of the paper by Edward C. Moxham, published in the Eng. and Mng. Journ., 1893, Vol. LVI, November 25th, p. 544.

Undersize from 2 mm. on 1 mm. goes to 5-compartment jigs; *1st* and *2nd* hutches and side-draw, making clean lead; *3rd* hutch and side-draw, middling; *4th* and *5th* hutches and side-draw, clean zinc. Tails go to boxes.

Undersize from 1 mm. screen goes to 3-compartment classifier; *1st* and *2nd* draw to 6-compartment jigs; *1st* and *2nd* hutches and side-draw, making clean lead; *3rd* and *4th* hutches and side-draw, middling; *5th* and *6th* hutches and side-draw, clean zinc. Tails go to boxes.

Third draw from classifier and overflow goes to 3-compartment double jigs; *1st* and *2nd* hutches, making clean lead; *3rd* hutch, middling, reworked. Tails go to boxes.

The middlings and tails from all jigs are treated the same as 4-compartments described above. The overflow from *1st* and *2nd* log-washer goes to settling boxes, 25 feet long and 8 feet wide; thence to oxide furnace, except the lower end or lighter material.

The lead concentrates, averaging 67 per cent. lead, 4.8 per cent. zinc and 3.29 per cent. iron, go to the Scotch hearth furnace, which makes metallic lead and grey slag, averaging 31 per cent. lead, 25 per cent. zinc and 13.3 per cent. iron. This slag goes to the slag furnace which makes metallic lead and slag averaging 3.5 per cent. lead.

The zinc concentrates are carried by tram-cars from the mill to the separators, where they are put through a revolving dryer to expel moisture and combined water to the amount of 7 per cent. Thence to water-cooled scraper conveyor to top of building by elevator to sizing screens of $\frac{1}{2}$ mm., 1 mm., 2 mm., and $\frac{1}{4}$ inch holes. Oversize from $\frac{1}{4}$ inch is returned to 12 by 14 inch rolls, set close. Undersize re-enters the system. From screens to bins, 4 sizes.

The four sizes which pass through screens go to magnetic separators (Wetherill), one 4- and one 6-magnet machine; the smallest sizes going to the smallest machine. Heads from separators contain 47 per cent. iron and 5 to 7 per cent. zinc, and are shipped to the iron furnace. Tails from separators contain 43.5 per cent. zinc, 5 to 6 per cent. iron and 15 to 20 per cent. lead, and are shipped to the zinc furnace. The capacity of the mill is about 90 tons of raw ore per day of 10 hours.

Zinc Oxide Plant.—This plant, consisting of 12 furnaces, has only recently been added, mainly for the purpose of utilizing the

low grade ore and tailings. After thorough testing the plant has proved entirely satisfactory. The grade of ore, including tailings, used for making the oxide, will run from 15 to 20 per cent. metallic zinc. The zinc oxide is conducted from the furnaces into bags through a 3-foot iron cylinder 600 feet long, where it loses nearly all of its heat in transit. At present, the zinc oxide goes to the furnaces at Pulaski, where it is used for making spelter.

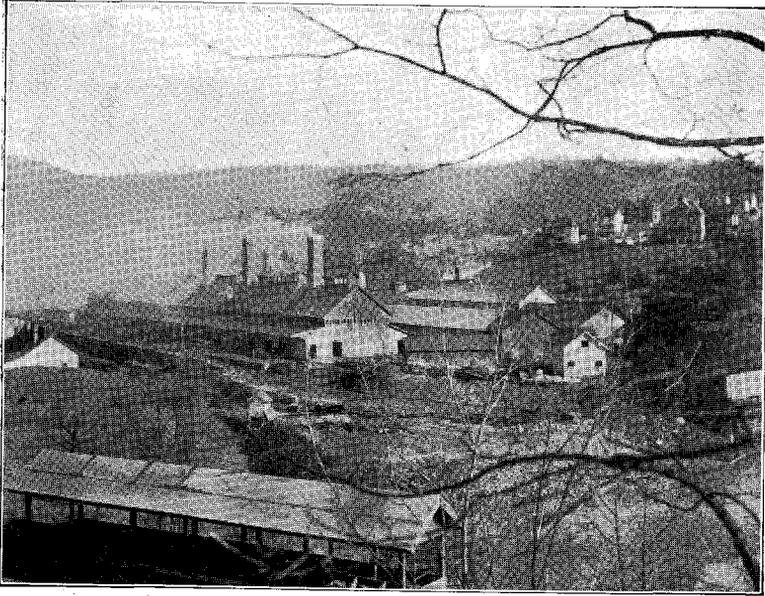
As made at Austinville the zinc oxide is white, regular oxide running perhaps 4 per cent. of lead.

