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ON THE
LEAD AND ZINC
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THE NATURE, COMPOUNDS, OCCURRENCE AND USES OF LEAD AND ZINC.

PROPERTIES OF THE METALS.

Lead is a soft, heavy metal of a blue-gray color, (which takes its name lead-gray from the metal) with a bright metallic luster on fresh surfaces. On exposed surfaces it tarnishes to a dull, dark gray. It has a hardness of 1.5 of the Moh's scale, which means that it is easily cut by a knife and can be scratched by the finger nail. Its specific gravity is 11.37. Its fusibility is 1 of Von Kobell's scale, which means that it fuses easily in a luminous lamp or gas flame, or in a closed tube below red heat (344° C. or 633° F.). At a red heat it volatilizes rapidly. It is malleable and can be hammered into thin sheets though not so thin as silver or gold, and is easily rolled into sheets which are pliable. It is ductile though not to a pronounced degree and can be drawn into only tolerably fine wires. Lead is always more or less impure unless made by special processes. Lead and all its compounds are poisonous.

Zinc is a white, lustrous metal on fresh surfaces, but tarnished surfaces are a dull, light gray. Its hardness is greater than that of lead, 2 in the mineral scale, and its specific gravity is 7.17. It melts at a dull red heat, 410°-430°C., and volatilizes at 1000°C. At ordinary temperatures it is brittle but becomes somewhat malleable and ductile at 100°-150°C. At 200° it again becomes brittle. Zinc is easily oxidized and the coating of oxide remains on the surface protecting the metal beneath from further oxidation. It is this property which renders zinc valuable for many of the uses to which it is put. Chemically, zinc is an active element and displaces several of the other metals from their compounds.

HISTORY OF LEAD AND ZINC.

The history of lead and zinc is discussed in some detail by Winslow in Volume VI of the Missouri Geological Survey. This volume is unfortunately out of print but the historical portion has been reproduced in Volume VIII of the University Geological Survey of

Kansas. In the present report a brief abstract of Winslow's paper is given and the reader is referred to the two reports mentioned above for more complete detail, and for the bibliography.

History of lead. Lead and its properties have been known for a long period, reaching back to the beginning of history. In America lead does not seem to have been separated from its ores in prehistoric times. No lead is found in the mounds of the Mississippi Valley. The Indians probably learned the reduction of lead from the white men.

In Africa and Asia lead has been worked since the beginning of historical times. The earliest Egyptians used it for many purposes and the Chinese were acquainted with the metal as early as 2000 B. C. Important deposits of silver-lead ores in Asia Minor and in India were worked in very early times.

In Europe lead mining began along the shores of the Mediterranean where the knowledge of the metal was acquired from the east. The famous lead mines at Laurium in Greece were probably worked as early as 1200 B. C., extensively worked in the 6th and 5th centuries B. C., and to a more limited extent down to the beginning of the Christian era. Mining was revived in this region in 1865.

The Phoenicians and Carthaginians worked the mines of southern Spain and probably those of northern Spain, southern France, Sardinia and Sicily. After these countries were conquered by the Romans the latter continued the lead mining in these regions and extended the operations into France and England, southern Italy and perhaps into Austria. Some of these mines have been revived in comparatively recent times and are still being worked.

There seems to have been little mining of lead in Germany in early times. Mining in the Harz Mountains seems to have begun in the 10th century but was not active until the 15th. The Silesian mines were producing in the 13th century. The German mines have been actively exploited since the 15th and 16th centuries. In Belgium mining was begun at an early period and continued to be an important industry up to comparatively recent times. The mines are practically exhausted at present. In Russia, mining operations on an extensive scale were not commenced until the 16th and 17th centuries. Lead mining in Great Britain was commenced by the Romans and continued less actively by the Saxons and Danes, but the production first became important about the 15th century and has continued up to the present.

In North America the earliest lead mining was in Mexico where the Aztecs mined the silver-lead ores before the Spanish conquest. The Spaniards began mining here in 1520 but the most important

development was after 1700. Since 1821 mining has been a very active industry principally through the influence of English and American capital.

Lead mining was begun in the United States near Jamestown, Virginia. The Wythe County deposits in the eastern part of the state were discovered in 1750 and have been worked intermittently up to the present. Some lead was mined in the New England States, New York, and Pennsylvania prior to 1850 but very little has been produced east of the Appalachian Mountains since that time. The production of these states has not reached 100 tons of metallic lead in any year since 1907.

Lead ore was found in the Mississippi Valley about 1700. The development of the southeastern Missouri ores began at Mine La Motte in 1720. It was much later before the ores of the Joplin district were discovered. These were not known before 1850 and were not developed until 1870. A more detailed history of this district is given in another connection. The northern Mississippi Valley ores in Iowa, Wisconsin, and Illinois were worked slightly from 1790 to 1821. In these states the industry became very important in 1840 to 1850 but has declined since that time, while zinc mining has increased in importance. In southern Illinois and the adjacent parts of Kentucky mining began about 1840 and was most active from 1865 to 1875.

Practically all of the important silver-lead deposits of the western states have been discovered in the last half-century. The principal deposits in Utah and Nevada were discovered between 1860 and 1870. In Colorado, the Georgetown deposits were discovered in 1866,, the Leadville deposits in 1874 and the Aspen deposits about 1880. In Idaho, the Idaho City deposits were discovered about 1867, the South Mountain deposits about 1871, the Wood River in 1872, and the important Coeur d'Alene deposits were found about 1880, although the value of the lead deposits was not recognized until a few years later.

History of zinc. Although zinc as a metal is a product of recent times, its ores have been known for a considerable period. The ores, principally the silicate and the carbonate, were used in the production of brass before the Christian era. It is probable that the metal was first found as an accidental product in the furnaces used in producing brass. The first intentional production of zinc in Europe was about 1720 although it has been produced in Asia as early as the 16th century. Works were established in England in 1743 and on the continent in Silesia about 1798. The Belgian process of reduction was established in 1809 but it was not until 1820 that the manufacture of zinc in Europe became a well established industry.

Very little zinc has ever been produced in South America and in North America outside of the United States.

In the United States the zinc ores usually accompany the lead ores, but in the early days of mining in this country the zinc ores were not recognized and their value was unknown. In many cases they were mined with the lead ores but were discarded, and no use was made of them until early in the 19th century. Zinc was first manufactured at the arsenal at Washington in 1838 from the red oxide ore of New Jersey, which had been discovered in 1820. Works were established at Newark, New Jersey, in 1848, and at Bethlehem, Pennsylvania, in 1853. For some time zinc white was the only product from the Pennsylvania ores but in 1860 the metal was obtained on a commercial scale. The Virginia and Tennessee ores were not utilized until after the Civil war. In the upper Mississippi Valley the zinc ores were first smelted at La Salle, Illinois, in 1860 although they were known for some time previous. Zinc was manufactured in Missouri in 1867 at Potosi, and in 1869 at Carondelet. The use of ores from the Joplin district began in 1871 and the first ore from this district was shipped to La Salle but smelters were built at Weir City and Pittsburg, Kansas, in 1873. The first smelters in southwestern Missouri were built at West Joplin in 1881.

The recovery of zinc in the western states has been largely incidental to the working of the ores of other metals, especially those of lead and silver, and its history is closely connected with that of the development of the lead ores which has already been briefly noted.

MINERALS CONTAINING LEAD.

The principal minerals containing lead as an important constituent are galena, cerussite, leadhillite, anglesite, pyromorphite, and minium. Besides these there are several other lead minerals which are so rare or which occur in so small quantities as to be of no value as a source of lead.

Native lead. Lead is very rarely found in the native state. It sometimes occurs in very small quantities where it has been reduced from the sulphide or other minerals. It also occurs in a few metorites.

Galena (PbS) is the sulphide of lead, containing, when pure, 86.6 per cent lead and 13.21 per cent sulphur. It is of a bright lead-gray color with a metallic lustre. It crystalizes in the orthorhombic system and has a perfect cubic cleavage. The form of occurrence is in imperfect cubes although octahedral forms are sometimes found. The specific gravity is 7.4 to 7.6; hardness, 2.5; and fusibility, 2. In nature galena is always more or less impure, silver and the sulphides of zins, copper, cadmium, and bismuth being the principal impurities,

Galena, which is called "mineral" or "lead" by the miners is by far the most important ore of lead.

Cerussite ($PbCO_3$) is the carbonate of lead, containing when pure, 16.5 per cent of carbon dioxide and 83.5 per cent of lead oxide or 77.5 per cent of lead. Its color is variable, ranging from white through gray into black, and is sometimes tinged blue or green by the presence of small amounts of copper compounds. The lustre is adamantine. Cerussite crystallizes in the orthorhombic system, and occurs as plates, prisms and in tabular forms, is sometimes compact or earthy in irregular shapes or may be granular, stalactitic or fibrous, or a powder coating galena. Its fracture is conchoidal; cleavage, distinct; specific gravity, 6.55; hardness, 3.35; fusibility, 1.5. Cerussite is probably formed through the oxidation of galena to lead sulphate and the subsequent action of surface waters carrying carbon dioxide on the sulphate. It generally contains small quantities of silica, iron and clayey matter as impurities. As an ore of lead it ranks far below galena in importance but is of considerable value locally.

Anglesite ($PbSO_4$) is the sulphate of lead, containing, when pure, 26.4 per cent sulphurtrioxide and 73.6 per cent lead oxide or 68.3 per cent lead. It crystallizes in the orthorhombic system and is prismatic, tabular or pyramidal when crystalline. Anglesite occurs in small quantities in cavities in galena crystals, is sometimes stalactitic, but is more commonly massive, granular or compact. It often forms a powdery coating on galena and crystals of galena may be largely altered to anglesite, leaving only a kernel of galena inside of concentric layers of anglesite. The color is white, pale yellow to pale green; lustre, adamantine, vitreous or resinous; cleavage, distinct; fracture, conchoidal; hardness, 3; specific gravity, 6.35; fusibility, 2.5. Anglesite seldom occurs in sufficient quantities to be important as an ore of lead.

Pyromorphite ($(3Pb_3PO_4)_2.PbCl_2$) is a phosphate of lead, containing 76.3 per cent of lead. It may be green, brown, yellow, gray, or white in color, and has a resinous lustre. It crystallizes in prismatic forms of the hexagonal system. When not crystalline it may be botryoidal, reniform, fibrous, granular or massive and earthy. Fracture is irregular; specific gravity, 6.5-7.1; hardness, 3.5-4; fusibility, 2. Impurities are often present, the principal ones being lime, arsenic, chromium, and iron. It is not important as an ore of lead.

Other minerals. In addition to the ones named above a large number (about 50) of other minerals contain lead, but they are never abundant enough to serve as a source of the metal. Among these are the hydrous sulpho-carbonate, leadhillite; the chromates, crocoite, phoenichloite, and vangueinite; the molybdate, wulfenite, the arsenate, mimetite; the vanadates, vanadinte and descloizite; the oxide minium, and many others.

MINERALS CONTAINING ZINC.

Native zinc has been reported in Australia, in Georgia and in California[1] but it is extremely rare.

Sphalerite or zinc blende (ZnS)is the sulphide of zinc containing when pure, 33 per cent of sulphur and 67 per cent of zinc. Pure sphalerite is almost colorless but it usually contains sufficient iron to give it a yellow or brown and sometimes black color. Green and lead blue sphalerite also occur. This mineral is transparent to translucent with a resinous to adamantine lustre and it crystallizes in dodecahedral forms of the isometric system, very commonly twinned. It occurs in imperfect crystals, isolated, or in large masses with well developed cleavage, in fine grained or compact masses, or disseminated through the various country rocks with which it may be associated. It may also be found lining cavities in the rock or as stalactites. In the Joplin district it is sometimes found as a white clay-like substance in pockets where it has apparently been re-deposited from solution. Sphalerite is brittle with a conchoidal fracture and with well developed cleavage in the large crystalline masses. It is specific gravity is 4.05; hardness, 3.5-4; fusibility, 5. At very high temperatures sphalerite volatilizes, apparently without passing through the liquid condition. Iron and manganese are very common impurities, while lead, copper, cadmium and silver are less commonly present. It is by far the most important ore of zinc, and is often known as "jack," "black jack" or "resin jack."

Calamine ($Zn(OH)_2\ SiO_3$) is the hydro-silicate of zinc, containing 54.2 per cent of the metal. It is colorless to pale green, blue, or brown, transparent to translucent, with a vitreous lustre. It crystallizes in the orthorhombic system, in tabular and prismatic forms, or grouped in sheaf-like forms. It occurs in mammillary and granular forms, in sheaf-like aggregates, lining cavities and in masses in clay. The cleavage is perfect along some faces; fracture, uneven; specific gravity, 3.45; hardness, 4.5-5; fusibility, 5. Clay is the principal impurity but iron and other metals may occur in small amounts. Calamine is probably formed by the action of surface waters upon sphalerite and is an important ore in workings above the level of ground water. It is known to the miners as "jack" or gray jack (in some districts) and as "silicate."

Smithsonite ($Zn\ CO_3$) is the anhydrous zinc carbonate, containing 52.03 per cent of zinc. It is normally colorless, but is often gray and may be tinged, brown, green or blue by impurities, and is translucent with a vitreous lustre. It crystallizes in the hexagonal system but is usually botryoidal and also occurs in stalactitic, incrusting and compact granular or earthy forms, resembling those of calamine. It

[1] Winslow, Mo. Geol. Surv., vol. VI, p. 24.

oftens forms psendormorphs after other minerals. Smithsonite is brittle with an uneven fracture. Its specific gravity is 4.30-4.35; hardness, 5; fusibility, very high. Iron, manganese, magnesium, calcium and cadmium compounds are common impurities. Smithsonite is often intimately mixed with calamine and with clay. It is an important ore of zinc in some localities (Northern Mississippi field) where it occurs near the surface in the oxidized zone. The miners of this field commonly call it "dry bone" ore, although the same term is applied to the lead carbonate, cerussite, in other districts.

Hydro-zincite ($ZnCO_3 2Zn(OH)_2$) is a phosphate of lead, concontaining 60.47 per cent of zinc. It is white, gray or yellowish in color. While it may occur in crystalline masses it is usually earthy or compact. Its specific gravity is 3.6-3.8; hardness, 2-2.5; fusibility, high. It is of rather common occurrence but is usually in too small quantities to be of any importance as an ore.

Zincite (ZnO) is the oxide of zinc, containing 80.3 per cent of the metal. The color of the native zincite is orange to deep red with adamantine lustre. Specific gravity is 5.43-5.7; hardness, 4-4.5; infusible. Zincite is usually an original mineral and is of rare occurrence. It is important as an ore only in the Franklin Furnace district of New Jersey.

Willemite (Zn_2SiO_4) is the anhydrous zinc silicate containing 58.62 per cent of zinc. The color varies from white to greenish through gray, yellow and brown to red. Willemite is transparent to opaque with a resinous lustre. Its specific gravity is 3.89-4.18; hardness, 5.5. The mineral is not abundant in nature and is produced as an ore only in the New Jersey field.

Other minerals. Franklinite, the ferrate of zinc is a black mineral with metallic lustre. It is common in some of the New Jersey zinc mines but is otherwise very rare. *Zahnite* or zinc spinel is an aluminate of zinc occurring at several localities but in small quantities. There are many other minerals of zinc but they are so rare and occur in such small quantities that they are of no importance from an economic standpoint.

OCCURRENCE OF LEAD AND ZINC IN THE UNITED STATES.

In this connection the general conditions of the occurrence of lead and zinc ores and the principal deposits of these metals in the United States are briefly noticed. The deposits of the Joplin district of which the Oklahoma area is a part, are considered more fully in succeeding chapter.

Classes of Deposits.

There are three general classes of lead and zinc ores: (1) those practically free from copper, silver and gold, (2) those carrying silver and gold with usually some copper in addition, and (3) the lead-silver ores which consist of galena or oxidized ores containing notable amounts of silver. The second and third groups are confined to the Rocky Mountain and Western States while ores of the first group occur in the Mississippi Valley and in the Eastern States.

Modes of Occurrence.

"Zinc and lead ores may occur under a variety of conditions, viz: (1) as true metalliferous veins; (2) as irregular disseminations, formed by replacement or impregnation in limestones or quartzites; (4) in contact metamorphic deposits; (5) in cavities not of the fissure vein type; and (6) in residual clays."[2] The famous zinc ore deposits of New Jersey belong to the second class, the ores of the remaining Eastern States and of the Mississippi Valley principally to the third, fifth and sixth classes and those of the Western States to the first, second, third and fourth. While the deposits of both the Mississippi Valley and the western region contain examples of the third class (irregular masses or disseminations produced by replacement of limestone or quartzite) the origin of this type of deposit in the two regions is very different as will be noticed in the discussion of the different producing areas.

Nature of Ores.

As has already been noted the principal ores of lead and zinc are the sulphides, galena and sphalerite. These minerals may be original constituents of igneous rocks but in ore deposits are almost invariably deposited from aqueous solution. While in solution the metals are probably in the oxidized form as sulphates, but are precipitated as the sulphides by the mixing of the solution with reducing solutions or by the solution coming into contact with reducing agents. Organic matter is usually regarded as the principal reducing agent but several other substances probably play an important part in the reduction.

After the sulphides are formed the surface of the ground is lowered by erosion and the upper parts of the deposits may be exposed. Part of the ores may be carried away and lost if erosion is rapid but probably the greater part of the ores near the surface, which are affected by surface waters, are oxidized to the sulphates and carbonates. These are dissolved and carried downward by percolating waters. When these reach lower levels they encounter reducing conditions and the

2. Ries, H., Economic Geology Of the United States, p. 427.

metals are again precipitated as the sulphides. This process greatly enriches the deposits at the level of the precipitation and is known as secondary sulphide enrichment.

In the majority of deposits of lead and zinc ores, then, the ores at a depth greater than that reached by the oxidizing waters from the surface, will be principally galena and sphalerite, while above this level the ores will be principally the oxidized ores, cerussite, calamine and smithsonite, with usually some unoxidized galena and sphalerite.

Geographic Distribution.

In the United States the ores containing lead or zinc or both in association with copper, silver, and gold are confined to the Rocky Mountain and Western States, principally Idaho, Colorado, and Utah; the ores containing lead and zinc or lead alone, without the precious metals occur in the Mississippi Valley, principally in southwestern Wisconsin and adjacent parts of Iowa and Illinois, and in southern Missouri and adjacent parts of Kansas, Oklahoma and Arkansas; the ores containing zinc alone or zinc with some lead and without the precious metals occur in the eastern states, principally in New Jersey and in Virginia.

Geologically, lead and zinc ores occur in small quantities in the rocks of all geological ages, but most of the important deposits are in the Paleozoic group and especially in rocks of the Cambrian, Ordovician and Mississippian ages. There are some important deposits in pre-Cambrian rocks.

Description of Producing Areas.

EASTERN STATES.

New Jersey[3]. The zinc ores of New Jersey occur in Sussex County. Two ore bodies, one at Mine Hill near Franklin Furnace and one at Sterling Hill near Ogdensburg, two miles to the south are worked. Both ore bodies are spoon or trough-shaped bodies lying in metamorphosed pre-Cambrian limestone. The Mine Hill deposit is near the contact of the limestone with the gneiss but the Sterling Hill ore body is about one-fifth mile from the outcrop of the gneiss. These deposits have been known since about 1650 and in 1838 the first zinc manufactured in the United States was made from the Mine Hill zincite at the United States arsenal at Washington. It was not until about 1850 that active development began. For several years the ore was used in the manufacture of zinc oxide but in 1860 the manufacture of spelter from the ore was placed on a commercial basis and development has proceeded rapidly since that time.

