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The lead and zinc deposits in the sedimentary rocks of East Tennessee and Southwest Virginia

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THE LEAD AND ZINC DEPOSITS IN THE SEDIMENTARY ROCKS OF EAST TENNESSEE AND SOUTHWEST VIRGINIA.

by

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GEOGRAPHY.

In its geographic and geologic relations this area forms a part of the Appalachian province, which extends from the Atlantic Coastal plain on the East to the Mississippi lowlands on the West and from Central Alabama to Southern New York. All parts of the region thus defined have a common history recorded in its rocks, its geologic structure and its topographic features.

The Appalachian province may be subdivided into three well-marked physiographic divisions, throughout which certain forces have produced similar results in sedimentation, in geologic structure and in topography. These divisions extend the entire length of the province from Northeast to Southwest.

The central division is the Appalachian Valley. It is the best defined and most uniform of the three and it is with that part of the central division which forms the Great Valley of East Tennessee and Southwest Virginia that this paper is concerned.

The area under discussion may be arbitrarily defined as extending from Chattanooga, Tennessee, on the South to Roanoke, Virginia, on the North and from the Appalachian Mountains on the East to the Cumberland

Plateau on the West.

TOPOGRAPHY.

The Great Valley is characterized by numerous low ridges and lines of knobs extending in a Northeast-Southwest direction, generally parallel among themselves, and with the limits of the district on either side. The ridges are formed by narrow belts of rock slightly harder than that on which the intervening valleys are located. The character of the surface is a direct result of the drainage system. Hence the valleys are on softer or more soluble limestone or soft shale and the ridges are formed by limestone containing a larger proportion of insoluble material or by tough shales or sandstones.

The drainage pattern shows a close adjustment to the structure, the streams in general cutting their valleys in the soft rocks and avoiding the belts of hard ones which are left standing as long, narrow ridges.

GENERAL GEOLOGY.

The rocks appearing at the surface within the limits of the zinc and lead region under discussion are without exception sedimentary. They consist of limestones, shales and sandstones and present a rather wide variety in appearance and composition.

The correlation of these formations, so far as is presented in the literature to date, must be regarded as only approximate and no discussion thereof will be undertaken in this paper, except to point out general relationships within the great series of limestones and dolomites involved in the discussion of the ore deposits.

The Knox dolomite of Cambro-Silurian age occupies practically all of the ore bearing area of East Tennessee. It consists of 3800 to 4500 feet of massively bedded and somewhat crystalline magnesian limestone. This limestone, or more properly dolomite, is dark to light gray or nearly white in color. It contains a large amount of silica in the form of layers and nodules of chert. In some places, portions of the formation contain, in place of the chert nodules, beds of rather coarse, calcareous sandstone. Upon weathering, the rock breaks down leaving behind the chert or sandstone usually embedded in red clay. This residual material covers the surface to great depths and the dolomite itself is seldom seen except in the channels of streams. Over wide areas some beds are coarsely crystalline, in fact they are marble.

Ellis* recognizes the Cotter formation, essentially dolomite beds, resting unconformably upon the Jefferson City formation at Jefferson City, Tennessee. A similar unconformity is reported at Mascot and recent investigations by the Tennessee Geological Survey will doubtless result in a further division of the Knox.

In Virginia the principal ore bearing formation is the Shenandoah limestone, which is correlated with the Knox dolomite, and which includes, in addition, at least 1500 feet of Cambrian strata beneath the Knox dolomite. The chief occurrences of the ores are in the lowest division of the Cambrian; the Shady dolomite.

The Appalachian Valley has been a land area since early Mesozoic time, during which time there were several periods of uplift, followed by periods of quiescence and there is, accordingly, evidence indicating several periods of base-leveling over the area.

STRUCTURE

In the Great Valley the rocks have been steeply tilted, bent into folds, broken by faults and to some extent altered to slates.

* - Ellis, E.E. A new zinc mine in Tennessee. Mining & Met. 1929 Vol. 10, p. 509.