The successful operation of this plant at Austinville is of very great importance, since it conclusively points out a method for utilizing low grade zinc ores, which elsewhere are claimed to be not profitably worked for spelter. In Europe the oxide is made from the spelter; and not, as at Austinville, the spelter made from the oxide.

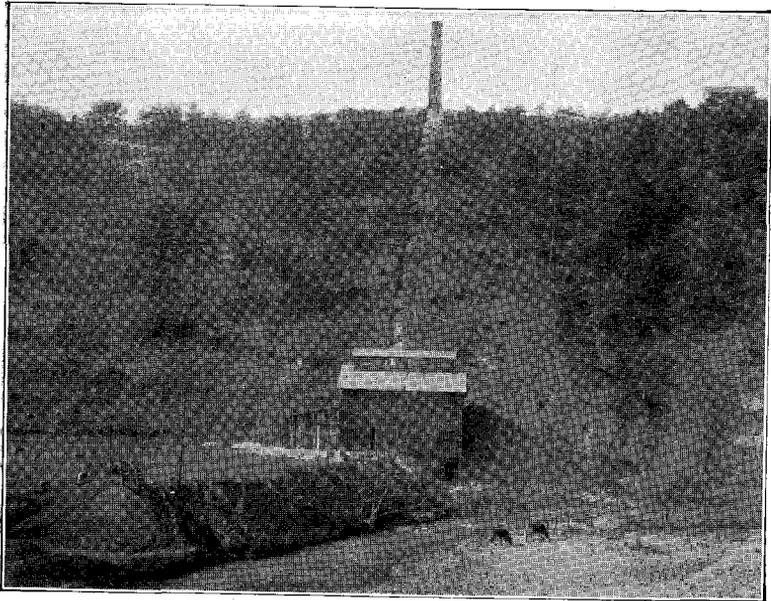
THE BERTHA SMELTING PLANT

Location and Equipment.—The only zinc smelting plant in the South is located at Pulaski, Virginia, on the Bristol branch of the Norfolk and Western railroad, and is owned and operated by the Bertha Mineral Company. This plant was built soon after the beginning of zinc mining at Bertha, Wythe county, Virginia, in 1879. It was remodeled and enlarged in 1886, and at present it consists of 10 large smelting furnaces, kilns, ore-sheds or bins, refiners, coal-pit, engine-room, pottery, metal storage houses; and across the creek, a roasting furnace. The office, laboratory and store are located across the road from the furnaces. A small railway is operated around the plant for shifting cars; and a narrow-gauge is built and operated between the plant and the company's coal mine at Altoona, from which all the coal formerly used was derived, but at present only the "firing" coal or reducing material is obtained. Plate XIII, figures A and B, are views of the Bertha Smelting Plant.

Furnaces.—The ten furnaces are of the Belgian type, hand fired, built in five blocks of two furnaces each, placed back to back. The furnaces are 8 feet deep, 30 feet wide and 24 feet from top to bottom of foundation. They have an average capacity of 20,000 pounds of spelter every 24 hours. The capacity of each furnace varies from 1,800 to 3,000 pounds of metal per 24 hours, depending