3 Spencer, A. C., Franklin folio (No. 161), Geol. Atlas. U. S., U. S. Geol. Survey.

The ores of these bodies are unique in that they consist of the oxide of zinc, zincite, the anhydrous silicate, willemite and a mixture of the oxides of zinc, iron and manganese, franklinite. These minerals are very rare in other localities and there is no other place in which they occur in this association. Some calamine and smithsonite were produced from near the surface. The ore bodies are usually called veins but are really layers in the limestone which are not sharply separated from the barren rock. The ore bodies are cut by pegmatite dikes. Various theories have been proposed to account for the origin of the ores, but the matter has not been definitely settled. It is generally held that the ores have been derived from the limestone subsequent to its deposition. The folded (trough-like) form of the bodies is considered due to their formation along a certain horizon in the limestone after the folding rather than to their formation before the folding took place. The deposits are cut by pegmatite dikes of later age. The contact metamorphism caused by these dikes has produced an extraordinary number of minerals, many of which are extremely rare except in this locality. The production from these two deposits has been very great and kept New Jersey second in the list of zinc producing states for several years. Large quantities of both zinc oxide and of spelter are produced and spiegeleisen is made from the franklinite after the separation of zinc.

Virginia-Tennessee Belt. In the folded region of western Virginia and eastern Tennessee there are some deposits of lead and zinc ores which have been worked in a small way. The ores are associated with the Knox dolomite of Cambro-Ordovician (Ozarkian) age. They occur in two ways: (1) as oxidized ores, cerussite, calamine and smithsonite in residual clay, and (2) as galena and sphalerite in fault breccias and along the axes of anticlines where the rock has been broken and brecciated[4]. This district has not so far been important as a producer, but promises further development.

Pennsylvania[5]. "The Saucon Valley deposits promised at one time to become prominent producers, but have not, owing more to geological conditions than to actual scarcity of ore."

MISSISSIPPI VALLEY.

Upper Mississippi Valley District.[6] This district includes the southwestern portion of Wisconsin, small areas in the northeastern portion of Iowa and northwestern Illinois. The lead and zinc ores occur principally in the Galena formation, a dolomitic limestone of Ordovician age. The Galena limestone, and dolomite is underlaid by the Platteville limestone and overlaid by the Maquoketa shale. The ore occurs in cracks and crevices and in solution channels and pockets of the Galena and also disseminated as a replacement of the dolomite.

4. Nelson, Wilbur A., Resources of Tennessee, vol. 2, No. 3, March, 1912.
5. Ries, H., Economic Geology of the United States, p. 436, 1910.
6. Bain, H. Foster, Bull. U. S. Geol. Survey No. 294.

The rocks generally dip to the southwest at low angles but there are variations in the dip and also broad low folds. The principal ore deposits are localized in the synclines

The ores are galena and sphalerite, the former being the more abundant in the higher levels and the latter increasing in proportion with depth. Marcasite is associated with the ores and materially lowers the grade of the zinc concentrates. This difficulty has been overcome in some measure by the introduction of electrostatic separation. It is believed that these ores were derived from the overlying Maquoketa shales which have been largely removed by erosion, and also that they were collected by circulating waters within the Galena itself, and were precipitated in the Galena by reducing solutions mingling with the ore bearing solutions.

Western Kentucky District.[7] This field occupies all of Crittenden, Livingston and Caldwell counties in western Kentucky. The ores, smithsomite, sphalerite and galena are found in rocks of Mississippian age, in fissure veins which have been produced by faulting and as metasomatic replacement of limestone. The lead and zinc ores are associated with large fluorspar deposits and are obtained principally as a by-product in the fluorspar mining. Basic dikes occur in the region but are not generally believed to have had any great influence upon the deposition of the ores.

Southeastern Missouri District.[8] This district which comprises the major portions of St. Francois, Washington and Madison counties, is one of the important lead producing districts of the United States. The ore is galena which occurs for the most part in the lower half of the Bonne Terre formation, magnesian limestones and dolomites of Cambrian age. The galena is principally a disseminated ore. It is believed to have been derived from the formations overlying the Bonne Terre and to have been carried down into the Bonne Terre by percolating waters and precipitated there by reducing agents, probably by the dolomite itself. Upward moving waters under hydrostatic pressure from the underlying LaMotte sandstone have probably added to the ore deposits.

The Joplin District in southwestern Missouri and adjoining portions of Kansas and Oklahoma is the most important zinc producing area, and is also a prominent producer of lead. This field is considered in detail in a succeeding chapter.

7. Smith, W. S. Tangier, Prof. Paper U. S. Geol. Survey No. 36, 1905.
8. Buckley, E. R., Missouri Bureau of Geology and Mines, vol. IX.

Northern Arkansas.[9] The Cambro-Ordovician limestones and dolomites of northern Arkansas contain some deposits of lead and zinc which have been worked on a small scale for many years, but which have never become important producers.

ROCKY MOUNTAIN AND WESTERN STATES.

In the Western States the ores are much more complex than in the eastern and Mississippi Valley regions. They usually carry gold and silver, copper, manganese and other metals. They are almost invariably associated with faulting, folding, and in the majority of cases with igneous intrusions from which the ores have been derived. Zinc is much less abundant than lead and the production of the western states is small compared to that of the eastern and central states. Only the more important of the deposits are noticed in this connection.

Idaho.[10] Idaho has for some years been either the first or second state in the production of lead. The principal production is from the Cour d'Alene district which lies on the western slopes of the Cour d'Alene Mountains in the northern part of the State. The lead deposits are metasomatic fissure veins of galena in a thick series of pre-Cambrian shales, sandstones and quartzites. Monzonite dikes are associated with the deposits and the ores are thought to have been deposited from hot solutions rising from the intrusions. The galena carries much silver, about one-half ounce for each per cent of lead per ton. The bulk of the ore ranges from 3 to 14 per cent lead and 2.5 to 6 ounces of silver per ton. It is concentrated to about 50 per cent lead. Sphalerite and pyrite accompany the ores but little zinc is produced. The galena reaches a known depth of 2600 feet but the deposits become poorer at 1000 to 2000 feet. The upper portions of the ore bodies are oxidized. The district also contains workable gold and copper deposits.

Colorado. In south-central Colorado the Leadville camp has been one of the important producers for many years. The lead and zinc ores, consisting principally of galena and sphalerite and their oxidized products, occur as replacement masses in Silurian and Mississippian dolomite and dolomitic limestones and in fissure veins in Cambrian quartzite. The region is strongly folded and faulted and there are large intrusions of porphyry. The ores were deposited subsequent to the intrusions and previous to the faulting. Emmons[11] states that the ores were derived from the neighboring igneous rocks, by downward circulating waters, and were deposited by replacement. It was his belief that the original source of the ores might have been at great depth. Other writers believe that the ores were derived directly from the underlying pre-Cambrian granite by an upward circulation. The lead and zinc ores carry gold and silver and are associated with manganese, copper and bismuth ores.

9. Adams, Geo. I., Prof. Paper U. S. Geol. Survey No. 24.
10. Ransome, F. L., Prof. Paper U. S. Geol. Survey No. 62.
11. Mon. U. S. Geol. Survey, vol. 2; Bull. No. 320.

Mines at Creede, Colorado, furnish lead and zinc (galena and blende) which occur in fissure veins.

At Aspen, silver-lead ore is found in limestone of Carboniferous age at the intersection of two sets of faults. Spurr[12] believes that the ores were deposited from magmatic waters which moved upwards along these intersections, precipitation being due to the reaction between the magmatic waters and the wall rocks. Silver and lead are the only metals produced at this mine and the former is the more important.

The ores at Rico occur as lodes, replacements in limestones, stocks and blankets, i. e. deposits usually lying parallel to the bedding planes or to the sheets of igneous rocks. The geologic section includes rocks ranging in age from pre-Cambrian to Jurassic, which are faulted and intruded by igneous rocks. The Hermosa formation of Carboniferous age is the principal lead bearing horizon and galena is the lead producing ore.

Utah.[13] In Utah the two principal lead producing camps are the Park City district and the Tintic district.

The Park City district is located 25 miles southeast of Salt Lake City. The rocks consist of about 6000 feet of sedimentaries mostly of Carboniferous age, in general dipping southwest but traversed by many fissures, faults and intrusions. In the oxidized zone the ores are cerussite, anglesite, azurite, malachite, and in the sulphide zone, galena, tetrahedrite and pyrite. They occur as fissure veins and as replacement bodies in limestone.

About 65 miles southwest of Salt Lake City lies the Tintic district. Here the rocks consist of a thick mass of Paleozoic sedimentaries which were folded and eroded before being covered by Tertiary lavas and tuffs. The ores occur in zones in the limestones, as fissures in the igneous rocks and along the contact of the two. Argentiferous galena, carrying a little copper and gold, is the principal ore.

Other states. The Eureka district of Nevada was once one of the most important producers but is principally of historic interest now. Montana has several camps producing silver-lead ore but none of them are as large as the ones which have been described. The same is true of New Mexico.

12. Mon. U. S. Geol. Survey, vol. 31.
13. Ries, H., Economic Geology of the United States, p. 464 et seq.

PRODUCTION OF LEAD IN THE UNITED STATES.

The production of lead in the United States for the year 1906 to 1910 inclusive in short tons is given in the following table. These figures do not include the antimonial lead produced nor the lead contined in pigments made directly from the ore[14]

STATE	1906		1907		1908		1909		1910	
	Quantity	Per cent. of To al	Quantity	Per cent. of Total	Quantity	Per cent. of Total	Quantity	Pe cent of Total	Quantity	Per ct. of Total
Missouri	111,075	31.91	122,856	33.77	122,461	39.57	142,650	40.40	161,659	43.43
Idaho	117,117	33.65	112,569	30.94	98,464	31.82	97,183	27.57	99,924	26.84
Utah	56,260	16.16	61,699	16.96	42,455	13.72	64,534	18.30	57,081	15.33
Colorado	50,497	14.51	48,876	13.43	28,728	9.28	29,326	8.32	35,685	9.61
Nevada	1,699	.48	3,380	.93	3,796	1.23	4,698	1.33	2,195	.59
Wisconsin	1,753	.50	3,551	.98	4,013	1.30	3,238	.92	3,884	1.04
Oklahoma .			404	.11	1,409	3.45	2,268	.64	1,805	.48
Other states	11,752	2.79	11,831	2.88	9,446	2.63	9,994	2.46	9,694	
Total ...	350,153		365,166		310,762		354,188		372,227	

The total production from domestic ores for the United States in short tons in previous years is indicated below. These figures include the antimonial lead but omit the lead in pigments made directly from the ores.

Years.	Amount.
1825 to 1868	676,200
1870	17,830
1875	59,640
1880	97,825
1883	143,957
1885	129,412
1890	143,630
1895	165,709
1900	208,466
1901	269,266
1902	276,455
1903	290,194
1904	308,603
1905	318,509

PRODUCTION OF SPELTER IN THE UNITED STATES.

Zinc in the crude metallic form in which it comes from the smelter is known as spelter. The production of spelter from ores from the different states for the years 1906 to 1910 inclusive in short tons is as follows:

14. Mineral Resources of the United States, U. S. Geological Survey.

STATE	1906		1907		1908		1909		1910	
	Quantity	Per cent. of Total	Quantity	Per cent. of Total	Quantity	Per cent. of Total	Quantity	Per cent. of Total	Quantity	Per ct. of Total
Missouri	130,348	65,27	141,824	63.99	123,665	64.83	140,676	61.10	140,652	55.71
Colorado	32,456	16.25	26,077	11.66	24,885	13.05	20,121	8.74	23,238	9.20
New Jersey	11,206	5.61	13,573	6.07	6,926	3.63	16,035	6.97	20,217	8.01
Wisconsin	11,057	5.54	15,273	6.83	17,538	9.19	20,381	8.85	19,752	7.82
Kansas	3,902	1.96	13,850	6.19	8,628	4.52	9,185	3.98	10,220	4.05
Oklahoma			719	.32	2,235	1.17	3,088	1.31	2,297	.91
Montana ...	1,415	.71			900	.47	4,725	2.05	12,408	4.91
Utah	2,449	1.23	1,972	.88	282	.15	5,960	2.59	7,221	2.86
Other states	6,861	3.43	10,457	4.84	5,700	2.88	10,134	4.41	16,474	6.53
Total ..	191,694	100.00	223,745	100.00	190.749	100.00	230,225	100.00	252,479	100.00

About 60,000 tons of zinc oxide are produced annually in the United States, of which 90 per cent or more is made directly from the ore and the zinc contained in the oxide is not considered in the above table.

METHODS OF PROSPECTING, MINING AND CONCENTRATING.

(Joplin District.)

Geological conditions under which the ores of the Joplin district occur render it unique among the important mining regions of the world. The shallow depth at which the ore is found makes thorough prospecting much cheaper and also makes the outlay for shaft sinking much less than in most other localities. Owing to the discontinuous or "pockety" occurrence of the upper ore bodies it is not feasible to erect large central concentrating plants as is the case in most mining districts, but is more economical to concentrate the ores in small mills which can be easily moved. The low grade of many of the sheet-ground ore bodies prohibits the shipping of these ores to a centrally located concentrating plant, but they may be handled profitably by plants of 100 to 400 tons daily capacity located at the mines. The abundance of fuel, water and transportation facilities makes this plan of concentration in many small mills more feasible than in the mining camps of the western states. The shallow depth at which the ore occurs and the relative ease with which the rock is worked make it possible to prospect and even to open a mine with a limited amount of capital so that the Joplin region has been known for years as a "poor man's camp."

Prospecting.

In recent years prospecting has been done almost entirely by means of the churn drill. Formerly shafts were sunk in localities which, from surface indications, were considered favorable and drifts driven from the bottom of the shaft. The use of a drill saves a great deal of time and expense in locating the ore bodies and at the present time shafts are not sunk until the drill has shown the presence of the ore, and something as to its thickness and extent. For detailed prospecting the drill holes must be close together and in many cases strings of holes 15 to 20 feet apart are drilled. The cost of churn drilling varies with conditions but in most parts of the Joplin district the cost for holes less than 300 feet falls between $1.00 and $2.00 per foot. In the Miami camp where the surface rocks are soft shales and sandstones the cost of drilling is reported to be as low as 50 cents per foot for the first 200 feet, but in these cases the drilling rig belonged to the owners of the leases and depreciation of machinery and interest on the investment were probably not considered. Core drills have been used to only a small extent in the Joplin district and not at all in the Oklahoma field.

Mining.

Shafts are sunk after the presence of a considerable ore body is shown by the drill. Drifts are driven from the bottom of the shaft principally by the method known as under-hand stoping. The ore after it is blasted loose is shoveled by hand into cans or tubs, of sheet steel, (occasionally of wood) holding 500 to 1000 pounds of ore. These cans are on small trucks running on steel rails and are pushed by hand to the foot of the shaft. The drifts are driven so that there is a slight fall from the working face to the foot of the shaft. Two or three hundred feet is considered the maximum length for the drifts since in the shallow workings it is considered cheaper to sink another shaft and to haul the ore to the mill in tram cars on the surface, than to have so long a haul underground.

Ventilation gives little trouble and usually no especial effort is made to procure forced ventilation. A second small shaft is sometimes sunk to produce a circulation through the workings when they become very extensive. *Pumping* is necessary in almost all of the mines. Various types of steam pumps are used but where the amount of water to be raised is large the use of the centrifugal pump is becoming common.

From the bottom of the shaft the cans are hoisted by wire cables attached to a drum at the top of the derrick or head frame. At the top the can passes through an opening in the floor of the dumping room, provided with a trap door which is closed by the operator of the hoist after the can passes it. Each can is fitted with a ring at the bottom. While the door is being closed, the operator fastens a hook, which is suspended by a rope from a beam or rafter of the roof into this ring and releases the drum so that the top of the can is lowered a few feet while the bottom is held by the rope, thus dumping the can.

Milling and Concentrating.

The ore is poured from the can onto a "grizzly," a coarse screen made of 60 or 80 pound iron rails set about 6 inches apart. The pieces of ore less than 6 inches in dimension fall between the rails into the ore bin and the larger pieces are broken up by hammers until they will pass through. Large pieces of barren rock are sorted out, thrown onto a small car and dumped from a short track on a trestle. Two men are usually employed in breaking the ore so it will pass through the grizzly and in sorting out the large pieces of barren rock.

At the shafts other than the mill shaft the ore bin empties into tram cars which are hauled to the mill, usually by wire cables attached

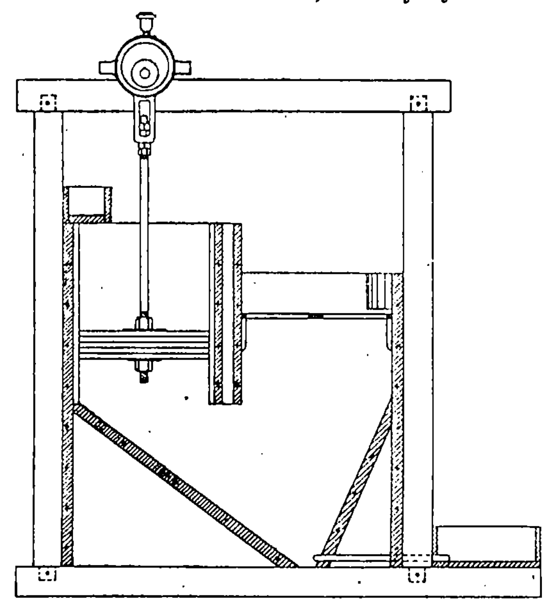


Fig. 1. Transverse section of power jig (after Crane)

to hoisting drum. These cars are self-dumping with the front end so it can be lifted from place. At the summit of the incline to the top of the ore bin the rails of the track turn to the horizontal, while rails which are set on the outside of the track rails continue the incline. The front wheels follow the horizontal rails while the rear wheels, which are wider, follow the inclined rails upward thus lowering the front end of the car so that what may be termed the end gate is drawn up by the cable and the ore dumped.

At the mill shaft the ore is fed from the bin to a jaw or Blake crusher and the crushed material goes to the rolls, of which there are usually two or three sets which reduce the ore to the proper size. Screens are placed after each set of rolls so that the over size material is returned to the rolls. The finer material is sent directly to the jig.

The jig (fig. 1) consists of a large tank, ordinarily built up of two by fours, which is divided by partitions into (usually) six compartments or cells. Each of these cells has a partition built from the top almost half-way to the bottom. In the front part of the cell a horizontal screen or grating is set firmly, the grating of each cell of the six being two or three inches lower than that of the preceding one. In the back part of the cell a plunger fitting the compartment tightly is worked up and down by an eccentric on a shaft. This gives the water with which the jig is filled an up-and-down motion in the front compartment. The ground ore is washed on to the screen of the first compartment and the pulsating movement of the water causes the heavy lead (galena) to settle to the bottom and fall through the screen into the lower part of the compartment which has sloping sides converging toward the bottom. From this bin the concentrates, "hutch", are drawn off through a spigot into a trough from which they are shoveled into cars on a small track which leads above the storage bins outside the mill. The lighter chats and sphalerite are washed over into the next cell and in this and the succeeding cells the sphalerite is removed in the same manner as the galena is in the first cell while the chats are continually rolled forward and at the lower end of the screens are elevated and washed down a sluice way to the tailing pile. In the tailing mills and in some standard mills a preliminary concentration is effected in a rougher jig, which is constructed in the same way as the ordinary cleaner jig, but instead of the material passing from one compartment to another, each cell is fed independently and the overflow and discharge as well as the "hutch" is taken from each separately.