The folds and the faults developed from them are generally parallel among themselves, extending in a Northeast-Southwest direction for great distances. It is said that some faults have been traced for a distance of 300 miles and some folds have even greater length. The crest of each anticline is generally uniform in height, so that for great distances it contains the same formations. These folds are also, more frequently than not, equal to one another in height, so that many of them bring to the surface the same formations. Most of the rocks dip at angles greater than 10° and frequently the sides of the folds are compressed till they are parallel. A striking feature of the folds is the prevalence of Southeast dips.

All of the major faults are of the overthrust type and were developed out of the close folds. With very few exceptions, the fault planes dip to the Southeast. The planes on which the rocks broke and moved are often parallel to the bedding planes, as the rocks slipped on bedding planes in folding. Along these planes of fracture, the rocks are said to have moved distances sometimes as great as eight miles. There is a progressive increase in the degree of deformation from Northeast to

Southwest, resulting in different types in different places. In Southern Virginia the folds are closely compressed and often closed, while occasional faults appear. Passing through Virginia and into Tennessee, the folds are more and more broken by faults until, halfway through Tennessee, nearly every fold is broken and the strata form a series of narrow, overlapping blocks, all dipping Eastward.

In addition to these forms, there have been developed a series of minute breaks across the strata, producing cleavage (or jointing) or a tendency to break or split readily along these new planes. These planes dip from 20° to 90° to the Eastward usually about 60°. This jointing reaches a higher development in the Appalachian Mountains, but it has been observed to a marked degree in all parts of the Valley. As these breaks became more frequent and greater, they resulted in a rearrangement of minerals as well as in various degrees of brecciation over poorly defined areas. Many of the beds underwent complete recrystallization in places and the final products of this metamorphism are often indistinguishable throughout the beds.

The structures above described are manifestly due chiefly to horizontal compression, which acted in a Northwest-Southeast direction, at right angles to the trend of the folds and cleavage plane. The compression, apparently, began in early Paleozaic time and probably continued at intervals up to its culimination, shortly after the close of the Carboniferous, when the greater portion of the folding was effected.

DISTRIBUTION OF THE ORES.

Geographically, the ores under discussion are confined to the Valley region of Eastern Tennessee and its equivalent in Southwestern Virginia, extending from the vicinity of Chattanooga, Tennessee, Northeastward to Roanoke, Virginia. Only a small portion of the area thus defined contains workable deposits of lead and zinc, in fact, up to the present time, the productive areas are confined within the limits of several counties in each State. However, throughout the whole area there is evidence, in some degree, of mineralization and it is safe to predict that new ore bodies will be discovered in the future.

In Tennessee the deposits now being worked are located at Mascot, Jefferson City and Embreeville.

At the present time the only operation of consequence in Virginia is the Bertha Mine of the New Jersey Zinc Company at Austinville. However, a proven lead deposit is now being developed at Ivanhoe and a drilling campaign is under way in Smyth County to the Southwest.

HISTORY OF MINING

The first authentic records of lead mining in Virginia date back nearly 200 years and the old lead mines at Austinville were the first to be worked. Colonel Chiswell, a native of Wales, first opened the mines in 1750 and operated them for a period of about 25 years. From that time to the present, mining has been carried on almost continuously in the Virginia area.

For many years after the mines were opened in Virginia, the operations were confined exclusively to the lead-ores. The zinc-ores seem not to have been recognized at the Austinville mines until sometime after the Civil War, when several tons were shipped to the smelter at Petersburg, Virginia.

Zinc-ores were first discovered at Bertha, near Austinville, in Wythe County in 1866 and mining of these ores properly dates from 1879 when the mine at Bertha was opened. Only oxidized ores were found at

Bertha and it is reported that a recent drilling campaign to explore the strata beneath the level of the old carbonate workings failed to develop any sulphide ore.

The history of lead and zinc mining in Tennessee dates back to 1856. In that year the Mossy Creek Mine at Jefferson City was discovered. The name of the discoverer is not known.

The mines at Straight Creek and Lead Mine Bend on Powell River were early operations which have been worked with varying degrees of success from time to time, but no authentic history of these operations is recorded.

An oxidized zinc-ore deposit was opened at New Market in 1900 and worked through the war period by the Grasselli Chemical Company. A sulphide deposit was developed in later years, but has not been worked.