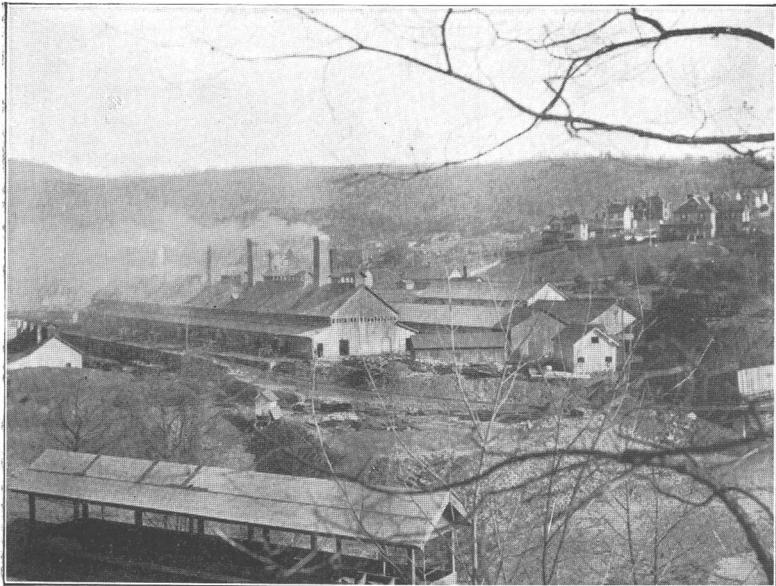


A

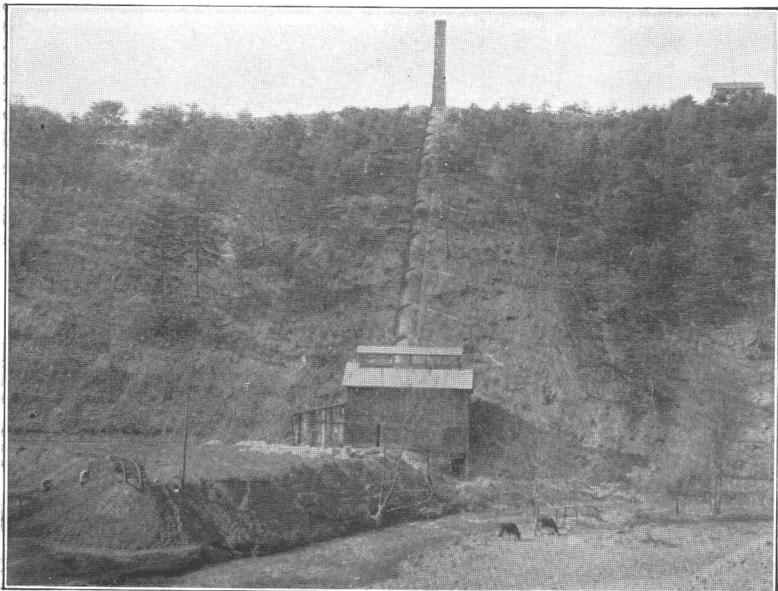


B

Zinc Smelting Plant, Bertha Mineral Company, Pulaski, Virginia.
A. General view of Plant. B. Roasting furnace for treating zinc skimmings.



A



B

Zinc Smelting Plant, Bertha Mineral Company, Pulaski, Virginia.
A. General view of Plant. B. Roasting furnace for treating zinc skimmings.

on the grade of ore used. Each furnace consists essentially of a large skeleton combustion chamber, lined in the back with fire-brick and having an iron framework in front, as shown in figure 27. The retorts are inserted from the front with the back ends resting on a fire-brick support built out from the back lining, so that when in position the retorts incline slightly toward the front

Fig. 27.

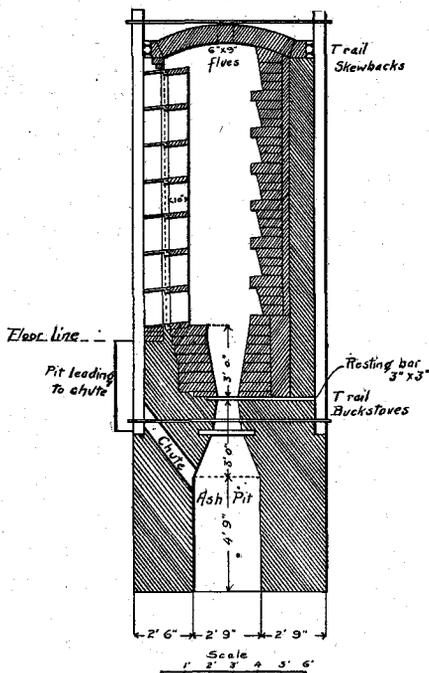


Diagram of zinc smelting furnace used by the Bertha Mineral Company, Pulaski, Virginia. (After Higgins.)

of the furnace. Each furnace is fitted with 140 retorts arranged in seven rows of 20 each.

The grates are placed $3\frac{1}{2}$ to 4 feet below the lowest row of retorts, and are 10 to 12 inches wide and 13 feet long. A peculiarity is that the grates have, beside the three solid bars placed lengthwise, two hollow ones arranged, one on either side, next to the wall. These are charged with water under pressure. Along the tops of the hollow bars are perforations, through which the water escapes when it is turned on at intervals. The water escapes through the perforations, striking the under side of the cinder

forming on the grate, which serves to break it up thoroughly, so that the ash is fine and pulverulent. This produces a clear fire and a cool ash pit. On a hot day, such as when visited, the interior of the underground ash-pit is actually the most comfortable place around the plant. Pocahontas coal is used, which on account of its high grade and the clean grates resulting from the use of the water-spray* described above, the consumption is low. A fairly uniform heat is obtained over all the furnaces.