The fine or slime material is screened from the crushed ore before the water enters the jig and is carried to Wilfley tables. The tables are set at an angle with the horizontal, are provided with riffles, for part of their length, and have a reciprocating backward and forward motion. The ore and water are fed along the upper side and the chats being lighter are carried down over the riffles into a discharge trough, while the galena and sphalerite being heavier are caught and by the motion of the table are carried to the end where there are no riffles. Here they become arranged in definite lines (fig. 2) in the order of their specific gravities, the lead toward the top of the table. A fairly sharp separation may be made between the galena and sphalerite but when pyrite is present it cannot be sharply separated from the sphalerite since the specific gravities of the two are so nearly the same that they travel along the table almost together. The pyrite tends to concentrate in the upper portion of the stream of zinc and this portion is often separated and run back over the tables. Some sphalerite is car-

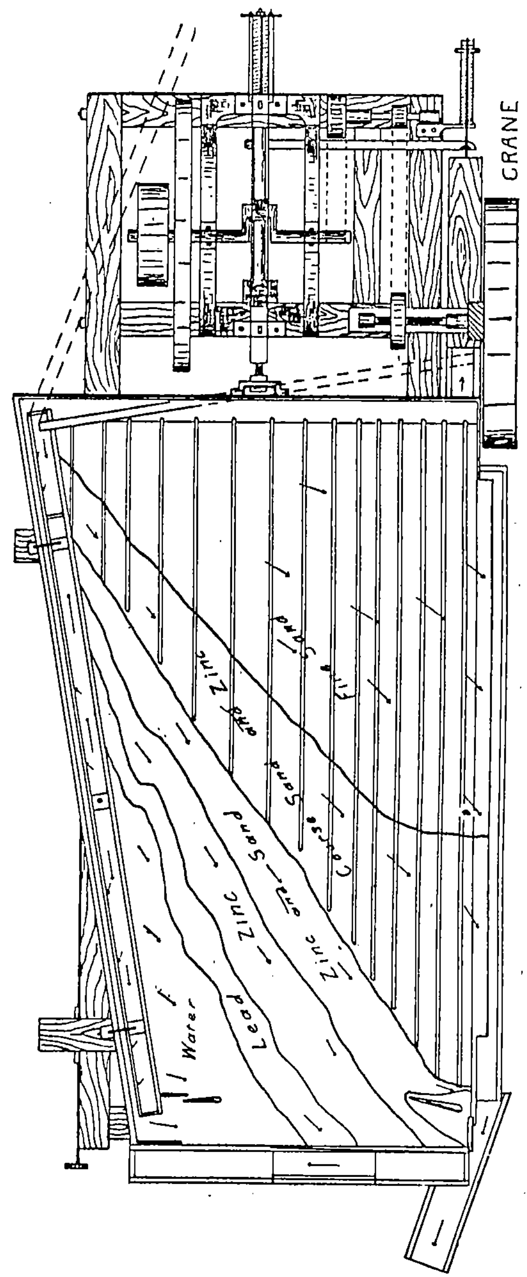


Fig. 2. Plan of Wilfley Table, showing separation of minerals.

ried by the coarse sand which passes to near the end of the table, and this material may also be returned to be worked over. The galena and sphalerite are caught in boxes provided with overflow pipes. From these boxes the concentrates are shoveled into small cars and wheeled to the storage bins.

The brief description given above applies to the ordinarily well equipped mine and mill in the northeastern Oklahoma field. There is considerable variation in the equipment of different mines and mills. In the early stages of development of a mine and in cases where the extent of the ore body is too small to justify the expense of erecting a mill, a hand jig may be used for concentration. The ore may be hoisted by a hand or horse windlass or by a small hoist driven by a gasoline engine or steam engine, which also drives the crusher and rolls. From the rolls the crushed ore is shoveled into the jig.

The hand jig (figs. 3 and 4) consists of a tank, 8 to 10 feet square and about two feet deep. The tank is well constructed, bound by plank and angle iron. Upright posts are bolted to the middle of opposite sides of the tank and extend about two feet above the top; the top of the posts are notched to form a bearing for a cross beam. At right angles to this beam is attached a long lever or arm, which is braced to the beam. The braces extend beyond the beam and from their ends is suspended a rectangular trough which hangs inside the tank. This trough is about one foot deep and is provided with a screen-grating bottom. The tank is filled with water usually from a launder or feed pipe and is provided with an overflow pipe. A plug at the bottom of the tank allows it to be completely emptied.

To operate the hand jig the lever is pulled down so that the trough is brought above the water and held there by fastening the end of the lever to a small post. The trough is then nearly filled with the crushed ore and the lever is released so that the trough comes under the water. By means of the lever the trough is then rapidly raised and lowered under water. By the action of the water through the slotted bottom of the trough, the materials in the trough become arranged in the order of their specific gravities, the lead (galena) at the bottom, sphalerite next, and the chats at the top. After the jig is worked a few minutes, the trough is raised from the water, the chats are shoveled off and the trough refilled with ore. When a good bed of ore has accumulated it is shoveled out and placed in a storage bin. A lever is placed on top of the tank on the side oposite the trough. This lever has a long hook which may be hooked into an eye hole on the trough. Then when the lever is drawn back and locked the trough is pulled to the middle of the tank so that the ore which has fallen through the screen may be shoveled up from the bottom of the tank. The lever which gives the up and down motion to the trough, is worked by hand, or may

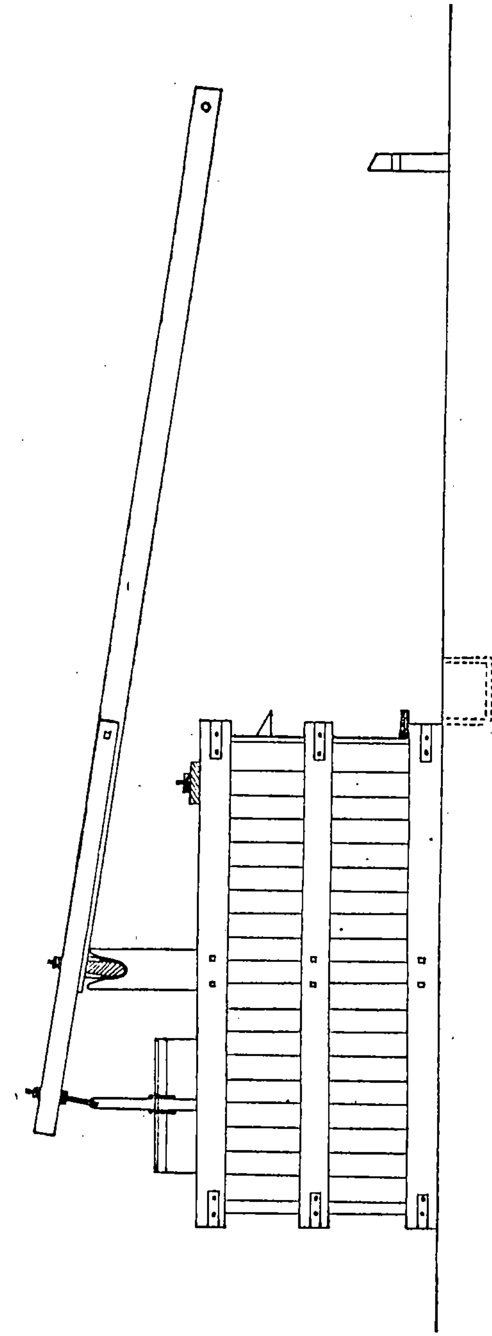


Fig. 3. Side view of hand jig.

be operated by a crank shaft from the engine when one is used for hoisting or for crushing the ore. It will be seen that the same principle of separation is used in the power and in the hand jig but that in the power jig the screen is stationary and the water is given a pulsating movement by a plunger, while in the hand jig the water is stationary and the pulsation is produced by rapidly lowering and raising the screen through the water. When properly worked the hand jig is a very efficient instrument and a surprisingly large amount of ore can be handled by it.

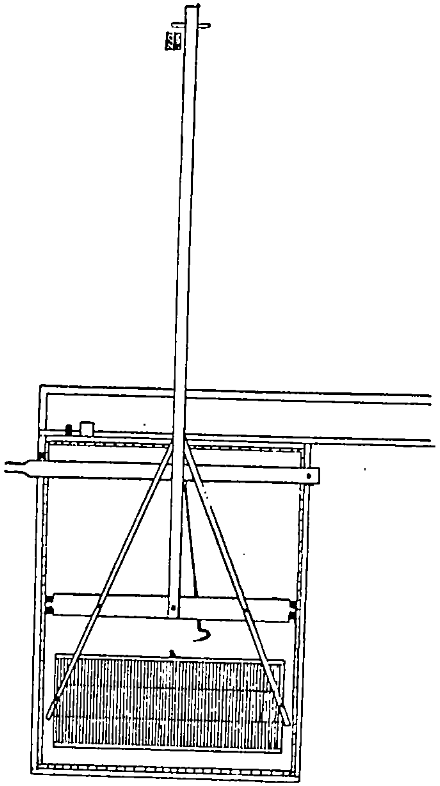


Fig. 4. Plan of hand jig.

Electrostatic and Flotation Methods of Concentration.

The great difficulty in the working of zinc ores is the great loss which results from the methods in use both in concentration and in smelting. The average recovery in the Joplin district is not over 60 to 65 per cent of the contents of the ore, and the zinc concentates contain so many impurities that a zinc content of 60 per cent is considered the standard although pure sphalerite contains 67 per cent of zinc.

These impurities lessen the percentage of zinc which is recovered in smelting, and consequently lower the price of the concentrates. This, as well as the direct penalty imposed on some impurities, such as iron, makes anything which will facilitate producing higher grade concentrates without too greatly increasing the cost of production, of great importance. The low grade of the zinc concentrates in the Joplin region is due principally to the presence of small quantities of sand (crushed chert) and of iron pyrites.

As has been noticed, the specific gravities of sphalerite and pyrite are so nearly the same that a perfect separation cannot be made by any process depending on the difference of specific gravity alone as a principle of separation. The difference in the specific gravities of the sphalerite and the gangue minerals (chats) except where barite is present is sufficient to effect a complete separation if the minerals are perfectly separated in crushing. This condition, however, is not realized, and is far from existing when the sphalerite is well disseminated through the country rock. A particle of material, even after tolerably fine grinding may contain both chert and sphalerite. Such particles when the sphalerite is in excess usually go into the concentrates, carrying the chert with them and lowering the grade of the concentrates, and when the chert (or other gangue mineral) is in excess they go into the tailings, carrying the sphalerite with them, thus reducing the percentage of recovery.

Fine grinding reduces the ore so that the sphalerite and country rock are divided in the crushed material. However, the very fine ground material requires more time in jigging, increases the amount of ore to run over the tables, and produces more finely divided galena and sphalerite which float off and are lost with the tailings. Other factors also enter into the separation of finely ground ore so that the fine concentrates are often of lower grade than the coarser and very seldom are enough higher in grade to offset the cost of the extra grinding and the extra time required in separation.

The needs of the situation, therefore, are means of concentration which will remove the pyrite and also make a cleaner separation between the sphalerite and the non-metallic substances.

The first part of the problem has been in a measure met by roasting the concentrates to a sufficiently high temperature to render the pyrite magnetic but not high enough to drive off any of the sulphur, and to pass the roasted product on conveyor belts under strong magnets which remove the pyrite. So far, this has not been attempted at the concentrating mills in Oklahoma. Some of the smelters of the Joplin region are equipped with the machinery for making this separation and make a specialty of buying concentrates high in pyrite and removing the pyrite, thus materially raising the grade of the concentrates and increasing the yield of zinc when they are smelted. The separated pyrit is used in the manufacture of sulphuric acid and commands a price of to 4 dollars per ton.

Instead of roasting the concentrates and separating the pyrite b magnetic means, the electro-static separation may be used with un roasted concentrates. This process is briefly described by Siebenthal a follows[15]

ELECTROSTATIC SEPARATION.

"The process of roasting and magnetic separation continues t be used for the separation of pyrite from blende on account of cheap ness, simplicity, and effectiveness of separation; but electrostatic sepa ration has made great advances for such purposes. The principle o electrostatic separation is that materials which are good conductors passing over a surface highly charged with electricity (an electrode) will be rapidly charged with like electricity and will consequently be repelled. Poor conductors, on the contrary, will be slowly affected and will drop nearly perpendicularly from the field. A separation is thus made, which may be made sharper by passing the concentrated material over a surface charged with the opposite electricity, when the charge in the good conducting material is reversed and the material is rapidly repelled, while the poorly conducting material, being charged with opposite electricity, is drawn to the electrode surface. Among the good conductors are nearly all the metallic minerals, and among the poor conductors are zinc blende and zinc carbonate, and nearly all gangue minerals and country rocks. Thus the process is especially adapted to make the difficult blende-pyrite separation."

The solution of the problem of better separation of the sphalerite from the siliceous country rock seems to be in an application of the flotation methods. These methods and their application in Europe and Australia are described by Siebenthal in the paper just quoted and his description is given here:

FLOTATION METHODS.

"The main feature of development in ore dressing during 1908 was the successful employment of flotation methods in practical use. Several of these methods had demonstrated their efficiency in experimental tests and a few in actual practice, but it was not until the latter part of 1907 that they were accounted completely successful and only in 1908 that they were widely employed. They have received their chief application in Australia and Europe, but have had several experimental tests and a few practical trials in the United States.

15. Siebenthal, C. E., Mineral Resources of the United States, for 1908, Pt. I, U. S. Geol. Survey, 1909 p. 256.

"Although the physics of ore flotation is as yet somewhat obscure, it is generally conceded that the principles concerned deal with the mechanics of the free surface of a liquid in contact with solids, and include adhesion, surface tension, and superficial viscosity, the latter more particularly in the case of the McQuisten process, to be described later. The liquid in question is water, and the free surface exists at the periphery of the bubbles of air or of carbonic acid gas, as well as at the upper surface of the liquid. In both cases the surface film of water resists rupture by different minerals with different degrees of strength, varying inversely with the adhesion of water to these different minerals. The greater the adhesion of water to the mineral the more easily it is wetted; the less the adhesion of water to the mineral the more it resists wetting. This property of resistance to wetting is the primary factor in ore flotation. Thus, the surface film of water resists rupture by the sulphides (or the sulphides resist wetting)most strongly, by the ordinary gangue minerals less strongly, and by quartz scarcely at all. It is found that these differences are emphasized if the material to be treated is mixed with oil, the adhesion of which to sulphides and gangue material is the reverse of that shown by water. Moreover, oil being lighter than water, is itself an active agent of flotation. Oil also assists in flotation by serving to agglomerate the sulphide particles.

"If carbonic acid gas be generated from the gangue minerals by the addition of sulphuric acid to the tank in which the ore is being treated, the small rising bubbles selectively attach themselves to the particles of metallic sulphide introduced at the bottom of the tank and float them to the surface, where they are drawn off as an oily metallic scum, the gangue settling to the bottom. The selective attachment of the gas bubbles, upon which the success of the flotation and concentration depends, is a measure of the degree of adherence of the gas bubble to the different sulphides and gangue minerals; and that in turn is an inverse measure of the adhesion of water for the same particles. The particle of sulphide for which water has least adhesion—that is, which resists wetting most strongly or with which water has the largest angle of capillarity—will on coming in contact with the gas bubble be forced farther into the bubble, with resulting greater adherence to it.

"Among the means used to accelerate the process and effect a more perfect separation are deepening the tanks, heating the liquid, and partially exhausting the air above the liquid in the tank.

"The forces employed in ore flotation are most delicately balanced Consequently in any given case the process to be worked will require adjustment to the character of the ore by careful experimentation. This undoubtedly accounts for the local failure of flotation processes elsewhere successful. The zincy tailings so well treated in Australia seem especially adapted to flotation. Experiments indicate that this success is largely due to the proportion of gangue to sulphide and to the presence of manganese and iron carbonates in the gangue. Experimentally the clean zinc concentrates refused to float. Upon the addition of the requisite amount of inert gangue the flotation was successful. But on the addition of an excess of inert gangue all sulphides, including the zinc sulphide, sank. As to the presence of an air film enveloping the sulphide particle and the part this film plays in the flotation there is difference in opinion. The papers of Messrs. Swinburne and Rudorf[a] and of Professor Huntington more over[b] while rather sharply opposed as to interpretation of the general facts of ore flotation, offer about the only available experimental data. These papers and their discussion comprise a general exposition of the subject from several points of view. As has been shown in the foregoing notes, the field of flotation concentration is limited to the separation of the minerals which resist wetting (generally the metallic sulphides) from the easily wetted minerals and gangue. Where two or more minerals are floated, a further separation must be made, magnetic or table, as the case may necessitate.

FLOTATION IN AUSTRALIA.

"In the Broken Hill district of Australia there are large accumulations of zinciferous tailings, the result of years of exploitation of the zinciferous silver-lead ores. By various authorities these heaps of tailings are estimated to amount to about 6,000,000 or 7,000,000 long tons, and to contain about 1,200,000 long tons of zinc, 350,000 long tons of lead, and 40,000,000 ounces of silver. Several of the companies mining these ores have developed flotation processes, more or less similar and all employing the buoyancy of air or carbonic acid gas bubbles. The oxidized and weathered tailings are somewhat harder to handle than the fresh tailings, but the addition of sulphuric acid to the solution cleans off the oxidized film and renders the sulphide particles subject to the forces of flotation.

"The importance of Australian competition in the production of zinc ore justifies a brief description of the principal flotation methods in use in that country. According to a table published in the London Mining Journal, the recovery of zinc concentrates from zincy tailings, both new and old, in the Broken Hill district in 1908 was as follows:

a Swindlburne, J., and Rudolf. The physics of ore flotation: Trans. Faraday Soc., vol. 1, pt. 4, pp. 336-344.

b Huntington, A. H., The concentration of metalliferous sulphides by flotation: Trans. Faraday Soc., vol. 1, pt. 4, pp. 346-355.

Production of zinc concentrates at Broken Hill, New South Wales, in 1908, by companies and processes.

Company.	Process	Tailings. Long tons.	Concentrates. Long tons.
Sulphide Corporation	Ballot	182,340	98,000
Broken Hill Proprietary	Potter	276,703	64,373
Zinc Corporation	Elmore	131,965	45,707
Minerals Separation Co.	Ballot	....	32,197
De Bavay's Treatment Co.	De Bavay	74,187	22,590

"The Broken Hill Proprietary Company (Limited), with a dump pile of 3,000,000 tons of tailings, first used the Delprat process, employing a dilute solution of salt and sulphuric acid as the agent of flotation. Litigation between this process and the Potter dilute sulphuric acid process, resulted in a compromise by which the Proprietary Company obtained the right to use the Potter process, and the owners of the Potter process were granted the use of the Delprat patents elsewhere in Australia. The plant operated by the Proprietary Company, now using the Potter process, has an annual capacity of over 50,000 tons of 42 per cent zinc concentrates.