In 1911, after several companies had made considerable progress in developing the Mascot area, the American Zinc Company entered the field and developed what was the first large scale or successful operation in Tennessee.

The Universal Exploration Company entered the Jefferson City district in 1926 and, after extensive exploration, has been operating an oxidized zinc deposit since January, 1928, and has been developing a sulphide ore body since July, 1928, which will be in production shortly.

Another zinc mine was opened at Jefferson City by the American Zinc Company in 1929 and is now in operation.

ORES AND ASSOCIATED MINERALS.

The minerals of this region are not numerous in species, being confined to a few of the commoner forms. They include, (1) the original sulphide forms, sphalerite, galena, pyrite and rarely chalcopyrite; and (2) the oxidized or secondary forms, which have been derived from the original sulphide forms and occur in the residual decay of the limestone. These include calamine, smithsonite, cerussite and limonite.

The associated non-metallic minerals, named in the order of their importance, are dolomite, calcite, barite, fluorite and quartz. Of these, dolomite and calcite are the principal ones and they occur in vastly the largest amount. In Tennessee, fluorite and quartz do not occur as abundantly as is the case in Virginia, but they have been observed in several localities.

GALENA - Throughout the region the occurrence of galena is, without exception, in association with the zinc-ores. At Mascot and Jefferson City, the principal districts in Tennessee, there is no occurrence of galena, but at Straight Creek, Lead Mine Bend and White Pine, none of which places are now productive, galena in considerable amounts is found in association with sphalerite. In Virginia the association of galena and sphalerite is much more common, in fact, at Austinville there is a predominance of galena in the ore and at Cedar Springs, where mining operations were carried on some years ago, the galena was nearly pure. Throughout the Virginia area the occurrence of galena in mineralized outcrops observed over a wide range is not uncommon. The usual occurrence of galena is granular and massive granular, less frequently in the form of crystals.

CERUSSITE - Cerussite is not a common form at any of the mines in Virginia. It has been noted in small quantities at Austinville and prospecting has disclosed lesser amounts in Russell and Roanoke Counties. In the old lead mine at Cedar Springs, small amounts of cerussite are to be found in the oxidized portion of the vein, but in general it may be said that the occurrence of this mineral in Virginia is rare. It is reported that, the period of early mining in East Tennessee, cerussite was noted in the residual soil of several operations and it is known that, during the early operations at Embreeville, cerussite was recovered in commercial quantities, and at Cleveland some was recovered during the early operations in the upper portion of the ore body. These deposits, however, have been depleted and there is no other known occurrence of the mineral in Tennessee in quantities larger than traces.

SPHALERITE - Sphalerite constitutes the most important ore in the Tennessee area and, it is thought, over much of the Virginia area. It is generally found below the ground-water level and varies in color from a light yellow, or straw-color, through brown to nearly black. At one prospect in the extreme Southern portion of Virginia, an unusual occurrence was observed where the sphalerite has a deep reddish color and is locally known as "strawberry-jack". At Mascot and Jefferson City the sphalerite has a pale yellow color and is of exceptional purity, being entirely free of galena and showing only an occasional yellow cadmium stain. In the non-productive mines at Cleveland, Lead Mine Bend and Straight Creek, however, considerable amounts of galena are found in association with the sphalerite and the same condition has been observed at a number of the undeveloped mineralized outcrops in the Tennessee district, a notable example of which is the rather well known prospect at White Pine. The normal occurrence of the mineral in Tennessee is as small disseminated grains, crystals being rarely found. At Austinville the sphalerite occurs with galena which, as has been noted, predominates. At Cedar Springs and Ivanhoe, however, exceptionally pure zinc sulphide has been found in surface outcrops.