The fire boxes are narrow, deep and long. The furnaces are fired from either end, the entire length of the grate surface being 26 feet, with a sloping divide in the middle and chimney draft. A very heavy bed is used so that each furnace practically becomes a gas producer. The doors are closed and air is introduced through small holes in the front of the furnace, which can be closed by heating, as they need. Additional draft is provided above the furnace for regulating the heat.

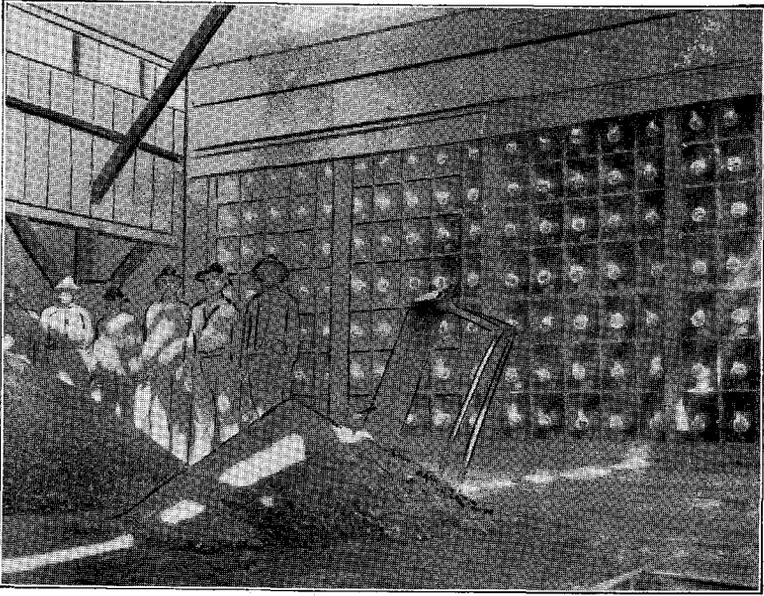
In plate XIV is shown two views, one of a furnace charged and in blast, the other of a dismantled furnace.

Retorts and Condensers.—The retorts used are of two kinds, round and oval. The dimensions of the first, or round retorts, are: length, 4 feet 2 inches; inside diameter, 8 inches; thickness $1\frac{1}{2}$ inches; capacity, 1,251 cubic feet. The oval or elliptical retort has a capacity of 1,228 cubic feet. This form of retort, oval shaped, is placed on the lower rows of the furnace, each retort being so placed that its greatest diameter is in a vertical position. The retorts are all made at the company's plant on a Wooley tile machine, whose capacity is 100 retorts per day of 10 hours. These are made from the best grade of St. Louis, Missouri, fire-clay, principally Evans and Howard's clay, which is perhaps not so refractory as some other more silicious clays, but it is the best material for this purpose.

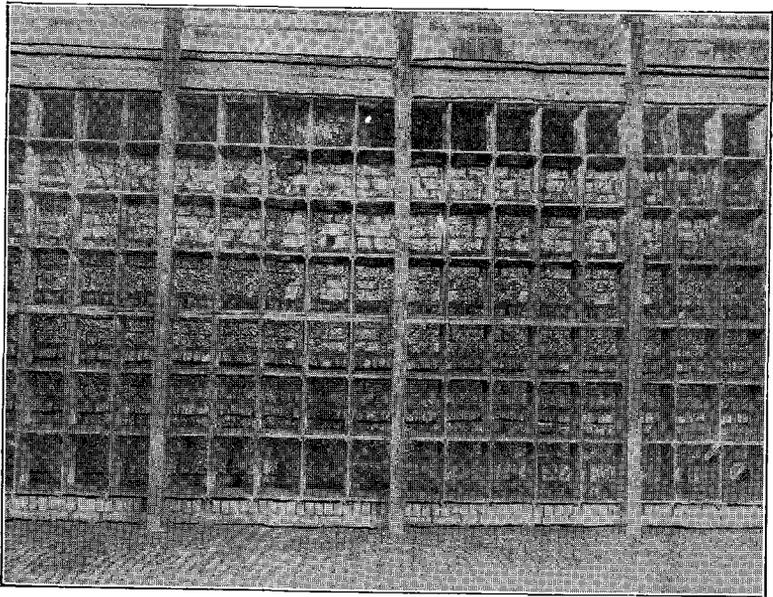
The following analysis of the St. Louis, Missouri, clay affords some idea of its composition: ⁴⁵

* Patented Feb. 13, 1900, by Mr. J. D. James, Superintendent Bertha Mineral Company's plant.