"The Sulphide Corporation (Limited), operating the Central mine, has a tailings stack of over 1,000,000 tons. The tailings are worked by the Minerals Separation Company operating the Sulman-Picard-Ballot process, in which the tailings are mixed with a small quantity of oil or oleic acid and some mineral acid and then violently agitated with the water in the flotation tank, the sulphide concentrates rising in a froth. Two plants are in operation, one upon the weathered tailings, the other upon the current product of the mine. The total daily capacity is about 1,200 tons of tailings.

"The zincy tailings from the Broken Hill North mine are handled by the DeBavay process. In this process the tailings, in the form of a thin paste, are gasified with carbonic acid gas and fed upon inclined tables which discharge into a trough where the sulphides float off and are carried to the bin for concentrates. The carbonic acid gas used may be ordinary flue gas. This process is slower, more complicated, more delicate, and apparently more expensive than the other processes, but is claimed to effect an almost perfect saving of the zinc. The De Bavay's Treatment Company has also acquired 370,000 tons of tailings from the Broken Hill Proprietary Block 10 Company and the current tailings output of the Broken Hill South Silver Mining Company.

"The Zinc Corporation (Limited) was formed to acquire the stocks of old zinc tailings. Among the tailings purchased were those of the Broken Hill Proprietary Block 10 Company, Broken Hill South Silver Mining Company, British Broken Hill Proprietary Company, and Broken Hill Proprietary Block 14 Company, amounting in all to over

2,000,000 long tons. These, with the current output of various mines already contracted for, are estimated to be sufficient to supply the present plant eleven years. The method used in the Elmore vacuum process, employing oil and dilute sulphuric acid, the flotation being assisted by a partial vacuum. The plant has a capacity of 806 tons of tailings per twenty-four hours. The tailings assay 20 per cent zinc, 5.75 per cent lead, and 8 ounces of silver to the long ton. The concentrates from the vacuum separation are treated on 20 Wilfley tables, which make 2 products, assaying as follows: (a) Zinc, 46.5 per cent; lead, 7.25 per cent; and silver, 16 ounces to the long ton; (b) lead, 58 per cent; zinc, 15 per cent; and silver, 39 ounces to the long ton.

FLOTATION IN EUROPE.

"The Elmore vacuum process has been installed in a considerable number of European mines, chiefly to separate copper sulphides from various gangue minerals, but in some instances to recover zinc blende.

FLOTATION IN THE UNITED STATES.

"Several systems of flotation have been developed in the United States and the Elmore and McQuisten processes have been tried at a number of places in the United States, as shown below.

"The 'Criley and Everson oil process' was tried at Baker City, Oreg., in 1890, to separate sulphide ores from their gangue.[a] The crushed ore was mixed with black, thick oil and added to water slightly acidulated with sulphuric acid and heated to near the boiling point. The sulphides rose to the surface in a thick scum, leaving clean quartz gangue behind. No details of further commercial utilization of the method are available.

"The Sanders flotation process was first tried in western Kentucky to make the difficult separation of zinc blende from fluorspar. The crude ore, containing lead, zinc, and fluorspar, is crushed and screened through a 20-mesh screen, after which it is passed to concentrating tables of the Wilfley type, which make three products—lead concentrates, zinc-fluorspar middlings, and fluorspar tailings. The middlings go to the flotation tanks, where they are gently agitated in a bath of neutral or basic aluminum sulphate (alum) at a temperature of 85° to 90°C. Small bubbles of gas, said to be H_2S, buoy the sulphides to the surface and float them off into the settling tank. The recovery of the zinc contents of the middlings is claimed to be from 80 to 90 per cent, and the cost of the flotation treatment is put at 34 cents per ton—both estimates as determined in a test upon western Kentucky fluorspar-lead-zinc ore at the plant in Marion, Ky. An equipment consisting of 2 flotation tanks, each of 100 tons capacity, employing the Sanders

a. Eng. and Min. Jour., vol. 50, Nov. 15, 1890, p. 581.

process, was installed in 1908 in the concentrating plant of the Tri-Bullion Smelting and Development Company at Kelly, N. Mex., to separate blende and pyrites.

"The original McQuisten process is a water flotation method pure and simple, but a later patent provides for the supplementary treatment of the tailings with oil. No acid or gas enters into the flotation. The machinery consists of a tube, 1 foot in diameter and 4 to 6 feet in length, which is slowly revolved with the horizontal axis slightly lower at the discharge end. The finely ground pulp is fed in at the upper end of the tube, the inside of which shows a closely coiled spiral groove. As the thin pulp discharges into the tube some of the sulphide particles are caught and held on the surface of the water by the surface tension and superficial viscosity of the water.

"The more easily wetted gangue minerals and the sulphides which do not float sink to the bottom of the tube; caught in the spiral grooves, the sunken material by the revolution of the tube is lifted above the surface of the water again, when another portion of the sulphides is floated. By the repetition of this action the surface of the water near the discharge end of the tube becomes covered with a dusty coat of the sulphide, which floats off into the discharge tank and is conveyed to the concentrate bins. The tailings from the tube are sent to other tubes, until there is no longer any flotation of sulphides. In a compact form of installation the tubes are arranged in series of two or three each, one above the other. For the successful operation of the process, the pulp must be deslimed before treatment, as otherwise the very fine slowly settling particles of gangue may be floated off with the ore. A plant of 125 tons capacity, employing 100 tubes arranged in sets of four each, as installed at the Adelaide mine, Golconda, Nev., is described[a] as making a successful separation of chalcopyrite with minor quantities of other sulphides from a dense quartzose gangue with spinel and garnet. Experimental tests have also been made upon the copper ore from Ely, Nev., upon copper ore from the Newhouse mine in Utah, and upon the zinc ore at Rico, Colo., the results of which are not available.

"The Elmore vacuum process has been tried experimentally upon various lead-zinc ores in the works of the Empire Zinc Company, at Canon City, Colo., and in the Layton mill, at Salt Lake City, Utah. So far, however, the tests have been successful on but few ores. Tests of zinc ores containing siderite from the Ruth and the Blue Bell mines of British Columbia[b], gave good results with simple acid flotation. Ores from similar mines which did not contain siderite gave poor results.

"Experience has shown that the Australian flotation methods can-

a. Eng. and Min. Jour., vol. 84, pp. 765-770.

b. Report of the British Columbia Zinc Commission, 1906, pp. 123-128.

not be applied bodily to the lead and zinc ores of this country, but that the delicate balance of the flotation forces must be adjusted to individual ores. Future experimentation will, no doubt, find here a profitable field for such methods."

So far as is known to the writer these methods have not been tried on the ores of the Joplin field and it is doubtful whether they could be made profitable under present conditions. If the price of concentrates should advance materially or if the ore reserve should become depleted, some improved method of separation and concentration will become, not only practicable, but advisable and at present it seems that some form of flotation will be the scheme most likely to be adopted.

METHODS OF SELLING CONCENTRATES.

The concentrates from the mills in the Oklahoma mining camps are sold to buyers from the smelters. Three different plans of determining the price of the zinc concentrates as follows:

(1) A certain price (base price) is allowed for concentrates carrying 60 per cent zinc. Each per cent of excess or of deficiency from 60 per cent adds or subtracts $1.00 per ton. One per cent of iron is usually allowed, and each additional per cent of iron penalizes the ore $1.00 per ton. Each per cent of bitumen gives the same penalty. The moisture is always determined and the percentages of metal determined in the moisture free concentrate.

Example: After the moisture is deducted a carload of concentrates is found to carry 53 per cent of zinc, and 3 per cent of iron. The base price is $40.00 per ton.

60 per cent — 53 per cent = 7 per cent deficiency.
7 per cent deficiency = $7.00 penalty.
3 per cent of iron = 2 per cent more than allowed or $2.00 penalty.
$7.00 + $2.00 = $9.00 penalty.
$40.00 — $9.00 = $31.00 price paid for ton of concentrates.

(2) A smelter will contract to take the output of a mine and pay the market price for spelter for 86 per cent of the zinc content. A fixed charge per ton which varies with the nature of the concentrates is deducted from amount per ton as determined by the spelter price.

Example: When spelter is worth 6 cents per pound, ore carrying 54 per cent zinc is worth (86 per cent of 54 per cent of 2000 lbs.) × .06) — $18.
.86 × .54 × 2000 × $.06 = $55.63.
$55.63 — $18. = $37.63 per ton.

(3) The base price 60 per cent concentrates is fixed at $37.50

when the market price of spelter is $.05 per lb. Fluctuation in the price of spelter is allowed for by a change of $8.50 per ton of concentrates for each cent of change in price of spelter per pound. Deduction for zinc content under 60 per cent and penalties for iron and bitumen are assessed in the same way as under the first plans of selling except that 2 per cent of iron is allowed.

Example: Dry concentrates carry 54 per cent of zinc and 3 per cent of iron. The market price of spelter is 6 cents per lb.

Base price of 60 per cent. concentrates when spelter is 5 cents per lb. = $37.50.

Price for 54 per cent concentrates = $31.50. Deduction of $1.00 for iron in excess of 2 per cent leaves $30.50.

Price of spelter is 1 cent in advance of the standard price of 5 cents, hence $8.50 must be added to $20.50, giving $39.00 per ton of concentrates.

The examples given above cannot be compared with each other in ascertaining the relative prices determined by the three methods. The second and third methods are by contract and the known nature of the ore; shipping conditions and other factors may enter into the determination of the fixed amount deducted in the second method, and the establishing of the base price and the ratio of fluctuation in the third method.

In any case the concentrates are sampled in the presence of the buyer and seller or their agents; the sample divided into three portions one of which is assayed by the buyer, one by the seller, and the third reserved to be assayed by an umpire should there be serious discrepancy between the other two assays.

The lead concentrates are usually much purer than the zinc concentrates and are sold at a flat rate per ton, the price depending upon the market price of pig lead.

USES OF LEAD.

Lead is used in many ways both in the metallic state and in compounds. In the metallic form lead is used principally for pipes in plumbing and for surrounding electric wire cables. Sheet lead is used in large quantities for lining sulphuric acid chambers and tank cars for the shipment of the acid. Thin sheet lead, known as tin foil, is used for lining boxes or containers used in packing substances which must be kept from the atmosphere, such as tea and tobacco. Considerable quantities of the metal are used in the manufacture of shot and bullets.

Lead forms an important constituent of several easily fusible alloys, such as type metal, babbitt metal and white metal.

The principal use of lead compounds is as pigments for paint, and about one-half of the lead produced is used for this purpose. White lead is the principal lead pigment and is used to a greater extent than all the others together. Red lead, chrome yellow, orange chrome, and Turners yellow are other lead pigments which have an extensive application.

Lead is used in small proportions in the making of several grades of glass, and some of its compounds, particularly the acetate, sugar of of lead, are used in medicine.

The amounts of lead used for the different uses mentioned above for the year 1907, 1908 and 1909 are shown in the following tables:[17]

Use of Lead in the United States, 1907-1909.

PRODUCTS	1907		1908		1909	
	Quantity	Per cent.	Quantity	Per cent.	Quantity	Per cent.
	short tons		short tons		short tons	
White lead and oxide	115,000	28.8	117,500	40.5	134,138	38.0
Pipe	41,000	12.4	33,800	11.6	52,914	15.2
Sheets	21,500	6.5	16,400	5.7	23,421	6,7
Shot	28,000	8.5	31,600	10.9	36,433	10.4
Other purposes	125,238	37.8	90,700	31.3	104,094	29.7
Total	330,738	100.0	290,000	100.0	351,000	100.0

USES OF ZINC.

The principal use of zinc is in galvanizing sheet iron and wire. By dipping iron into molten zinc, the surface of the iron is covered with film of zinc. When exposed to the weather this becomes covered with a coating of the oxide of zinc which remains on the surface and acts as a protective coating, preventing the further decay of the metal. Sheet zinc is used to some extent for roofing and for stove boards and similar uses. Zinc dust is used in large quantities in dyeing, fire works, manufacture of hydrogen, and as a means of precipitating gold and silver in the cyanide process of extraction of those metals.

Zinc oxide, zinc-lead oxide and lithophone are pigments which are extensively used and which consume large quantities of zinc. They are usually made directly from the ores. Zinc chloride is coming into use as a preservative for wood, especially for railroad ties and for mine timbering. Zinc sulphate and some other compounds are used in medicine.

17. Mineral Resources of the U. S. for 1910, part I, p. 252, from figures in the Engineering and Mining Journal.

CHAPTER II.

THE NORTHEASTERN OKLAHOMA FIELD

INTRODUCTION.

The Northeastern Oklahoma lead and zinc field is the southwestward continuation of the Joplin district and the general conditions of ore occurrence and of mining are the same as for that area. In view of this fact the general features of the stratigraphy, structure, nature of ores and rocks, shape of ore bodies, and the genesis of the ores are considered in reference to the whole Joplin district. These general considerations are then applied to each of the three mining camps in Oklahoma and the mining development of each camp discussed in some detail.

PHYSIOGRAPHY.

The Northeastern Oklahoma lead and zinc field lies on the extreme southwestern flank of the Ozark Mountains. The surface slopes to the southwest, from a maximum elevation of 1050 feet along the Kansas and Missouri State lines to an elevation of 750 feet at the junction of Spring and Neosho rivers. The region to the east of Spring River (except Jackson Prairie) is hilly, but to the west it grades rapidly into a level prairie underlaid by Cherokee shales.

The drainage is through Spring and Neosho rivers which unite near Wyandotte in the southwestern part of T. 27 N., R. 24 E. to form Grand River.[16] Spring River enters the state from Kansas in sec. 16, T. 29 N., R. 24 E., and flows in a winding course in a general southerly direction to its confluence with Neosho River. For the greater portion of its course it flows on the Boone chert. Owing to the westerly dip of the rocks all the principal tributaries come in from the east. Five Mile Creek, Warren Branch, Flint Branch, and Shawnee Branch rise near or a few miles to the east of the Oklahoma-Missouri State line and flow to the south of west into Spring River.

16. According to a ruling of the United States Board of Geographic Names, the name Neosho is applied to this stream to its confluence with the Arkansas. This ruling, however, conflicts with long established usage and in this report the stream below the confluence of Neosho and Spring River will be called Grand River. In the quotations from the United States Geological Survey, the name Neosho applies to the entire stream.

Neosho River rises in Kansas, crosses the State line in sec. 15, T. 29 N., R. 21 E., and flows southeast in a winding course to its confluence with Spring River. The tributaries from the north flow almost straight south while those on the opposite side of the river have a generally eastward course. Elm Creek, Tar Creek, and Little Elm Creek are the principal tributaries which flow south through the productive lead and zinc areas.

GENERAL GEOLOGY OF THE OZARK UPLIFT.

The Ozark Uplift includes almost all of that part of Missouri lying south of Missouri River, northern Arkansas, the southeastern corner of Kansas, and the portion of Oklahoma lying east of Grand River and north of Arkansas River. The core of the uplift is the St. Francois Mountains, a mass of granite and rhyolite in southeastern Missouri. Lying unconformably on the granite is a great thickness of Cambro-Ordovician limestones and dolomites. The lead of southeastern Missouri and most of the lead and zinc of northern Arkansas are found at this horizon. The Cambro-Ordovician rocks extend into Oklahoma, but the dip is in general to the southwest and these rocks soon pass under younger formations. The surface rocks of most of this area belong to the Mississippian system. The nature of the section of rocks and the formation names vary in different parts of the uplift. In this connection only those rocks outcropping in Oklahoma are considered. The succession of rocks is shown in the generalized geologic section (fig. 5).

Stratigraphy.

Ordovician rocks. The oldest formation exposed in northeastern Oklahoma is the *Burgen sandstone,* a white fine-grained, saccharroidal sandstone which is exposed in the valley of Illinois River in the Tahlequah and Siloam Springs quadrangles. In the Tahlequah quadrangle Taff[17] gives it a thickness of 5 to upwards of 100 feet with the base not exposed. The outcrop widens somewhat to the north in the Siloam Springs quadrangle although only the upper portion of the formation is exposed. At Spavinaw in Spavinaw Creek in the extreme northeastern part of Pryor Creek quadrangle, there is an exposure of white, siliceous, dolomitic rock, which in its sandier portions greatly resembles the Burgen sandstone and which occupies the same stratigraphic position. The Burgen is correlated with the Saccharroidal sandstone, of the Arkansas Geological Survey, which lies immediately above the Yellville limestone. Taff reports the Burgen as nonfossiliferous but the writer has observed a few very poorly preserved *Orthoceras* on the surface of blocks near the Tahlequah-Siloam Springs quadrangle line near Illinois River.

17. Taff, J. A., Tahlequah folio (No. 122), Geol. Atlas U. S, U. S. Geol. Survey, 1906, p. 2.

Above the Burgen sandstone is a series of greenish shales with some brown sandstone and some limestone known as the Tyner formation. Along Illinois River northeast of Tahlequah the top of the formation is

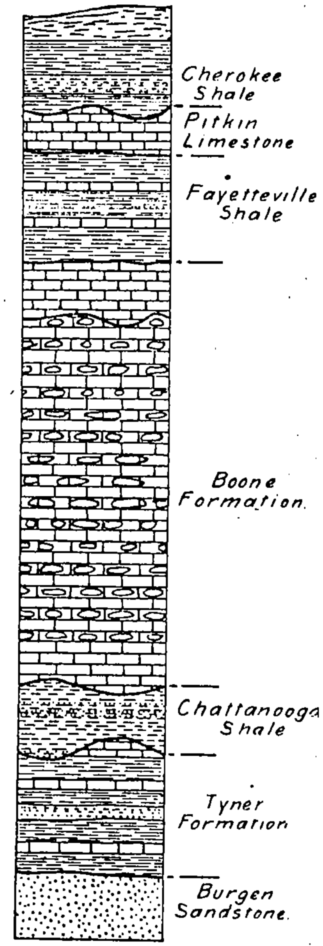


Fig. 5. Generalized geologic section for Northeastern Oklahoma.

a limestone of variable thickness (a few inches to 20 feet) containing fossils of Black River age. Along Barren Fork River only the top of the formation is exposed and it consists of thin shales and sandstones containing fossils of Lorraine age. This horizon is therefore believed to be above that of the limestone at the top of the formation along

Illinois River. Since the entire Silurian is unrepresented in this locality, the upper beds were probably removed by erosion during Silurian times, before the deposition of the Devonian black shale which succeeds it. At Spavinaw a single exposure of a green shale was noted below the black shale and a "copper-stained shale" is reported from the same horizon by the driller of a deep well near Vinita. This would indicate that the Tyner formation is persistent to the northeast under the younger rocks.

Silurian rocks. The St. Clair marble of Silurian age outcrops in the southeastern part of the Tahlequah quadrangle where it is brought to the surface by faulting. Silurian rocks are not represented in the northern part of the Tahlequah nor in the Siloam Springs, Pryor Creek, or Wyandotte quadrangles.

Devonian rocks. The Devonian system is represented by the Chattanooga shale which outcrops in stream valleys south of Cowskin River. This is a black, bituminous, slaty shale of very uniform texture and composition and of great areal extent, the black shales at this same horizon in Arkansas, Tennessee, Kentucky, Indiana, and Ohio being continuous and so uniform in character as to be indistinguishable. Since it is limited both above and below by unconformities the thickness is very irregular. Siebenthal[18] gives the thickness in different localities as follows:

"* * * In the east bluff of Neosho [Grand] River, 3 miles above the mouth of Cowskin River, the thickness is 26 feet; on Buffalo Creek it is 20 feet, at Southwest City 50 feet, at the mouth of Honey Creek 83 feet, and at Spavinaw 90 feet. On Spring Creek 25 feet, not the full thickness, was noted." Taff reports the thickness in the northern part of the Tahlequah quadrangle as 40 feet, and in the southern part as 20 feet.