<u>SMITHSONITE</u> - Smithsonite has been in Virginia and is yet in Tennessee, a rather important ore of zinc. During the period of early mining in Virginia, the Bertha mines were opened near Austinville and were productive for a number of years. These deposits, all oxidized ore, were worked out and no sulphide body was ever developed. At Ivanhoe, the property of the Ivanhoe Mining and Smelting Company, which was originally worked for its iron-ore, has produced considerable smithsonite and still is producing small amounts. In the course of iron mining operations at the Little Wythe workings in Wythe County of the Virginia Iron Coal and Coke Company, a small body of oxidized zinc-ore was encountered and recovered. At Embreeville, Tennessee, a large quantity of smithsonite has been

produced. This property, also worked originally for its iron-ore, has been producing oxidized zinc-ores since 1919 and is still in production. Extensive and systematic drilling has failed, however, to locate sulphides below the level of the secondary ores. At Jefferson City, smithsonite was found during the earliest development and the exploitation of the oxidized ores led to the discovery of some of the sulphide bodies. In the same district and near New Market, much smithsonite was recovered at the property of the Grasselli Chemical Company. This mine produced more than 25,000 tons of oxidized zinc-ore from 1900 to 1918. Smithsonite is an important ore of zinc at the property of the Universal Exploration Company at Jefferson City, where the oxidized ore body has been worked since 1928. It is reported that another body of oxidized zinc ore, of which smithsonite is an important part, has been discovered at Idol, Tennessee, but this property is not as yet in operation.

The smithsonite occurs generally as earthy, crystalline incrustations and as a porous, spongy material with cavities frequently filled with a powdery form of the mineral. It is found in the residual decay of the magnesian limestones, concentrated generally in the bottom portions of the clays and resting on the irregularly weathered surface of the limestone.

CALAMINE - Calamine is usually much more abundant in the secondary ores than smithsonite. In occurrence it is almost exactly the same as smithsonite and the two are often so intimately intermixed that it is impossible to distinguish between them. At Embreeville and at Jefferson City, beautiful white incrustations of the mineral, presenting both mammillary and stalactitic surfaces, have been observed between more massive forms of the ore and embedded in the clays. Granular massive and honey-comb forms are quite common.

ASSOCIATED ORES - Over the Virginia area and to a much lesser extent in Tennessee, iron-ores and manganese-ores, especially the former, have been abundant in the residual clays. These residual deposits have been largely exhausted, but, in the period of early mining operations, the exploitation of one ore often led to the discovery and development of another, as has been mentioned in the case of the Ivanhoe, Little Wythe and Embreeville properties.

MODE OF OCCURRENCE OF THE ORES

THE SULPHIDE ORE - As has been stated, the sulphide ore at the principal developments in Tennessee consists of a zinc blende of high purity. In Virginia the ore at the one large producer consists of associated sulphides of lead and zinc, but, otherwise, the mode of occurrence is very similar to that of the Tennessee deposits. These ores occur principally in dolomite, occasionally in limestone, but always associated with a white, secondary dolomite which is typical vein material and which, for the purpose of distinction from the dolomitic country rock, is called "gangue dolomite". Two general types of ore are recognized. One is known as the breccia type and one is called recrystallized ore.

In the breccia type of ore there is evidence that replacement has played some part in the ore formation, but in many instances there is slight, if any, indication of replacement. The breccia zones are direct results of faulting and folding and, where mineralization has taken place, the ore is composed of sharp, angular fragments of dolomite and, in rarer cases, limestone cemented by a matrix of gangue dolomite and zinc blende, with or without replacement of the rock fragments. The bodies of ore at Jefferson City are rather irregular in shape, often with a nearly vertical boundary on one side and narrowing down on the other side. Thicknesses of 40 to

50 feet are common and they occasionally reach 90 feet. At Mascot and at Austinville the tendency is for the ore bodies to follow more closely the dip of the beds, which, in both cases, is approximately 20°.

An interesting feature of the breccia ores, as pointed out by Ellis*, is that they always occur in the dolomitized portions of the ore-bearing formation. The formation normally consists of alternating beds, probably lenses, of limestone and dolomite, but in the ore areas nearly complete dolomitization has taken place and a good breccia ore-hole will not show a trace of limestone, while a hole 50 feet away may show 40% limestone for the same horizon.

In the recrystallized ore the zinc sulphide occurs disseminated throughout the coarsely crystalline dolomite rather than as stringers, veinlets and fracture fellings, as in the breccia ore. These ores occur at times in the breccia masses, but in general they follow the bedding of the formation.