⁴⁵ Moxham, Edgar C., Eng. and Mng. Journ., 1893, Vol. LVI, November 25, p. 544.

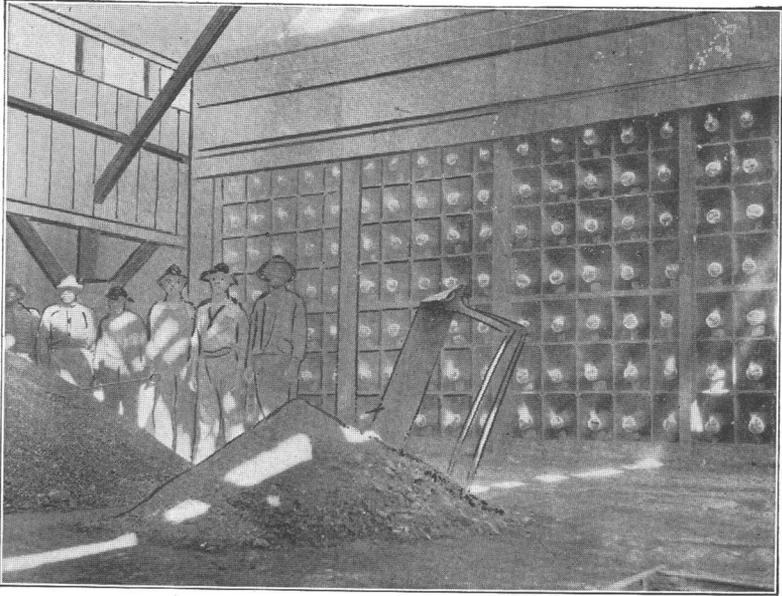


A

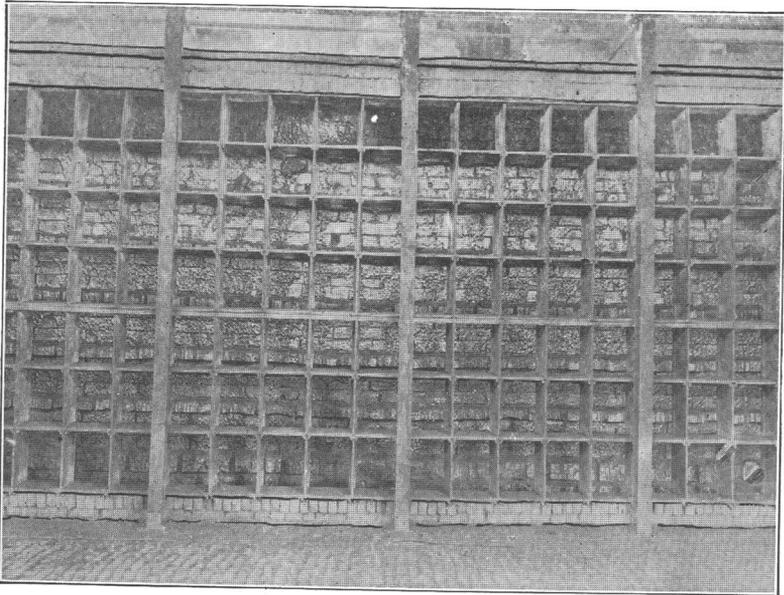


B

Zinc Furnaces, Bertha Mineral Company, Pulaski, Virginia.
A. Furnace charged and in blast. B. Furnace dismantled.



A



B

Zinc Furnaces, Bertha Mineral Company, Pulaski, Virginia.
A. Furnace charged and in blast. B. Furnace dismantled.

	Per Cent.
Silica (combined).....	38.10
Alumina.....	31.53
Combined moisture.....	11.30
Titanic oxide.....	1.50
Free silica (quartz).....	12.70
Potash.....	.40
Soda.....	none
Iron sesquioxide.....	1.92
Hygroscopic moisture.....	2.50
Total.....	99.95

After coming from the machine, the retorts are arranged in a drying-room for two weeks and held at a constant temperature of about 80° F. They are then placed in another room whose temperature is 100° F., where they are kept for two months. Just before being placed in the furnace the retorts are stacked in kilns and fired for 16 hours.