In the bluff of Illinois River near the southern line of the Siloam Springs quadrangle the thickness is 60 feet and at the confluence of Flint Creek with Illinois River it is between 30 and 40 feet disregarding the Sylamore member. The Chattanooga is also reported in deep wells at Grove and at Vinita. The Sylamore sandstone member lies at the base of the Chattanooga shale. It is exposed in Arkansas and in the southeastern part of the Tahlequah quadrangle but is absent or very thin in the northwest part of the Tahlequah and southwest part of the Siloam Springs quadrangle and in the Spavinaw region. Along Flint Creek in the central part of the Siloam Springs quadrangle it is 15 to 20 feet thick.

Mississippian rocks. The rocks of Mississippian age include the Boone chert, the Fayetteville shale with its Wedington sandstone member, the Batesville formation and the Pitkin limestone. The Boone chert is of Burlington-Keokuk age and the other formations are correlated with the Chester group.

18. Siebenthal, C. E., Bull. U. S. Geol. Survey, No. 340, 1907, p. 189.

The Boone chert is the thickest formation of the region and outcrops over a far greater area than all the other formations combined. In Oklahoma its outcrop includes practically all of Delaware and Adair counties, the southern half of Ottawa County, the southeastern corner of Craig County, the eastern half of Mayes County, and all except the southwestern one-fourth of Cherokee County. It also occupies a large area in northeastern Arkansas and practically all of the Joplin district in southwestern Missouri and southeastern Kansas.

The nature of the formation varies considerably in different parts of its outcrop. In the southern part of its outcrop in Oklahoma, in the Tahlequah quadrangle (Adair and eastern Cherokee counties) Taff[19] describes it as follows:

"The rocks of the Boone formation consist of interestratified chert and cherty limestone. At the base there are in places thin limestones free from chert, while at other localities the chert rests on the Chattanooga shale without intervening limestone beds. The limestone beds at the bottom, being distinct in lithologic character from the body of the formation and variable in thickness, are properly characterized as a member of the formation.

"The base of the Boone formation is exposed in twelve localities, and in four of these limestone was found beneath the chert. Of the known occurrences of limestone beneath the chert two were found bordering the small areas of the Chattanooga shale in Barren Fork Valley south of Westville. In the smaller area in the west side of sec. 34, T. 17 N., R. 26 E., the limestone is about 5 feet thick. At the other locality, 3 miles down the stream, it is 10 to 15 feet thick. At these places it consists of fine-textured and dense, white to pinkish, even-bedded limestone. Light-colored crinoidal limestone beds 10 to 15 feet thick occur at the base of the Boone formation in the south bank of Barren Fork at the road crossing in the NW.¼ sec. 13, T. 17 N., R. 23 E. No fossils were collected from this limestone at the three localities named, but its position in the formation and its lithologic character strongly indicate that it should be correlated with the basal St. Joe member of the Boone formation exposed in the northern part of the Fayetteville quadrangle and farther east in northern Arkansas.

"A fourth locality of the basal limestone member of the Boone formation is in a small valley leading into Illinois River in sec. 36, T. 18 N., R. 22 E., very near the north border of the quadrangle. Here the beds consist of dull blue and earthy fossiliferous limestone in the lower part,

19. Taff, J. A., Tahlequah folio (No. 122), U. S. Geol. Survey, 1905, p. 2.

followed above by thicker and harder limestone beds, the thickness of the whole being 6 feet. These beds belong stratigraphically below the lighter-colored crinoidal limestones, both being locally developed. They contain the following fossils, together with a number of undetermined and mostly undescribed species, all indicating Kinderhook age:

Leptaena rhomboidalis Wilckens.
Productella concentrica Hall.
Spirifer cf. peculiaris Shumard.

"The lighter-colored, often pink, and generally crystalline crinoidal limestone, together with the lower part of the cherty limestone, overlying it, contains a Burlington fauna. The common fossils in this division include the following species:

Schizoblastus sayi Shumard.
Platycrinus and fragments of other crinoids.
Spirifer grimesi Hall.
Syringothyris sp.
Productus cf. semireticulatus.

"The middle member constitutes almost the whole of the Boone formation as exposed in this quadrangle, and is made up essentially of calcareous chert or flint with variable bands or beds of limestone.

"Fresh exposures occur in but few places and these are in steep bluffs and cliffs where the larger streams meander against the sides of their valleys, or more rarely in the beds of the smaller streams in their middle or lower courses where the grades are sufficiently steep and the volume of water great enough to induce active erosion. The chert element predominates so greatly over the limestone in abundance, and is so resistant to the effects of erosion, that almost the entire surface rock consists of angular chert bowlders and fragments.

"The cherts in the upper part of the formation are locally very fossiliferous. The following list includes the species most commonly found, and their association is decidedly indicative of Keokuk age:

Amplexus fragilis White and St. John.
Glyptopora keyserlingi Prout.
Fenestella multispinosa Ulrich.
Polypora maccoyana Ulrich.
Hemitrypa proutana Ulrich.
Pinnatopora striata Ulrich.
Spirifer logani Hall.
Reticularia pseudolineata Hall.
Productus setigerus Hall.
Orthotetes keokuk Hall.
Capulus equilaterus Hall.

"The limestone overlying the chert was believed to be a part of the

Boone formation at the time the Tahlequah quadrangle was surveyed and is included with it in the mapping. Later studies of this limestone made in connection with the survey of the Muskogee and Winslow quadrangles, west and east of the Tahlequah, have shown that locally, at least, a thin bed of black shale occurs between this limestone and the Boone chert. An abundant fauna, also, which has been collected from it, shows that it is higher geologically than the Boone and should be classed with the Fayetteville formation.

"The thickness of the Boone formation is variable. It ranges from a minimum of 100 feet to a maximum approximating 300 feet. Except in a few localities the top and base are separated in outcrop by several miles, and the rocks are so concealed by surface chert debris that the determination of thickness are at best only approximate."

In the Siloam Springs quadrangle, (northern Adair, northeastern Cherokee, and southern Delaware counties) the base of the formation is exposed for a considerable distance along Illinois River, especially along the west side (fig. 2). Good exposures of the base are also had along Flint Creek and along Spavinaw Creek from its confluence with Cloud Creek to below Spavinaw post office in northeastern Mayes County. In this region the lowest portion is of limestone which rests on the uneven surface of the Chattanooga shale. Immediately above the shale on Illinois is a variable thickness of shaly thin-bedded bluish and greenish fossiliferous limestone. The thickness of this horizon varies widely within short distances. In Eagle Bluff on the west bank of Illinois River in northern Cherokee County, (southwestern part of the Siloam Springs quadrangle) the bed thickens from 15 feet to 60 feet and thins again to 12 feet in a distance of less than one-half mile. Some fossils from this horizon indicate that these beds are the equivalent of the Fern Glen formation at the top of the Kinderhook. This fossiliferous limestone is absent at Spavinaw or is represented by about 6 inches of greenish shale. Above the basal shaly limestone bed is a hard, pinkish, crinoidal limestone from 6 to 12 feet in thickness. This limestone is a good horizon marker as it is often exposed and breaks off into large blocks.

Above the crinoidal limestone is a succession of limestones and cherts, usually in layers 6 to 10 inches thick, which continues nearly to the top of the formation.

Thicker limestones occur at the top of the formation which are well exposed near Grove in northern Delaware County where one of them has been used for burning into lime.

In the Joplin district of Missouri and Kansas, the Chattanooga shale seems to be absent and the Boone rests upon the non-persistent Hannibal shale.[20] Two members are recognized, the Short Creek

20. Siebenthal, C. E., Joplin District folio (No. 148), Geol. Atlas U. S., U. S. Geol. Survey, 1907.

oolite member 8 feet thick which lies about 100 feet below the top of the formation and the Grand Falls chert, 35 to 55 feet thick which occurs 100 feet below the Short Creek oolite. This chert represents the lowest horizon of commercial lead and zinc deposits in southwest Missouri.

In the paper on the Mineral Resources of Northeastern Oklahoma,[21] Siebenthal gives the following description of the Boone:

"The Boone formation is made up of an alternating series of limestones and cherts, approximately 300 to 350 feet in thickness where fully developed. It forms the surface rock over by far the largest part of the area of Mississippian rocks. At the base of the formation there is always present a limestone member, consisting at the top of a heavy ledge of coarsely crystalline encrinital limestone, or marble, which is usually 10 to 15 feet in thickness. This bed is separated by several feet of shaly limestone from a lower ledge of flaggy limestone, locally rather cherty and in many places irregularly bedded, which lies upon the Chattanooga shale. The upper ledge usually outcrops as a smooth, wall-like bluff, from which large blocks, the full thickness of the ledge, break away. It has been correlated with the St. Joe limestone member in the Tahlequah and Fayetteville folios. This limestone is normally overlain by a series of dark limestones and cherts from 50 to 80 feet in thickness. Above these, to the top of the formation, are lighter colored cherts and limestones, with one or more massive ledges of limestone 10 to 20 feet in thickness. The Short Creek oolite member, noted in the Joplin district, is found in the east half of the Wyandotte quadrangle wherever its horizon is exposed, though west of Spring and Neosho rivers it usually pinches out or loses its oolite character."

The rocks of Chester age outcrop in a belt of variable width between the Boone outcrop and that of the Pennsylvanian rocks. In the Tahlequah quadrangle (in southern Adair and southeastern Cherokee counties) the rocks consist of the Fayetteville shale with the Wedington sandstone member near the top, and the Pitkin limestone. The Wedington sandstone member is about 20 feet thick and caps the hills in the vicinity of Westville. To the west the Wedington thins out and is not represented in the Muskogee quadrangle (in western Cherokee, northeastern Muskogee, and southeastern Wagoner counties). In this vicinity there are local limestone lenses and thin limestone near the top and the bottom of the formation which are continuous over considerable areas.

In the Wyandotte quadrangle (western Ottawa County) Siebenthal[22] gives the Batesville, Fayetteville (with its Wedington member) and Pitkin formations as members of the Chester group. The Batesville sandstone in Arkansas lies between the Boone and the Fayetteville but thins

21. Bull., U. S. Geol. Survey, No. 340, 1907, p. 190.
22. Op. Cit.

rapidly to the west and does not appear in the Tahlequah or Muskogee quadrangles. In the Joplin folio Siebenthal gives the Carterville formation as occupying the horizon of the Chester group in the Joplin district so the formation which he calls Batesville in the Wyandotte quadrangle is evidently not continuous with the Batesville in Arkansas. The same thing applies to the Wedington sandstone member of the Fayetteville shale for as has been noticed in the preceding paragraph it does not appear in the Muskogee quadrangle and the whole Batesville-Fayetteville interval is represented by the Carterville formation in southwestern Missouri.

In the portion of the Pryor quadrangle east of Grand River (eastern Mayes and northwestern Cherokee counties) is a considerable thickness of limestone which occurs immediately above the Boone formation. This is probably the limestone which was included in the base of the Fayetteville by Taff. In the Pryor quadrangle, however, it has sufficient thickness and outcrops over sufficient area to be ranked as a distinct formation. Two limestone horizons occur in the Fayetteville but they are distinct from the one just mentioned.

The Pitkin limestone is described by Taff[23] in the Muscogee folio as follows:

"The Pitkin limestone consists of light-blue to brown, granular, earthy, slightly oolitic strata interbedded with fine-textured massive layers. The granular and oolitic types of rock are the more common and may be said generally to characterize the formation. The thickness of beds is variable, ranging from thin platy strata to beds 1 or 2 feet thick. The thinner strata are usually more argillaceous, and thin shale layers not uncommonly separate them.

"The Pitkin limestone is considered to be the top of the Mississippian series of the Carboniferous. The fossils listed as from the upper limestone of the Fayetteville formation are equally characteristic of the Pitkin.

"In thickness the Pitkin limestone in the Muscogee quadrangle varies but little from 50 feet, such slight changes as probably occur being due to erosion of its upper beds prior to the deposition of the overlying formation. Where the shaly bed is concealed the boundary between the Pitkin and Morrow formations is difficult to determine without a careful study of the fossils in the limestones both above and below the contact. In places shale, and in other localities sandy shale as well, may be found above the Pitkin limestone. This represents the Hale sandstone member of the Morrow formation, which is well developed in the Tahlequah quadrangle and farther east in Arkansas.

22. Muscogee folio (No. 132), Geol. Atlas, U. S., U. S. Geol. Survey, 1905.

Fig. 6. Map of Northeastern Oklahoma showing the Mississippian-Pen nsylvaanian contact.

"The Pitkin limestone crops out generally at the bases of hills and in steep slopes, bluffs, and escarpments of the higher Morrow and Winslow formations, the talus from which frequently conceals the contact. Toward the east, beyond the Tahlequah quadrangle, the Pitkin limestone occurs in isolated areas and crops out along the northern foothills of the Boston Mountains in northwestern Arkansas. Typical exposures occur in the north slopes of the Boston Mountains near Pitkin, on the St. Louis and San Francisco Railroad, from which place the name of the limestone has been taken. The formation was described by Dr. F. W. Simonds (Arkansas Geol. Survey, vol. 4, 1889), by whom it was called the Archimedes limestone. Archimedes, the generic name of one of the characteristic fossils, not being an appropriate designation for a formation, a name of geographic significance has been substituted."

Siebenthal mentions the Pitkin as outcropping in the Wyandotte quadrangle but gives no description of it in the paper previously cited. In the southeastern corner of the Vinita quadrangle Ohern reports a limestone which is much thinner and more argillaceous than the Pitkin, but which is correlated with it on account of its position and the preliminary paleontological studies which have been made. A limestone which has about the stratigraphic position of the Pitkin outcrops near the top of the hills in the vicinity east of Pryor Creek but detailed work in this quadrangle is necessary before the horizons in the north can be definitely correlated with the section as exposed in the Muscogee quadrangle.

Pennsylvanian rocks. In the southern part of the area the Morrow and Winslow formations are exposed. To the north these formations cannot be distinguished. There are three possible causes for their disappearance: (1) they may actually pinch out entirely; (2) they may thin out and merge with the Cherokee (Vinita of Ohern)[24] shales; (3) the strike may continue to the northwest and pass under the Cherokee shales, i. e., the Cherokee shales may be uncomformable by overlap on the older Pennsylvanian sediments. Siebenthal seems to hold to the last conclusion since on page 191 of U. S. G. S. Bulletin No. 340 he says: "The continuation of the sandstone and the shales of the Winslow beneath the overlapping formations would naturally be sought in the line of strike of the present outcrop of these rocks. Because of the probable curvature of the shore line of the uplift, the buried extension of the Winslow should be expected somewhere between Chelsea, Nowata, and Coffeyville, Kansas."

Considerable field work is necessary to settle this question. The important point in connection with this report is that the westward trend of the overlying formations places the beginning of the warping of this portion of the Ozark Uplift near the end of Winslow time.

24. Univ. of Oklahoma Research Bull. No. 4.

Structure.

The entire area under discussion is the southwestward extension of the Ozark Uplift. The dip is usually southwest at low angles. Around the southern portion of the area of Mississippian rocks in Oklahoma the dip is to the south and southeast.

The chief structural features of the region have been described by Siebenthal in the work previously cited and his discussion is given in full. (See fig. 6.)

"As has been remarked in the section on the correlation of the Cherokee formation, the discordance of strike of the Winslow, Savanna, and Boggy with the Fort Scott and overlying formations shows a warping of the west end of the Ozark uplift somewhere in the period between the close of the Winslow deposition and the early part of the Cherokee. The southern portion was elevated, crowding the shore line far to the southwest, while the northern portion was depressed, allowing the sea to advance to the east. The northeast-southwest orientation of the shore line was well established early in Cherokee time, and this relative attitude was maintained through the remainder of the Pennsylvanian, the various formations of this age outcropping in this region in lines parallel to the Fort Scott limestone, with gentle northwesterly dips ranging from 30 feet per mile in the northern portion of the area to 50 feet in the southern portion.

FOLDING AND FAULTING.

"The folds and faults of the area are so closely related that their joint discussion seems preferable.

"The axis of that part of the Ozark uplift included in Oklahoma trends from northeast to southwest, and the margin of the uplift is serrated by an interesting system of parallel normal faults, which Taff has described in the Tahlequah and Muscogee folios. These faults trend parallel to the axis of the uplift, and at either end usually develop into monoclines or asymmetric anticlines and gradually die out. An inspection of the map will show the close relation of the minor drainage to the faults. Northwest of Tahlequah the parallelism of the faults is not so pronounced and the system is somewhat complicated by intersecting cross faults. These faults are of post-Winslow age, but no relation to later formations can be established.

"Extending southward from Locust Grove is a prominent fault with the downthrow to the west, which brings the Chester down to a level 100 to 150 feet lower than the top of the Boone chert hills immediately east.

"The next prominent structural feature toward the north is the Seneca fault, which extends from a point midway between Choteau and

Pryor Creek to a point several miles northeast of Spurgeon, beyond the limits of the area shown on the accompanying map, having an almost due northeast course parallel to the main axis of the uplift and roughly parallel to its northwest margin. This fault is double and in places multiple, letting down a long, narrow block of Boone, Chester, and overlying rocks into the Boone formation. In addition to the down-thrown block, the strata for some distance, in places for a mile or two on either side, dip toward the fault. This combination has had a strong influence on the drainage, as may be seen from the map. From Seneca toward the northeast the fault closely follows the valley of Lost Creek. South of Seneca it crosses the divide to Sycamore Creek and follows down the valley to Neosho River. From the mouth of Sycamore Creek the fault cuts across the various meanders of Neosho River to a point just above the mouth of Spavinaw Creek. Southwest of this point it traverses the flat upland to and beyond Pryor Creek. Near the Neosho, where the rocks on either side are the cherty limestones of the Boone formation, it is easy to trace the down-dropped strip of Chester consisting of limestone and sandstone. Farther to the southwest, where the Chester formations become the prevailing surface rocks, the fault is difficult to follow. In the Pennsylvanian area it is quite impossible to trace the fault, but whether this is due to its absence, to the uniformity of the rocks, or to the concealment of the faulted Winslow by the overlapping Cherokee was not determined. If the last explanation is correct, as is quite likely, the fault is post-Winslow and pre-Cherokee and probably of the same age as the parallel faults of the Tahlequah-Muskogee region and as the warping to which all the faults are with little doubt genetically related. Owing to the fact that the amount of throw is variable within short distances along the fault and to the further fact that the fault line coincides so closely with the drainage lines, the Chester formations are preserved but here and there along the fault.

"The intersections of this fault line with the meanders of Neosho (Grand) River afford many fine cross sections of the faulted area. The width of the down-dropped block ranges from less than 200 feet to more than 1,500 feet. The fault ranges in character from a simple pair of opposed breaks with the down-thrown block between them, and with the strata of the wall rock on either side dipping more or less steeply toward the faulted block, to a sort of faulted syncline, the limbs of which are made up of distributive faults with the cummulative downthrow toward the axis of the syncline. The best view of the latter phase is shown in the west bluff of the Neosho opposite the mouth of Cowskin River, where the south limb dips from 2° to 5° N., the angle increasing toward the axis, and shows four distinct dislocations, one being opposed to the other three, but leaving a resultant throw of 14 feet to the north. On the north side there is a faulted zone 55 feet wide in which there is an up-throw of 18 feet, but this is more than counterbalanced by three small faults and one with a throw of 22 feet to the south, and by the southerly dip of 2° some distance from the fault and of 11° adjacent to the fault.