At Mascot the ore bodies occur on the flank of a faulted anticline which dips to the Southeast at approximately 20°. The bulk of the ore occurs in the

* - Ellis, E.E. A new zinc mine in Tennessee. Mining & Met. 1929 Vol. 10, p. 509.

Cotter formation, but recent developments have proven ore in the Jefferson City formation below the unconformity. The general structure at Jefferson City is a broad flat anticline pitching to the Southwest with the Universal Exploration Company and American Zinc Company ore bodies on the Southeast flank and the Grasselli Chemical Company ore body on the Northwest flank. The ore zones are below the plane of a great thrust fault which passes along the Southeast border of the district. Most of the ores occur in the Jefferson City formation, but there is some occurrence in the Cotter formation above the unconformity. At Austinville the New Jersey Zinc Company deposits occur on the Northwest flank of an anticline in the vicinity of a great thrust fault, while the properties of the Ivanhoe Mining and Smelting Company, now being explored, lie on the Southeast flank. These deposits are in the Shady dolomite of lower Cambrian age and, hence, are at least 1000 feet below the horizon of the larger developments in Tennessee, although all of these ore bodies show a close similarity in type. It is thought that these relations are significant and more will be said of them later.

THE OXIDIZED ORE - The secondary ores have been derived from the original sulphides of lead and zinc by the ordinary processes of oxidation, carbonation and silication above the ground-water level. They are generally rich and often are concentrated massively as large, irregular masses and layers. The concentration of the oxidized ores has taken place at or near the bottom of the residual clays close to the weathered and partially decayed surfaces of the country rock.

As a rule the residual clays are highly ferruginous. In some cases large amounts of limonite occur in the clays and it was derived from the original pyrite disseminated through the limestone. In some places, as is the case at Embreeville, some parts of the ore bodies are so intimately intermixed with limonite that they cannot be satisfactorily treated.

RELATION OF THE ORES TO GEOLOGIC STRUCTURE

It has been noted that all of the important lead and zinc deposits of the area under discussion are situated on anticlinal structure and that they are found in the vicinity of great faults. It is clear that these ore bodies were formed after a period of intense deformation had resulted in the structural forms which have been described. This period of earth movement came at, or near, the close of Carboniferous time and establishes, without question, within certain limits the age of the ores. Certain evidence, however, which will be discussed later, seems to indicate that the ore was deposited, or at least reached its present state of enrichment, considerably later than the close of the Carboniferous.

It has been shown by Van Hise* that the complex movements of ground-water may be resolved into horizontal and lateral components. Meteoric waters sink into the ground by gravity and follow circuitous routes through pore spaces and openings into the main channels of underground circulation, the course of which is governed by gravity and pressure. The maximum of breaking and shattering of the rocks must come on the folds where deformation has been most intense and it is, therefore, apparent that these structures would facilitate the convergence of the circulating solutions and, hence, make the most favorable areas of ore deposition.

In any theory of ore deposition from ascending solutions, the faults must be regarded as important structures through which solutions, from depth, might have entered the upper strata. It is regarded

* - Van Hise, C.R. A Treatise on Metamorphism:U.S.G.S. Mono.47 pp 572 - 576, 1904.

as more likely, however, that the faults are, as Secrest* points out, important only in that they tend to limit the circulation of ground-waters. He believes that, while faulting does not necessarily destroy circulation over wide areas, it does render such circulation improbable and that movement of ground-water should be considered with regard to each structural unit rather than as a wide regional circulation.

Some investigators have suggested that unconformity has played an important part in the deposition of ores in this region. It has been shown that ore bodies occur both above and below the unconformities recognized at Mascot and Jefferson City, but there seems to be no ore deposition at the horizon of these unconformities. If an unconformity provided the channel through which the mineralizing solutions entered, both upward and downward circulation of solutions would obviously be required to deposit ore above and below the unconformity, and such a circulation does not seem highly probable.

GENESIS OF THE ORES.

Considerable divergence of opinion is expressed as to the origin of the ores of the Great Valley

* - Secrest, Mark H. Zinc Deposits of East Tenn. Bull. Tenn.Geol.Survey p. 159.

region. Ascending thermal solutions have been suggested as the source of the ore and theories of both downward and upward circulation of meteoric solutions are advanced.