The condensers are 21 inches long and 3½ inches in diameter at one end, the other end being slightly smaller than the retorts. These are all made of local clay mixed with that from grinding the old retorts. Shortly before being used or placed in position they are washed inside with a mixture of water and fire-clay in order to prevent the metal from soaking into them. The retorts are luted to the condensers with a mixture of one-third clay and two-thirds coal, enough water being added to bring the mixture to the proper consistency.

Materials Used in Charging.—At present the principal zinc materials used in preparing the charges are: local ores, including the silicate and carbonate of zinc; crude zinc oxide, containing 70 to 80 per cent. metallic zinc, and made from local ores at Austinville; willemite, anhydrous zinc silicate, shipped from Franklin, New Jersey, and averaging 48 per cent. metallic zinc; zinc flue dust from the iron furnaces; and zinc skimmings from the galvanizers, which are first given a preliminary roast in a special furnace to drive off the ammonia and chlorine. Plate XIII, figure B. The zinc skimmings are easily fired and are usually smelted alone. No sulphide ores are handled at present.

As a rule, the ore as delivered at the plant is ready for the furnaces; it being sized to pass about a 6 mm. mesh screen. However, some lump ore is received which is crushed and sized to a

1/8-mesh before using. The retort charges are usually mixed, though some of the furnaces are run as occasion demands on special material alone, such as the zinc oxide from Austinville. The only difficulty in smelting the oxide alone is its slight tendency to ball up, which makes it necessary to introduce a mechanical mixer in order to produce a more intimate contact between the ore and the carbon. For this reason the oxide is usually mixed with some ore for smelting. At present some material, Bertha tailings, averaging as low as 33 per cent., is being used. The writer is reliably informed that the furnace has been run for two years at a time on furnace charges of 35 per cent. metallic zinc.

The charges, consisting of ore and fuel mixed in the proper proportions, are wheeled to the furnaces, moistened with water, and mixed on the hearth by a process of shoveling. The charges are all mixed by weight. At present the oxide, willemite, crude ore, coal and coke are mixed on the hearth as described and used for charging. The operation of charging usually begins about 6 o'clock in the morning. The mixture of ore and fuel is charged tightly into the retorts; the condensers are then inserted into the mouth of the retorts, luted and sealed perfectly tight. The small end of the condensers is packed with coal dust, leaving an opening of about one-quarter inch for the escape of the gases, when the furnace is ready for a 24-hour run.

Distillation and Tapping.—The furnaces having been made ready as described above and fired, the inside temperature of the retorts is gradually raised until it reaches 1500° C. or more. The condensers are not subjected, of course, to this high temperature, since their position is on the outside of the combustion chamber. Reduction of the zinc in the retorts takes place, according to the following formula: $ZnO + C = Zn + CO$. The CO acts as a further reducing agent, thus: $ZnO + CO = Zn + CO_2$. The zinc vapor passes from the retorts into the condensers, where it collects in the form of molten metallic zinc. When the furnaces are charged and fired at 6 o'clock in the morning for a run of 24 hours, the first "tap" for metal is made at 3 P. M. This is accomplished by removing the luting from the ends of the condensers and the molten zinc metal run therefrom into iron ladles, from which it is poured into the molds for casting into slabs of a given size and shape. A second "tap" is made at 11 P. M., and the third and last at 4 o'clock the

next morning. After the last "tap" is made the fires are allowed to slacken, the condensers are removed, and the retorts are thoroughly cleaned with an iron ravel. Each retort is inspected with a hook before recharging to be sure of its being thoroughly clean; and it is also inspected for holes and cracks. It is claimed that the retorts can not be cleaned by blowing out with steam, as is practiced in the West on account of the siliceous character of the materials used. The time required to complete the process at the Virginia furnaces is considerably longer than at the Western furnaces, so that in case of the former the furnaces are cooler for a much longer time than the Western ones.

After the last "tap" is made in the morning, the residue from the charge, called "seconds," is passed into the ash-pit below through the chute in front of the furnace. The "seconds" are said to contain from $1\frac{1}{2}$ to 4 per cent. metallic zinc. The "sweeps," composed of the old condenser ends and the luting, which contain some metallic zinc, are saved and added to the next day's charge. Retorts, which are cracked or burned out, are replaced by new ones; and recharging and replenishing of fires completed, when the furnaces are ready for another day's run. The breakage of retorts is small, amounting to only .60 to .90 per ton of ore.