"The amount of displacement on either side of the block varies from place to place. In the west bluff of Neosho River 2 miles below the mouth of Horse Creek it is more than 90 feet. At the Bedker mines, south of Seneca, it is from 100 feet to 140 feet. Between Seneca and Spurgeon it must be as much as 100 feet in many places, for it serves to bring the Chester formation down to the level of the valley, though the Boone forms the top of the hills on either side.

"The Horse Creek anticline is an asymmetric fold which starts at a point on Cabin Creek, 5 miles southeast of Big Cabin station and trends east northeastward by Cleora to the mouth of Cowskin River, where it intersects the Seneca fault. East of this point it swings a little more eastward to the vicinity of Tiff City, where it trends nearly due east for 10 miles and farther east gradually dies out. The anticline has a gently sloping northern limb and a steeper southern limb. To the south of the anticline and parallel to it is a long, low synclinal trough beyond which the strata rise again to the south, with a gentle incline. The average dip of the northern limb of the anticline is about 2°; the dip of the southern limb ranges from 5° to 18°. West of Neosho River the fold expresses itself topographically in an abrupt fault-like escarpment to the south and a low upland slope to the north. East of the Neosho the anticline is cut through on either side by many short, steep hollows, and forms the greatly dissected highland known as the Seneca Hills. In places, notably where the fold is cut through by Neosho River, the rocks lie nearly flat, but where it is crossed by Buffalo Creek and Horse Creek the dip is about 5° SE. About 2 miles west of Horse Creek Gap the dip is 18° SE. For the most part the dip of the southern limb is concealed by debris washed down from the steep slope, and can be made out only in exceptional places. It is entirely possible that for short distances along the axis west of Horse Creek the anticline may break down into small faults. Though cut across in several places by streams, this fold is nowhere breached parallel to the axis, a fact due doubtless to its monoclinal nature."

The faults and folds in the southwestern margin of the uplift which are mentioned in the first paragraph probably extend for a considerable distance to the east, although it is not possible to trace them across the hills which are covered to a depth of several feet with loose, residual Boone chert. Folds were noticed along the Illinois River in the southern part of the Siloam Springs quadrangle (northeastern Cherokee County) whose axes had approximately the same direction as those around the margin of the Mississippian rocks to the southwest. One fault was observed which brings the portion of the Boone chert above the crinoidal member near the base into contact with the Chattanooga shale. Both the folding and the fault can be distinguished only in the bluffs of the river and it is impossible to see any evidence of them on the timbered Boone chert hills.

The effects of the pre-Cherokee underground solution which are so closely related to the lead and zinc deposits in the whole Joplin district occur only in a small area in the extreme northeast corner of the State. This subject of underground solution and its relation to the lead and zinc ore deposits is considered more fully in connection with the origin of the ores.

Review of the Geological History.

The area of the Ozark uplift was probably a land mass during the greater part of pre-Cambrian and during Lower Cambrain time. The igneous rocks were deeply eroded in these periods as is shown by the extremely uneven floor upon which the Cambrian sediments rest, although the irregularities have probably been emphasized by post-Cambrian disturbances.[25]

During the Middle Cambrian the entire area was submerged and during this epoch and Upper Cambrian (Ozarkian of Ulrich)times a great thickness of sandstones, limestones and dolomites was deposited. In southeastern Missouri the Upper Cambrian or Ozarkian is separated from the basal Ordovician sandstone (St. Peters) by an unconformity but in northern Arkansas there is no break between the two systems and the sedimentation of limestones and dolomites (Yellville formation) seems to have been continuous. The Yellville formation extends westward under the younger rocks into Oklahoma so that in this region, also, the deposition was not interrupted between Cambrian and Ordovician times, and was continuous to the end of the time of deposition of the Burgen sandstone. There may have been periods of non-deposition during Upper Ordovician time since there are pronounced faunal breaks in the Tyner formation but there are no unconformities which indicate long periods of erosion.

The Silurian is represented by the St. Clair limestone in Arkansas and in the southern part of the Oklahoma area, but farther north and west there was no deposition and there was at least local emergence, evidenced by the absence locally of the upper beds of the Tyner and uneven lower surface of the Chattanooga shale.

The region probably remained near the surface or above the water during lower and middle Devonian times since there are no deposits representing these periods, and there is no evidence of sufficient erosion to have removed them, but was resubmerged during the upper Devonian,

25. Missouri Bureau of Geol. & Mines, vol. IX, part I, pp. 17-18.

and the Chattanooga shale was deposited. Another emergence followed and the upper surface of the Chattanooga was eroded.

About the end of Kinderhook times the Mississippian sea advanced and the Boone formation was deposited. The deposition of the Boone probably occupied all of Burlington-Keokuk times. The Boone was probably deposited far to the east of its present outcrop, the outcrop having been carried toward the margin of the uplift by erosion in subsequent times. After the deposition of the Boone, there was a period of emergence. The Warsaw, Salem, St. Louis and lower part of the Chester formations are absent and were probably not deposited.

After the deposition of the Pitkin there was a slight emergence and a resubmergence during which the Morrow and the Winslow formations of Pennsylvanian age were deposited to the southwest. This submergence advanced to the north and east and gradually covered the country to the north and east to a considerable distance. In this sea the Cherokee shales were laid down on the unevenly eroded surface of the Boone chert. The erosion interval in latest Mississippian times and early Pennsylvanian times is of supreme importance in the deposition of the lead and zinc ores of the Ozark uplift. This subject is discussed by Buckley and Buehler in their report on the Granby area[26] as follows:

"At the close of the Mississippian, there was an erosion interval of considerable duration. During this period the upper beds were removed and the land deeply trenched by running water. The underground waters flowing along joints took the limestone into solution, producing caves, caverns and sink holes.

"During this period there was also a process of concentration, recrystallization and silicification in progress. The beds of limestone became more completely crystalline; the original flint nodules were enlarged through the replacement of the limestone by silica; and the limestone beds were silicified. Perhaps, near the surface, during the latter part of this erosion interval, the flint may have been partly decomposed forming cellular chert (flint).

"Just the order in which these changes occurred and the position of the altered beds with respect to the surface, are not known. We only know that the limestone was saturated with mineralizing solutions, carrying chiefly calcium carbonate and silica; and that zinc and lead salts were not deposited, and therefore probably not carried in solution.

"The great thickness of the limestone deposits of the Mississippian and the enormous deposits of coal formed during the Pennsylvanian, have lead some to believe that the atmosphere during the post-Mississippian erosion interval was heavily charged with carbon dioxide. If

26. Missouri Bureau of Geol. & Mines, vol. IV. 2nd series, pp. 31-32.

NATURE OF THE ORES.

The ores of the entire Joplin district fall into two classes; the oxidized ores, or those found above the level of the ground water in the zone of surface weathering, and the unoxided or sulphide ores found in the deeper workings.

The oxidized ores are zinc carbonate, smithsonite or "dry bone"; zinc silicate, calamine, or "silicate"; lead carbonate, cerrussite or "dry bone" and subordinate amounts of lead sulphate, anglesite. These ores have been produced by the oxidizing action of the surface weathering agencies on the sulphides. Considerable galena or "lead" is found near the surface usually associated with calamine or anglesite. It may be regarded as being the residuum of the sulphide ores which has not been acted upon by the oxidizing agencies.

Zinc carbonate, smithsonite, which is called "dry bone" in the northern Mississippian fields is of small importance in the Joplin district. It is not present in commercial quantities in the northeastern Oklahoma area.

Zinc silicate, calamine, or "silicate" is produced by the oxidation of zinc sulphide. It occurs in Oklahoma usually in irregular forms which are finely crystalline. The color is a gray on the outer surface and usually vitreous on freshly broken surfaces. Some mammillary and stalactitic forms occur, and also small rounded grains known as fish egg silicate. This ore has been produced in considerable quantities in the Peoria camp and to some extent in the Quapaw camp. It does not occur at Miami.

Lead carbonate, cerussite, is usually known in the Joplin district as "dry bone". It occurs at Peoria in rather small amounts usually as flat plates showing little or no crystalization. It also occurs as a coating on galena crystals. No cerussite was observed at Miami.

Lead sulphate, anglesite, occurs as white powder coating galena. It is also associated with lead carbonate. By itself it cannot be considered as an ore of lead as it occurs in too small quantities.

Below the zone of oxidation, i. e. below the level of ground water, the lead and zinc ores are in the form of the sulphides. Lead sulphide, galena or "lead" as it is called by the miners, is a mineral of a gray color characterized by its cubical cleavage. Zinc sulphide, sphalerite, or blende is usually called "jack" by the miners although in some districts calamine is called jack. Sphalerite when pure is almost colorless but usually contains sufficient iron to darken the color to that of resin and sometimes almost to a black. The lustre is resinous. The ordinary form of crystallization is tetrahedral but the crystal form is not distinguishable in large masses of the material. Small crystals of spalerite often show the tetrahedral form. Large pieces of sphalerite cleave easily into approximately cubical pieces.

In the majority of the mines in the Joplin district sphalerite and galena are mingled so that small specimens of ore contain both minerals. The proportions of the two vary widely and irregularly. As a general rule the proportion of lead decreases with depth but locally the reverse is true.

ASSOCIATED ROCKS AND MINERALS.

The principal rocks and minerals associated with the lead and zinc ores in the Joplin district are as follows: Chert, or flint or limestone, sandstone (in the Miami camp), shale, clay, bitumen, pyrite, calcite, dolomite, barite, chalcopyrite, and greenockite.

Chert or Flint. Buckley and Buehler[28] recognize three generations of chert in the Joplin district. First a white, primary variety which occurs as layers between the limestones of the Boone formation and as lenses and nodules through the limestone. This chert is devoid of fossils, is dense and compact, breaks with a sharp splintery and sometimes conchoidal fracture. This rock makes a considerable portion of the Boone formation and owing to the greater solubility of the limestone remains as a covering of residual chert over the hills of the entire region. The chert weathers locally to a soft porous rock known as tripoli.

A second generation of flint is a white, gray, or blue variety containing fossils, and thought to be a replacement of the limestone. The third is a black flint which contains no fossils, and which occurs as a matrix in which are imbedded angular pieces of the primary flint (fig. 8). It is considered as having been formed by the hardening of siliceous mud which formed contemporaneously with the deposition of the ores.

The first and second generations of flint contain no lead or zinc ores but the third contains both sphalerite and galena together with their accompanying minerals.

Smith and Siebenthal[29] mention only two varieties, apparently classing the second and third together as one variety under the name jasperoid. Smith regards this jasperoid as being formed by the metasomatic replacement of limestone. A very complete description of the material and a discussion of its relations is given in the folio cited.

The discovery of gradations between limestone and jasperoid makes a strong case for the idea of the formation of jasperoid by replacement

28. Missouri Bureau of Geol. & Mines, vol. IV, 2nd. series, pp. 30, 37-40.
29. Joplin District folio (No. 148), Geol. Atlas U. S., U. S. Geol. Survey, 1907, pp. 13-14.

of limestone but in many cases the appearance of the breccia makes it hard to believe that all the jasperoid could have been produced in that way. The presence of the sharp angular fragments of primary flint would be practically impossible in primary limestone, and if the breccia were ever recemented by calcareous cement, it is very strange that so few traces of the calcereous portion remain since the recementation must have taken place after the fracturing of the chert. If the spaces between the angular pieces of primary flint represent the size and shape of limestone fragments which were present in the breccia when it was first formed, these fragments were extremely angular and different from anything

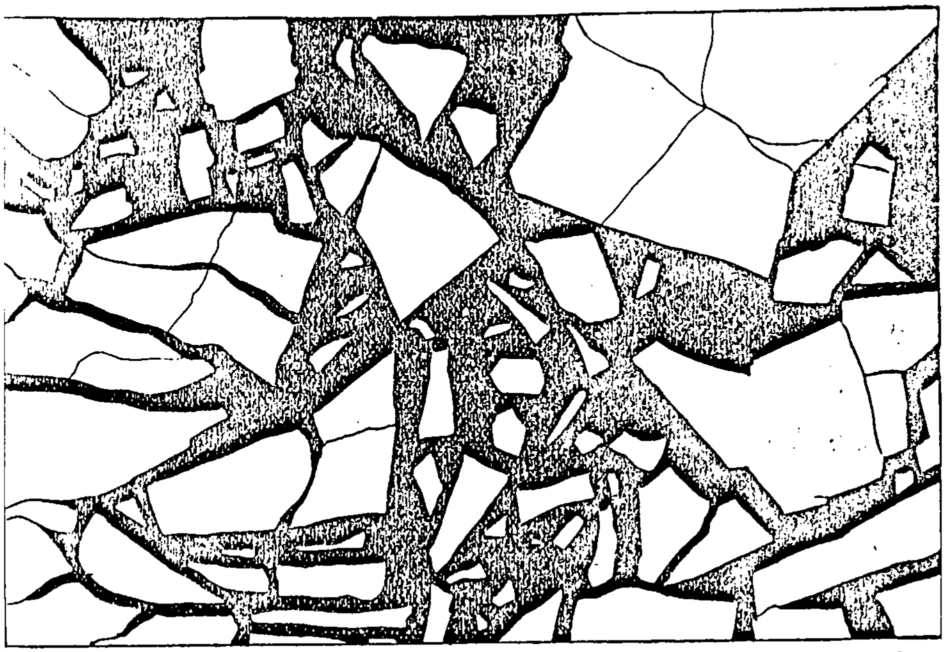


Fig. 8. Flint Breccia. Drawn from a specimen collected from one of the mine dumps (Mo. Bureau of Geology and Mines).

now known in Oklahoma. The absence of limestone from the breccia does not seem to require the replacement of the limestone for an explanation, for as has been pointed out by Buckley and Buehler in the report previously mentioned, the hill sides of the entire Boone area are covered with a mantle of loose angular chert fragments which show no limestone, although the formations from which this material is produced generally contain more limestone than flint. The writer therefore, believes that the "breccia" as it is shown in Oklahoma, is derived from a basal conglomerate of weathered chert fragments such as occur on the hill sides of the region at present, and that the black secondary flint or

jasperoid, at least in part, was deposited from solution in a colloidal condition. The white or gray secondary flint is probably a metasomatic replacement of limestone.

Limestone. The occurrence of limestone in the Boone formation has already been noticed. In relation to the mining industry it is important from the standpoint of its solubility, the solution of the limestone having produced the physical conditions favorable to ore deposition. The limestone occurring in the mines is always barren of ore. The ore bodies may pass around bodies of limestone, but never through them.

Sandstone. Sandstone is seldom important in relation to the lead and zinc mines of the Joplin district of Missouri, but in the Miami camp it forms the mineral bearing rock in most of the ore so far produced. The fine-grained sandstones have been broken and brecciated by settling into cavities formed by the solution of underlying limestones. The ore occurs in the brecciated sandstone in the same manner as it does in the brecciated chert in the other camps in the district.

Shale. The Cherokee shale forms the surface rocks at the Miami camp and occurs in small patches farther to the east. A black carbonaceous shale lies immediately above the ore bearing horizon at Miami and Quapaw mines. It is badly crumpled and slickensided by the movements of the rocks.

Clay. Clay occurs in the shallow diggings and in pockets and openings in workings of moderate depth. It is a very fine-grained plastic clay ordinarily of yellowish or a reddish color and is called "tallow" clay by the miners. Analyses of the clay usually show considerable percentages of zinc in the form of calamine. The calamine ore at Peoria occurs in a stiff, very plastic, red clay.

Calcite and dolomite. These minerals in crystalline form occur very abundantly in the Missouri mines where they are generally known as tiff and spar. The presence of dolomite was taken by Bain to indicate the origin of the ores in the Cambro-Ordovician limestones. In Oklahoma, however, both minerals are comparatively rare in connection with the ores. Calcite is found in a few cases in the Miami camp but no dolomite has been observed. Both occur in small quantities in some of the mines at the Quapaw camp.

Barite. Barite is very abundant in the lead mines of southeast Missouri and also locally in the Joplin district. It has not been reported from the Oklahoma camps.

Bitumen. A soft asphaltic bitumen is present in pockets and crevices in many of the mines of the Joplin district. In some cases it is in sufficient quantity to cause considerable trouble in concentrating the ore.

as it causes the material to "ball up" in the jig cells. It also lowers the grade of the concentrates. This is especially true in the Miami camp where the bitumen is unusually abundant. As the water is permanently lowered by pumping or by the opening of mines with a lower water level. the bitumen seems to follow the water and practically disappears. The bitumen is probably derived from the Cherokee shales since it occurs most abundantly in the mines under or near the shale outcrops. Bitumen is very abundant in the shales. A body of almost pure asphalt in the Cherokee shales about two miles north of the Miami camp is two feet thick and covers several acres. On the other hand the Boone chert at a distance from the shale outcrops is never noticeably bituminous and the spring water from it shows no trace of oil.

Pyrite and marcasite. The iron sulphide, pyrite or marcasite according to crystallization, is called "mundic" by the miners. It is an almost constant accompaniment of the lead and zinc ores, usually occuring in crystals on the surfaces of the blende and galena. It also occurs in the Cherokee shales, some especially fine specimens of pyrite having been picked up along Tar Creek east of the Miami camp.

The great amount of pyrite in the concentrates from the Miami camp lowers the grade of the ore very markedly. The complete separation of the pyrite from the sphalerite by the concentrating methods in use is almost impossible owing to their having so nearly the same specific gravity. Pyrite and marcasite are very similar in appearance. In the remainder of this chapter the term pyrite is used to refer to iron sulphide although marcasite probably forms a portion of the material called pyrite.

Chalcopyrite. Chalcopyrite, copper-iron sulphide, occurs as small crystals in the dolomite of the Joplin region. In Oklahoma, no chalcopyrite has been observed but on some of the oxidized ores in the Quapaw camp there are green stains which are probably malachite produced by the oxidation of chalcopyrite.

Greenockite. Greenockite, cadmium sulphide, forms a yellow coating on the surface and in cracks of the sphalerite, in the Quapaw camp. No crystals have been observed.

SHAPE OF THE ORE BODIES.

The subject is discussed fully by Smith and Siebenthal in the Joplin District folio of the United States Geological Survey and extracts from that report are given below:

"The forms of the ore bodies, some simple, others complex, all fall into two general groups, the first including runs and their modifications; the second consisting of blanket veins, or, as they are generally known in this district, sheet ground deposits.

Runs.

"Runs are irregular but usually elongated, in places tabular and inclined, bodies of ore, uniformly associated with disturbed strata which have been subjected to brecciation, slickensiding, and moderate displacement as the result of minor faulting or of dislocation due to underground solution. Simple runs are linear and continuous, straight or simply curved, ore bodies, usually at nearly the same level throughout their extent. On account of the complication of minor faulting, underground solution, and general deformation in the ore-bearing areas of the district, such runs are rare. Many runs which have a simple structure in cross section and which for short distances appear to be simple runs are found on further exploration to be compound. Even the few instances of simple runs which have been noted may present more complex features as the development of the ore body proceeds. It thus happens that there are all gradations from simple runs to complicated compound runs. Among the latter are those formed by the lateral connection of two nearly parallel simple runs so as to form a single ore body. Another class, comprising by far the larger number of runs in the district, consists of the irregular ore bodies formed in disturbed areas that are due to complicated underground drainage. Combinations of these give runs of great complexity, among them, here and there, circular or subcircular deposits. It will be seen, therefore, that while theoretically the different types of ore deposits are distinct, practically they grade into one another, with no hard and fast lines between them.