Within the limits of the Great Valley region of the Virginia-Tennessee area, no igneous intrusions have been found with which to connect the ores. There is no evidence that the ore has been brought up in solutions from great depth and deposited in the breccia zones of the dolomite. None of the minerals, characteristically associated with such deposits, are found with the exception of an occasional trace of fluorspar and, in the absence of even the slightest indication of igneous activity, this could not be regarded as sufficient evidence upon which to base a theory of ascending magmetic solutions.

The theory of upward circulating groundwater has been advanced, but, as this would involve artesian circulation of waters within the brecciated zones, which are necessarily zones of low pressure, it, too, would seem improbable.

Watson* advances the theory that lead and

* - Watson, T.L. Lead and Zinc Deposits of Virginia. Va.Geol. Survey Bull. 1.

zinc particles were widely disseminated in the overlying Cambro-Silurian strata and were carried down in solution by ground-waters to be precipitated by organic matter and mingling solutions in the breccia zones. A similar theory has been advanced by Buckley* and Buehler* in which they suggest that the lead and zinc of the Southwest Missouri deposits was derived from very sparsely disseminated sulphides of lead and zinc in the Pennsylvanian.

Field evidence supports their views as applied to the ores of the area under discussion and, considering the nature of other known regions of lead and zinc deposits, it does not seem unreasonable to suggest that the ores of the Tennessee-Virginia district were derived, not only from the fine disseminations in the Cambro-Silurian strata, but, possibly, from the Carboniferous as well. This would involve a long interval of erosion in which certain concentrations of ore must have occurred, later to be redissolved and carried to successively lower levels and redeposited as sulphides as erosion progressed. Such a process would place the age of the present enrichments much later than the close of the Carboniferous when the greater part of the brecciation was effected.

* - Buckley, E.R. and Buehler, H.A. Geol. of the Granby Area.Mo.Bur.Geol.and Mines Vol IV.

The circulation of ground-waters, the processes of concentration and the physical and chemical factors involved in the deposition of the ores have been fully covered in the literature and no further discussion thereof will be made in this paper.

CONCLUSION

It has been pointed out that the large deposits of lead and zinc in the area are located on anticlinal structure where brecciation has reached its maximum; that major faults traverse the districts of greatest mineralization; that dolomite, both as country rock and gangue, is intimately associated with the ores, and that the age of the mineralization is definitely fixed as post-Pennsylvanian. All of this is regarded as highly significant for, in these respects, there is a marked similarity among practically all of the larger areas of sedimentary lead and zinc deposits.

It is well known that the ores of the Tri-State Region are situated on a flat anticline in brecciated beds of dolomite and chert and that the district is traversed by the Miami and Seneca faults. There is some question as to structure in the Southeast Missouri area and the age of the deposits cannot be definitely fixed as post-Pennsylvanian. The ores are, is general, of the disseminated type, but throughout the district there is evidence of brecciation in some degree. The Moresnet district of Belgium, Luxemburg and Prussia, the district of Silesia in Poland, and the great district of Santander, Spain, all have lead and zinc deposits in sedimentary beds, where structure and dolomitization have been important factors in ore deposition, and in all of these districts the ores are of post-Pennsylvanian age.

It is not contended that all of these deposits were formed contemporaneously, although some of them may, in part, have been so. It may be suggested, however, that the lead and zinc now concentrated in these deposits was derived from rocks of about the same age and that the great earth movement at the close of the Carboniferous, which was effective not only in the Appalachian province, produced, in a large measure, the conditions which seem essential to the deposition of ores of this type.

As has been stated, only a very small portion of the area under consideration is productive. It is only reasonable to believe that the conditions under which the ore occurs are repeated many times throughout the region and, in some of these parallel conditions, other large ore bodies must occur. However, due to the great thickness of overburden, which is common to the area and which makes prospecting and drilling very difficult and expensive, it is probable that the development of the area will be slow until such time as the price of the metals will warrant the expenditure of large sums in drilling operations.

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