Spelter.—Three grades of spelter are produced, branded according to purity: (1) Bertha Pure Spelter; (2) Old Dominion; and (3) Southern. The Bertha Pure Spelter has a world-wide reputation, there being no better grade of metal found on the market. It is sold under guarantee of 99.98 per cent. metallic zinc. The following analyses afford an excellent idea of the purity of the metal:

	I	II	III	IV
Zinc (by difference)....	99.8419	99.949	99.981	99.963
Iron.....	.014	.010	.019	.012
Lead.....	.050	.035	trace	.022
Sulphur.....	none	none	trace	.001
Silicon.....	.036	.006	none	.002
Carbon.....	.058	trace	none	none
Arsenic.....	.0001	none	none	none

I and II. Analyses by F. P. Dunnington. The Virginias, 1881, Vol. II, p. 147.

III and IV. Analyses quoted by E. Higgins, Jr. Eng. and Mng. Journ., 1905, Vol. LXXIX, p. 659.

As will be noted from these analyses, the Bertha brand of spelter is practically free from all impurities. It possesses, therefore, that high degree of fluidity, ductility and tenacity necessary in casting perfect statuary. This metal is extensively used abroad and in the United States for government work.

The Bertha brand of spelter is produced in part directly from the furnace, but it can be produced from either of the other brands, Old Dominion or Southern, and it is so produced, mainly, by refining in a special patented furnace, which amounts to redistilling it carefully to avoid carrying over the lead. The Bertha grade of spelter is cast into slabs having square corners and weighing 37 pounds per slab.

The "Old Dominion" brand of spelter contains from 0.2 to 0.4 per cent. of lead and is cast into rectangular slabs, or blocks, weighing 45 pounds each. The "Southern" brand will average from 0.8 to 1 per cent. of lead, and the blocks into which it is moulded will weigh 30 pounds each.

The Bertha Mineral Company's plant is famous for the high grade spelter produced. To some extent this seems to be due to the purity of the material used, it being particularly free from iron, and to the added fact that only carbonate and silicate ores have been used. It is due mainly, however, to the matter of good furnace work. A large quantity of good metal is produced, the third tap, when the furnace is fired hard and forced, running from $2\frac{1}{2}$ to $3\frac{1}{2}$ per cent. lead. This is further reduced to from 0.98 to 1.17 per cent. by remelting and settling.

The high lead metal is run into finger bars having the approximate dimensions of $1\frac{1}{2}$ "x1"x18". These bars are treated in a special form of furnace which, in a two weeks' run, refines all the base metal made from the ten furnaces during one month's work. The furnace is then cleaned up, yielding about 2500 pounds of lead, and remains idle until the next run.

An accurate and careful sampling record is kept of all the spelter produced. This is done by drilling $\frac{1}{2}$ -inch plugs from the spelter bars or slabs, smelting the plugs of each lot to the form of a test bar, and then boring the latter. A record is kept thus of the assay of each row of each furnace and of each tap.

The metal is all marketed by Sales Agents of the New Jersey Zinc Company. Usually the metal is shipped direct to the con-

sumer on order; although a small stock is kept on hand in a New York warehouse. The higher grade metal goes largely into government work, both in the United States and abroad; into bronzes and brasses; and into friction metal. The lower grades are consumed in the galvanizing trade.

Tests.—Recently the Bertha Mineral Company at Pulaski has conducted some very interesting, as well as important, experiments at its plant, on low grade mixed ores. One of the most important of these was on a lot of mixed carbonate and sulphide ores from north Arkansas. It was found necessary first to give the mixture a roast in order to desulphurize the blende, zinc sulphide. It was found that, by giving the mixture a slow roast, the sulphur could be driven off without loss of zinc in the carbonate and, at the same time, the carbonate was benefited thereby in having the CO_2 expelled. The success of this experiment has resulted in the willingness of the Bertha plant to treat the Arkansas ore, which at present is a drag on the western market. This probably opens up a better future for the Arkansas ores, and at the same time points to an additional source of supply of ore to the Virginia plant.

Whenever it was possible to buy it, Tennessee ore has been used. However, the lime present in the Tennessee sulphide ores seems to interfere with the work, since by desulphurizing the ore calcium sulphate (CaSO_4) is formed, which cannot be gotten rid of.

The Bertha Company has not been producing ore from its property for the past year, for the reason that it has been and is still engaged in exploiting and developing the very promising bodies of sulphide ore at Austinville. At the time of the writer's visit, an average only of about 3 tons of ore per day was being shipped to the plant at Pulaski from the company's property. The local iron furnaces furnish about two cars of zinc flue-dust per year to the Bertha smelting plant.