"The greatest dimension of the runs is horizontal, although as compared with that of ore bodies in other regions this linear extent is generally short, as a rule not exceeding a few hundred feet. The Arkansas run at Belleville, with a length of over one-fourth of a mile, described by Bain, is exceptionally long. It does not, however, preserve a uniform direction, but varies from southeast to east, then to south, and finally to west. The runs have a maximum width of 300 feet, but as a rule are between 10 and 50 feet wide. The average vertical extent is about the same, but in some cases reaches 150 feet.........................

Circles.

"Circular, subcircular, and roughly elliptical closed runs, commonly known as "circles," constitute one of the most distinctive and constantly recurring types of ore bodies in the district.........................

"The common structural relations that have been described for the simple runs likewise prevail in the circle deposits, though, owing to variation in texture and perhaps in initial structure of the rocks, the circles are not as a rule equally developed throughout, the width, vertical extent, and general character of the brecciated zone and the associated ore deposit varying more or less in different parts of the circle. The circular zone of ore-bearing chert breccia, grading into the country rock on the outside, is separated from the dolomite zone, which either forms a ring inside of this ore body or more or less completely fills the central mass or core of the circle, by a more or less sharp plane of demarcation which shades outward all around the circle. The larger slabs of chert in the breccias usually have an outward radial or quaquaversal dip, and in places the same is true of the limestones and dolomites making up the central barren core, which in such instances has a dome structure.

"Thus the ore body has generally the form of a cylinder, dome, or truncated cone, and a horizontal section except near the top of the dome has the shape of a circular or elliptical ring. In vertical extent, mode of occurrence, and character of their ore deposits circles do not in general differ essentially from the simplest runs, and like them are associated in many places with an irregular overlying area of shale. From the hooked and curved forms of runs all gradations to typical circles can be observed, and manifestly they should be ascribed to a common origin. As previously set forth, they are believed to be but special cases of the effects of underground solution.

Sheet Ground or Blanket Veins.

"Blanket veins, or, as they are more commonly known, "sheet ground" deposits, are nearly horizontal, tabular ore bodies, many of them of great lateral extent, developed parallel to the bedding planes of the rocks. They are to a certain degree limited, much as the runs are, to valleys and to areas of brecciation and solution.

"The ores of the sheet ground are both galena and sphalerite, occurring in part along the bedding planes of cherts and in part in breccias resulting from slight folding or faulting of the bedded rocks or from slight differential horizontal movements between the beds. In the breccias the ores occur either directly as cement or disseminated in jasperoid. As found along the bedding planes, the ores are either in cavities formed by solution, chiefly of thin intercalated beds or lenses of limestone, or else in jasperoid, which results from a metasomatic replacement of this limestone. The jasperoid thus occurs in sheets or lenses of variable thickness, from a fraction of an inch to 6 inches or more. Locally it completely fills the interval between the beds of chert; in many places, however, there are open spaces here and there between it and the chert above.

"In these cavities more or less ore has crystallized and either lines or completely fills the cavity. Sphalerite usually forms on the bottom of the cavity, while galena, in places with marcasite on or about it, tends to form on the roof. Where the cavities have been completely filled the filling may consist wholly of sphalerite or galena, or of sphalerite in the lower part and galena, with or without marcasite, above. Locally a bed of limestone, especially where thin, may be completely removed without replacement by jasperoid, the filling of the cavity thus formed resulting in a sheet composed wholly of granular sphalerite or galena or of both.

"The ore of the cavities locally occurs in two or more generations. A first generation of sphalerite with galena may be coated with a later generation of sphalerite, both generations of this material consisting essentially of "rosin jack." A still later generation of both sphalerite and galena is often seen, the crystals usually small, or at least smaller than those of earlier growth, the galena in many cases of different habit, and the sphalerite largely of the variety known as "ruby jack."

"The horizons of the sheet ground, unlike those in which the runs occur, appear to be well defined. Small deposits of this character occur, in association with runs, at various horizons throughout the Boone formation, and in particular just above the Grand Falls chert, but the typical sheet ground seems to be developed invariably in the Grand Falls chert.

"The sheet ground, as a rule, is firm, requiring for the support of the roof only scattered pillars which are left at irregular intervals, usually in the leaner parts of the ore body..........................

"The sheet ground is fairly uniform in its ore percentages for considerable distances, such as might be included within the limits of a single mine, but it varies considerably at greater intervals. The percentage of ore is on the whole considerably lower than the average in the runs, but this is to a certain extent offset by the lateral extent of these deposits, by their occurrence at a single horizon, nearly level, and by the usual ready separation of the rocks along the bedding planes, all of which conduce to ease and rapidity of ore extraction. Another advantage is that the dead expense of prospecting in following the ore of runs is practically eliminated in sheet ground. The ground requires blasting, however, and on account of the predominance of siliceous material the drills are rapidly worn down and the rolls worn out in milling. With 2 or 2½ per cent ore, the mines in sheet ground, as worked at present and at current ore values, scarcely more than make expenses. From this percentage the yield of the ground as worked ranges locally up to 25 per cent or more of ore."

All the forms mentioned as occurring in the Joplin district occur in Oklahoma. The ore body at the Miami camp is a run which probably exceeds in length any of those mentioned as occurring in Kansas or Missouri. The apparent length of this run is over one-half mile although it is possible that the run nearest the surface at the south end of the camp plays out to the north and that the ore at the north end is from a deeper run. In any event the run is continuous for over one-fourth mile. Small runs and circles as well as sheet or blanket ground occur in the Quapaw camp.

THEORIES OF ORIGIN OF THE ORES.

The various theories of origin of the lead and zinc deposits of the Mississippi Valley and of the Ozark region have been discussed fully in several reports and papers, the principal ones of which are given herewith:

The Ore Deposits of Southwestern Wisconsin, by T. C. Chamberlin, Geological Survey of Wisconsin, volume IV (1873-1879), 1882.

Lead and Zinc, by Nrthur Winslow, Missouri Geological Survey, volume VII, 1892, pages 467-487.

Lead and Zinc Deposits of the Mississippi Valley, by W. P. Jenney, Transactions of the American Institute of Mining Engineers, volume XXXII, 1894.

Lead and Zinc Deposits of the Ozark Region, by C. R. Van Hise and H. Foster Bain, United States Geological Survey, Twenty-second Annual Report, Part II, 1901.

Special Report on Lead and Zinc, by Erasmus Haworth and others, University Geological Survey of Kansas, volume VII, 1904.

Geology of the Granby Area, by E. R. Buckley and H. A. Buehler, Missouri Bureau of Geology and Mines, volume IV, second series, 1905.

Geology of the Disseminated Lead Deposits of St. Francois and Washington counties, by E. R. Buckley, Missouri Bureau of Geology and Mines, volume IX, Part I, second series, 1908.

For the purpose of this report it is deemed advisable to give only a brief statement of the two leading theories as developed for the Ozark Region by Van Hise and Bain in Part II of the 22nd Annual Report of the United States Geological Survey, and by Buckley and Buehler in vol. IV, 2nd series of the Missouri Bureau of Geology and Mines.

All who have examined the deposits agree that the ores were deposited from solution in ground water. There is no evidence of igneous activity in the region although the miners have several terms such as "blow outs" indicating such an origin. The theory of igneous origin is entirely untenable in any portion of the Mississippi Valley and may be disregarded.

While there is no question as to the aqueous origin of the ores, there are two distinct theories as to the method of deposition. One school, the ascensionists, believe that the ores were first deposited by ascending currents of water and later concentrated by descending currents, while the other school, decensionists, believe that only descending currents have had any important part in ore deposition.

Jenney, Van Hise and Bain have been the principal adherents to the doctrine of deposition by ascending waters and concentration by descending waters. The source of the ores is believed to be the Cambro-Ordovician dolomites and limestones. Waters from these dolomites and limestones carrying the metals in the oxidized forms are thought to have passed upward through the Devonian shales and the Mississippian limestones. The oxidized compounds were reduced by the organic matter in the Devonian shales and also by the mixing of the artesian circulation with the circulation from the surface. The ores were deposited throughout the Mississippian limestones and cherts and on up into the Pennsylvanian rocks and were later concentrated at or near the surface by the erosion of the upper rocks and the solution of the ores contained in them by the descending waters. This ore was then deposited by coming into contact with reducing media. The principal deposition took place in the open chert "breccia" at the base of the Pennsylvanian rocks, which was taken by Bain to be a fault breccia.

This theory was founded on several conditions such as (1) the supposed presence of deep faults which would pass downward through the Devonian shales and into the Cambro-Ordovician limestones and dolomites; (2) the artesian character of the mine water, Bain making the statement that the amount of water pumped from the mines did not vary with the season; (3) the association of dolomite with the ores, which was regarded as being practically universal and which was supposed to indicate the origin from the Cambro-Ordovician dolomites.

Buckley and Buehler in the report on the Granby area have shown that Bain was mistaken in his interpretation of the conditions in the district, and (1) that what he supposed to be faulting was due to an unconformity at the base of the Pennsylvanian, and to minor readjustments of the Pennsylvanian rocks to an unevenly eroded surface, and to a sink hole topography, (2) that the breccia was not due to faulting but to the cementation of the surface chert fragments such as now cover the surface in the region, (3) that the mine water varied greatly in wet and dry seasons, (4) that the dolomite was by no means a constant accompaniment of the ores and was no greater in amount than can be accounted for by solution from the shales and limestones of the Pennsylvanian and Mississippian, (5) that the organic matter which was probably the precipitating agent was almost certainly derived from the overlying Pennsylvanian shales, (6) that from an upward circulation the lead sulphide would have been deposited in the lowest levels of deposition, reversing the conditions as found in the district, (7) that the Pennsylvanian shales contain sufficient lead and zinc to account for the ore bodies, while the waters from the Cambro-Ordovician rocks contain mere traces of the metals.

Haworth, in the Kansas report referred to above, as a result of careful investigations estimates that more than 90 per cent. of the mine waters in the Galena district can be accounted for by the rainfall in the district and the territory immediately to the east. He states that it would be impossible for the rainfall on the outcrop of the Cambro-Ordovician rocks in southeast Missouri to supply more than a tithe of the water pumped from the mines at Galena.

Smith and Siebenthal in their folio on the Joplin District accept (with some modifications) the Van Hise-Bain theory of deposition by ascending waters and apparently regard the association of ore bodies with the outcrop of the Pennsylvanian rocks as largely accidental. They do not, however, find any great faults or attempt to account for the upward circulation of the ground water.

In this connection it is interesting to note that the most recent work in the northern Illinois-southwestern Wisconsin district, the region to which Bain first applied the theory of deposition by ascending water, tends to show that the ores are derived from the Maquoketa shales which overrlie the ore bearing rock instead of from the limestones which underlie it, in other words that the ore has been deposited from descending waters[30].

The bearing of observed facts in the Oklahoma field is in the same diection. No deep seated faults are observed in the productive areas, and on the other hand ore is not known to occur in the deeply faulted area to the south of the producing field. The large faults do not produce a fault breccia of such extent as the "breccia" in the producing areas. There is very little calcite and practically no dolomite in connection with the ores. The water in the Peoria and Lincolnville camps is not artesian and that in the Miami camp can probably be accounted for by the rainfall on the territory immediately to the east. The ores are intimately associated with outcrops of the Pennsylvanian shales which contain small quantities of galena, of sphalerite and considerable pyrite and bitumen.

DESCRIPTION OF THE MINING CAMPS.

Up to the present time three mining camps have been developed in the portion of the Joplin district lying in Oklahoma. These are in

30. Cox, G. H., Elizabeth sheet of the lead and zinc district of northern Illinois, Bull. Ill. Geol. Survey, No. 16, 1910 .

order of age, the Peoria, Quapaw or Lincolnville, and Miami. Their location is shown on the accompanying map (fig. 8.)

The Peoria Camp.[31]

Location. The Peoria camp is located at the village of Peoria, six miles south of the Kansas-Oklahoma and three miles west of the Missouri-Oklahoma line in sec. 12, T. 28 N., R. 24 E. of the Indian Meridian. Some digging has been done in sections 13, 14 and 15.

History of development. The first work was done in this camp by the Peoria Mining Company in May, 1891. The town of Peoria, the first town incorporated in Indian Territory, was laid out and incorporated in 1892. The Peoria Mining Company sold about $1,000 worth of ore during 1891 and 1892. In 1893 the company was reorganized as the Peoria Mining, Construction and Land Company. From May 1, 1893 to September 16, 1894, 2,726,418 pounds of galena were produced and hauled by wagon to the Joplin White Lead works where it was sold at $44 per ton. During the same time 56 tons of sphalerite (jack) and 332 tons of silicate were hauled to Baxter Springs, Kansas, where the sphalerite was sold for $11 per ton and the silicate for $8 per ton. The value of the production of the camp during this period was about $63,250.

The absence of transportation facilities worked a hardship on the camp in rendering the marketing of the ore very expensive and by making it difficult to secure and hold suitable labor. As a result development since 1894 has been on a small scale and of an intermittent nature. The following quotation[32] gives the conditions of the camp in 1907.

"The mines at Peoria were opened in 1891 on land the first lease of which is held by the Peoria Mining, Construction and Land Company, a New Jersey corporation. The most productive area adjoins the village on the northwest, and underlies the bottom and north bluff of Warren Branch. In the creek bottom, over an area 300 feet long east and west by 100 feet wide, known as the Playhouse diggings, a solid sheet of galena was found in chert at a depth of 7 to 10 feet. This sheet, narrowing to 60 feet, extended northward for 600 feet under Monkey Hill and is reported to have been from 6 to 22 inches thick. Other shallow deposits of lead have been worked on the first and second hills west of Monkey Hill. Not much sphalerite has been mined at these places. A sheet of sphalerite from 4 to 18 inches in thickness, with a thin sheet of galena just above it, which yielded two carloads of ore, was struck about 12 feet above the level now worked for silicate.

31. For the information regarding the early days of the Peoria camp and the presence of the deeper ores I am indebted to Mr. J. P. McNaughton of Miami, Oklahoma.

32. Siebenthal, C. E., Bull. U. S. Geol. Survey No. 340, 1907, pp. 201-202.

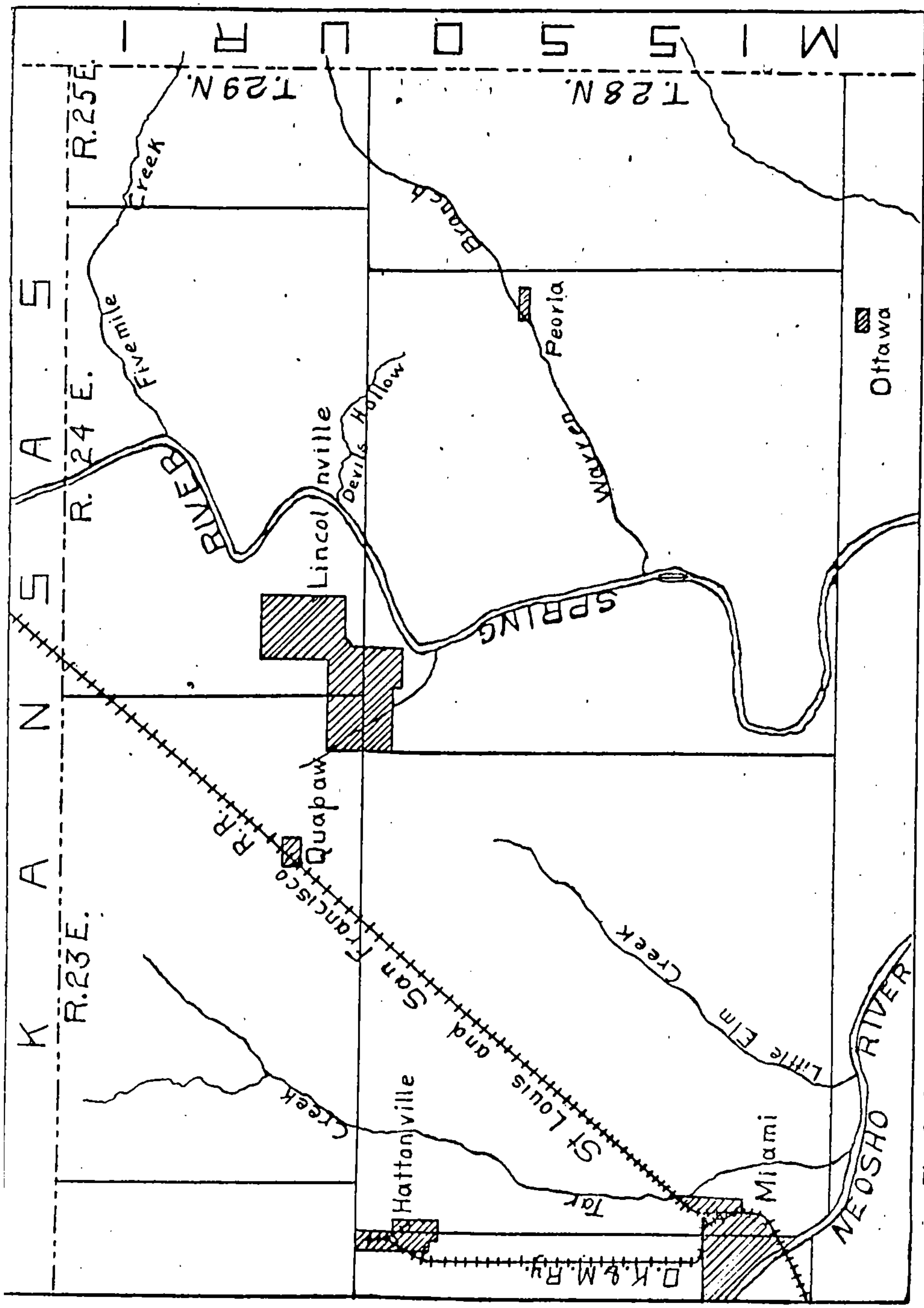


Fig. 8. Map of extreme northeastern portion of Oklahoma showing location of mining camps.

"*Silicate mine.* The Silicate mine is operated by Gordon & Wilkins. The shaft is in the face of the hill just north of the creek, about 50 feet west of the edge of the Playhouse diggings, and some of the drifts extend under those old workings. The face of ore ranges from 1 to 7 feet in height, averaging 2½ feet. The drifts are carried 6 to 8 feet in height and from 10 to 12 feet in width, and have a total length of approximately 1,000 feet, covering an area less than 200 feet square. The ore occurs either in slabs or as "fish-egg silicate," in clay interbedded with red tallow clay and layers of soft, rotten chert, the whole conforming to the limestone horses and bowlders which are present here and there. In one place the walls of the run closed in, nearly pinching out the ore, which continued on through the opening in the solid limestone. The ore in the main is plainly the result of a carbonate replacement of the limestone country rock, associated with more or less underground solution, the latter in part antedating the ore deposition, giving rise to the openings through which the ore-bearing solutions passed, and in part contemporaneous with the ore deposition. The ore is concentrated on hand jigs, the quantity of fine fish-egg silicate associated with flat shapes requiring an elaborate scheme of concentration. Women and girls are employed to hand pick the screenings—probably the only instance of such employment in the Joplin region.