Furnace Work.—The furnace work of the Pulaski plant is unusually good. At 3 P. M. on April 10, 1905, eight of the ten furnaces then in operation were visited, and in no case did more than two retorts show even a trace of zinc burning at the face; and in most cases only one. The saving for the last month as shown by averages from authentic records, was running 89 to 91 per cent. on furnace charges; an average equivalent to about 49 per cent. metallic zinc.

The furnace men work in shifts of 24 hours. The last tap is finished usually about 5 o'clock in the morning, when the new shift, including one "foreman," one "second hand," one "third hand," and two helpers, goes on duty. The foreman works up the fire, arranges the charges and looks over the furnace generally during charging; while the other four men clean and charge the furnaces. After the charging is completed, the two helpers are dispensed with, all work during the run, such as firing, tapping, and keeping the furnaces in trim, is performed by the three remaining men.⁴⁶

FUTURE DEVELOPMENT

From the beginning of mining zinc ores in Southwest Virginia to the present time, about 35 years, attention has been given exclusively to the removal of the soft or oxidized ores, carbonate and silicate. Now that the known supply of these ores in the district are rapidly diminishing, the problem in the future will be that of mining sulphide ores. Already considerable activity is manifested over parts of the district in prospecting for and developing sulphide ores. Very encouraging results are obtained in places and there seems sufficient reason for believing that a part of the district at least promises well in the way of workable bodies of sulphide ores. At Austinville large bodies of sulphide ores in the form of ore-shoots are being developed. At other points developments indicate a workable grade of sulphide breccia ore. At Cedar Springs the blende is in massive crystalline form of exceptional purity and should prove an easy milling proposition.

The very favorable location of the district as regards abundant fuel supplies, cheap labor and ample transportation facilities, should make it possible to more profitably work lower grade ores here than in the districts of the Central and Western states. The East Tennessee district which is a continuation southwestward of the Virginia district, and the Arkansas district, should prove to be additional possible sources of ore for the Virginia furnaces. The ores of the former district, East Tennessee, would naturally be supplied to the Virginia furnaces for smelting. Since successful tests have been made at the Virginia furnaces on the Arkansas ores, a mixture of soft and sulphide ores, and since the Missouri furnaces

⁴⁶ Higgins, E., Jr., Eng. and Mng. Jour., 1905, Vol. LXXIX, pp. 658-659.

impose a heavy penalty on the Arkansas ores, a market for these ores is made possible in Virginia and at the same time Arkansas offers an additional source of supply of ores to the Virginia furnaces.

A word in regard to future prospecting. The ores are as yet found only in the Shenandoah or Valley limestone. They apparently extend from near the bottom to the top of the limestone, and they appear to be rather closely associated with the folding, faulting and brecciation of the district. If this association of ore to limestone and its structural features prove true then prospecting should be more wisely directed in the future, and at a minimum expenditure.

In conclusion it may be stated that in the writer's judgment the district is yet far from being exhausted, and that while the soft ores are rapidly decreasing, there are good reserves of workable sulphide ores to draw from, which should entitle the district to not less importance than it formerly had.

The East Tennessee Deposits

In prosecuting the field study of the Southwest Virginia lead and zinc deposits it soon became apparent that the deposits of East Tennessee formed a part of the same general area and that the two could not be separated geologically. In other words similar geological conditions obtain in both areas; the type of ore-deposit is the same, and the Tennessee deposits are but a continuation of the Virginia deposits southwestward. Accordingly the writer visited the Tennessee district with a view of determining the bearing of it on the Virginia district.

The same ores are found, including among the sulphides, sphalerite and galenite, with a slight sprinkling in some of the mine openings of pyrite; and the altered ores, smithsonite and calamine. The associated minerals, gangue, are dolomite and calcite. These are formed in breccias, the sulphides often replacing to a more or less extent the substance of the limestone fragments. Like the Virginia ores, those of Tennessee are found in the Cambro-Ordovician limestone, known in Tennessee and farther southward in Georgia and Alabama as the Knox dolomite, which is the equivalent of the Shenandoah limestone in Virginia.

Two belts of the ores are recognized, which follow more or less closely the Powell and Holston rivers. Moreover the ores are closely associated with the faulting and brecciation of the anti-clinal folding. As in Virginia much of the zinc-mining in Tennessee has been done on the soft ores, smithsonite and calamine, alteration products from the original sulphides.

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