"*Chicago Syndicate Mining Company.*—In 1907 the Chicago Syndicate Mining Company erected a mill over some old workings half a mile northwest of Peoria. The level worked at the mill shaft is 120 feet deep, but at another shaft on the edge of a small, oblong solution patch of shale and sandstone of Chester age, the mining was done at the 160-foot level. A considerable amount of lead was taken from this shale patch at a depth of 12 to 22 feet, the ore occurring near the base of the sandstone and shale. In the drifts now being worked the ore is sphalerite disseminated in rather coarse crystals through the bluish-gray jasperoid cement of chert breccia. In places this cement makes up one-third to one-half of the mass of the breccia, the chert bowlders and slabs being suspended in it. Considerable spar is present here and there, and where decomposition has progressed far there is much tallow clay.

"*Other mines.*—The Poor Boys Mining Company is operating a silicate mine, and several other companies are prospecting in the immediate vicinity of Peoria.

"Three miles due east of Peoria, on a tract of land belonging to S. L. Davis and adjoining the State line, in the vicinity of the Pinnick mines, there have been some recent strikes of ore. The Grimes & Williams shaft is sunk near the border of a circular solution patch, bordered by an outcrop of brecciated chert with a jasperoid matrix showing impressions of sphalerite crystals which have been leached out. Within the circle there are scattered sandstone bowlders of Chester age. The ore is sphalerite and occurs at the 90-foot level in the matrix of the chert breccia. This matrix consists of jasperoid in some places and of dolomite in others; in still others the ore itself acts as the cement. In the McKisson shaft, on the same tract, a 3-foot run of lead was struck at the 60-foot level in yellow flint ground."

Since 1907 there has been very little new development and only a few new prospects have been made. The mill of the Chicago Syndicate Mining Company has run very little. The Silicate Mine has been worked on a small scale most of the time. At present the silicate is separated from the stiff red clay in which it occurs, by sluicing with water pumped from the shaft by means of a gasoline engine. In dry seasons the water from the sluice box is run back into a sump at the bottom of the shaft, and is used over and over. A small production of silicate is made from several other shafts in the neighborhood.

Very little prospecting for deeper seated ore has been done. A few holes are reported to have shown considerable bodies of low grade sulphide ores in sections 12 and 13 but the head of water is so strong that concerted action would be necessary to lower it.

With the present conditions of transportation there does not seem to be any immediate prospect of great development in this camp, but if a railroad should be built through the camp and if further prospecting should show that the sulphide ores of the deeper levels are present in quantity, the Peoria camp has a good prospect of becoming an important producer.

The Quapaw or Lincolnville Camp

As is the case for the Peoria camp, the Quapaw camp has shown little development since 1907 when the article by Siebenthal, which has been used extensively in this report, was written. His remarks on this camp are therefore given in full and afterward a few notes showing the present condition of the camp. The state of development of the camp in 1908 is shown in figure 9.

Introduction. "The Quapaw mines extend from 1 to 4 miles east of Quapaw station, and from 5 to 7 miles south of Baxter Springs. The ore-bearing ground has been proved by drilling to extend for some distance beyond these limits on all sides, notably to the west, in the vicinity of Quapaw station, where a good strike was made in drilling the town well. The main ore deposits occur at a depth of 80 to 150 feet in blanket-ground formation, rarely in confused broken ground. Ore at shallower depths is limited chiefly to the region lying immediately south of Lincolnville, the village at the Quapaw mines. On the eastern edge of the Quapaw district the blanket ground rests upon the Short Creek oolite member of the Boone formation, which is usually penetrated by the

mine sump. Though doubtless the blanket breccia forms an uninterrupted sheet throughout the area of the Quapaw mines, the oolite is not found in the western mines. This is because the bed, as noted in its description, thins out or loses its oolitic character along a north-south line which bisects the district. The ores found in the blanket ground are sphalerite and lead in about the proportion of 5 to 1. In a part of the blanket ground there has been some oxidization in the upper part and a little calamine is present. No ore is mined below the Quapaw blanket ground, although the drill has shown ore at deeper levels. In the shallow ground, the ore, which is principally silicate and galena, occurs in runs and circles. In addition to the circular solution patch (with a probable circular ore deposit) on the Cherokee Lead and Zinc Mining Company's land, described below, there are several other shale and sandstone patches of the same shape. A circular shale patch at the FFF mine had much sphalerite and pyrite in the lower part of the shale, and ore continued in broken ground down to the main blanket ground at 90 feet. There is a large circular solution patch on the Red Eagle tract, in the NE. ¼SE. ¼ sec. 31 T. 29 N., R. 24 E. The shale area is 350 feet in length north and south by 300 feet in width. A shaft near its southeastern margin shows a thickness of 70 feet of shale. The shale area is surrounded by a low rim of chert which dips away from the center on all sides. Near its contact with the shale the chert is brecciated and recemented with jasperoid from which considerable sphalerite has been leached. It seems reasonably certain that the ore here, should it occur in workable quantity, will be found in circular shape.

"There are in the Quapaw district 25 steam concentrating plants, with a daily capacity of 3,300 tons, besides 7 mines operating hand-jig plants. In the typical blanket ground hand jigs can not be operated to much advantage, as the ore must be crushed very fine to free it from the rock. Those in operation are working with dirt from the shallow ground or the more oxidized portions of the blanket ground. In addition to the mines with concentrating outfits there are about 30 prospects which have shafts down to the ore. The owners of some of these prospects have planned to build mills; others are waiting for ore prices to become better.

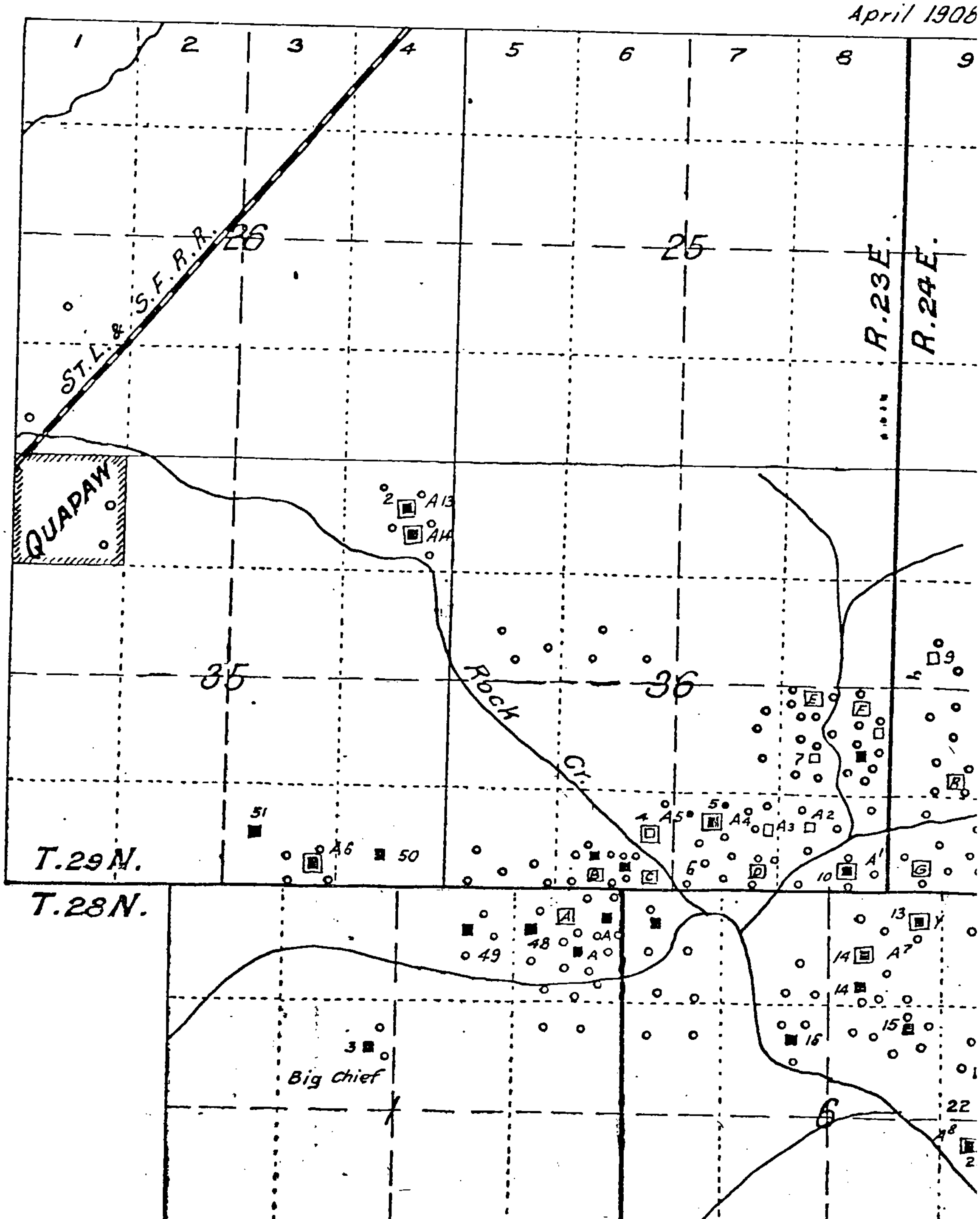
"*Cherokee Lead and Zinc Mining Company.*—In a field on the Cherokee Lead and Zinc Mining Company's lease just southwest of Lincolnville several wagon loads of calamine were picked up, having been plowed up and cast aside in ignorance of its value. Approximately 50 tons of silicate with a little lead were taken from shallow open cuts less than 15 feet in depth, along the southwest margin of a circular solution patch at this place. Limestone and sandstone of Chester age co[illegible] the surface except for the circle 125 to 150 feet in diameter. The bo[illegible] of the circle is marked by a ring of sandstone bowlders. Inside this rim shafts and borings strike Cherokee shale with a little coal. Between

Shafts.

No.	Name.
1	Virginia.
2	Quapaw Lead & Zinc Co.
3	Hannibal & St. Joe.
4	Pasture.
5	Common Law.
6	Hash, Kenedy & Hash.
7	Cherokee.
8	Diamond C.
9	Hall.
10	Mc. Alister.
11	Little Four.
12	E. L. Wright.
13	Canterbury.
14	Rock Creek.
15	Mc. Kinley.
16	Baldwin Marlin.
17	Syndicate.
18	Chicago Quapaw
19	Big Squaw.
20	Farmer Boy.
21	Lone Elm.
22	Bliss.
23	Craney Bro's.
24	Irish Maid.
25	Independence.
26	Cramer & Parker.
27	Niorrito & Newland.
28	Red Eagle.
29	Eleventh hour.
30	Three Queens.
31	First Chance.
32	Good Luck.
83	Sun Burst.
34	Hobo.
35	Tipton.
36	Majeska.
37	Dark Horse.
38	Isley.
39	Gatlin.
40	Indiana.
41	Eastman.
42	Gray Eagle.
43	Quapaw.
44	Last Chance.
45	Amos Kenedy.
46	Luther.
47	Three.
48	Miss[redacted]
49	Gaines.
50	Virginia.

MAP SHOWING L
of
Mills, Shafts & D.
LINCOLNVILLE

April 1906

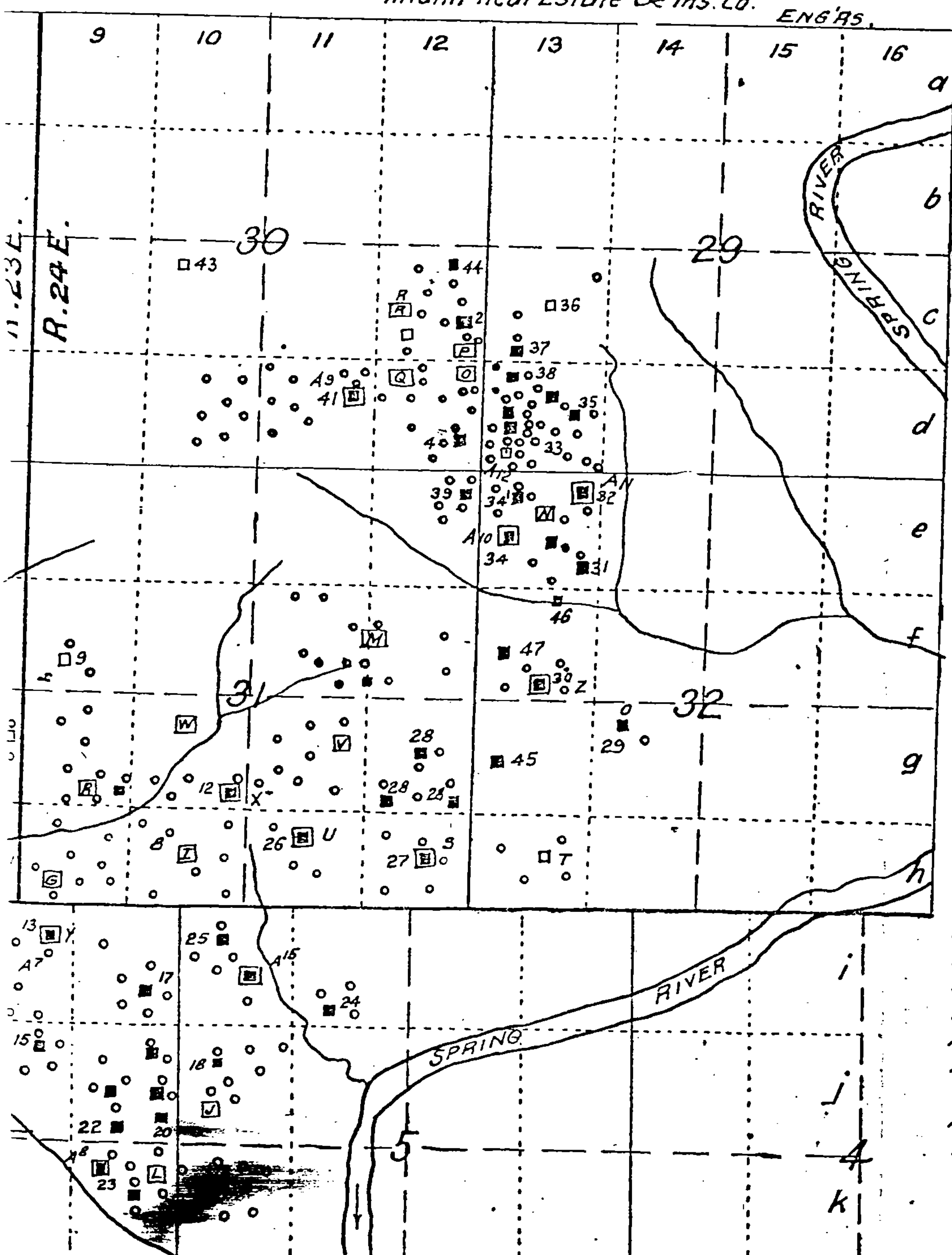


…ving Location
of
…s & Drill holes.

…le District.

…ril 1908.

Miami Real Estate & Ins. Co. Eng'rs.



Mills.		No. Shafts	Index
A	Mission	3	i-6
B	Ward	2	h-6
C	M.K.&T.	2	h-6
D	Micauber	1	h-7
E	Cherry Vale	1	g-8
F	Monon	2	g-8
G	Old Abe	2	h-9
H	"F&F"	2	g-9
I	Hawkeye		h-8
J	Joanna	1	j-10,11
K	Spring Riser	1	k-10
L	"J&L"	2	k-9
M	Querera	2	f-12
N	Omaha	2	e-13
O	Sunny Side	3	d-12
P	Dark Horse	2	c-12
Q	White Eagle	1	d-12
R	Ayers Sloan	2	c-12
S	Newlands		h-12
T	Lincolnville		h-13
U	Lucille		h-11
V	Big Four		g-11
W	E.G. Lawley		g-10
X	Read Eagle		g-10
Y	Big Jack		i-9
Z	Lancaster		f-13
A[1]	Sweeney		h-8
A[2]	Timothy		h-8
A[3]	Micawber		h-7
A[4]	Common Law		h-7
A[5]	Lennox		h-6
A[6]	Virginia		h-3
A[7]	Mason		i-9
A[8]	Alabama		k-9
A[9]	Indiana		d-11
A[10]	Hobo		e-13
A[11]	Good Luck		e-13
A[12]	Sunburst No. 2		d-13
A[13]	Hannibal-St. Joe.		e-4
A[14]	Quapaw L. Co.		e-4
A[15]	Heep O Brien		i-10

□ Mills.
■ Shafts.
○ Drill holes

the sandstone ring and the adjacent limestone there is, along the south-west margin, a strip of chert breccia with a matrix of jasperoid. This matrix has been ore bearing, as shown by the cavities from which sphalerite has been leached. The ore found in the shallow diggings lay mainly between the breccia and the limestone, but also extended in clay seams into both the limestone and the jasperoid. In the shaft just west of the circle ore was found at a depth of 35 feet in the clay and limestone bowlder filling of a solution chamber at the base of the limestone of Chester age.

"A sheet of lead ranging up to 6 inches in thickness was struck at a depth of 40 feet in the shaft of the Alabama Mining Company, a hundred yards south of the locality just mentioned.

"*Good Luck mine.*—Soft "confused ground" occurs at the Good Luck mine, as well as in some other mines in the northeastern portion of the Quapaw district. In the No. 1 shaft of the Good Luck mine the soft ground joins the blanket ground along a north-south line and the east-west drift is partly in each kind of ground. The blanket ground exposed by the drift is fractured and broken, but not recemented, and in places the bedding is entirely obscured. Clay and shale occur in the fractures and joints and between the chert beds. The blanket ground was evidently much softened by the solution which is responsible for the confused ground adjoining. The latter is the typical soft ground of chert and limestone bowlders in soapstone and yellow clay. Tiff and pink spar are present in veins and pockets in the unoxidized ground and impressions of spar and sphalerite occur in the jasperoid cement of the oxidized ground. Weathered lead occupies seams and fractures in the jasperoid. The No. 2 shaft was sunk on a drill hole showing rich lead cuttings that were found to have come from a solid chunk of galena a foot or two in thickness, which did not reach completely across the shaft. When followed to the south the lead gave out within 2½ feet of the shaft, but the drift soon ran into good zinc ore. The ground here consists of dull chert and rotten limestone bowlders in a matrix of shale, clay, and tallow clay. Some of the bowlders are of secondary limestone, highly crystalline and very rich in ruby sphalerite in grains of the same size as those of the limestone. In some of these limestone bowlders the sphalerite constitutes from 15 to 25 per cent of the mass.

"*Mission mine.*—The Mission mine may be chosen to exemplify the blanket-ground mines because it is typical, because its underground workings are the most extensive, and because it is the best-known mine in the district, having been the "show" mine from the beginning of the camp. The mined area extends over approximately 5 acres in the NE. ¼ sec. 1, T. 28 N., R. 23 E. The blanket ground is about 30 feet in thickness, the top of the ore being reached at about 50 feet from the surface and the limestone upon which it rests at about 80 feet. Only the

upper 18 to 20 feet of this ground has been worked, though at the time the mine was visited a lower stope 10 or 12 feet in height was being taken up from the pump shaft.

"In this mine, as generally in the district, there is at the top of the blanket ground 2 or 3 feet of soft ground, containing more or less black shale and yellow clay. Locally solution has progressed so far that slabs only of limestone and chert occur in the shale and clay. There is as a rule more or less spar and tiff in veins and pockets, and here and there a little bitumen. Much of the shale is slickensided. This zone is apparently not one of general movement, but one of accommodation to the slight stresses resulting from underground solution and the weight of the superincumbent strata. It seems likely that the opening at the top of the blanket breccia, into which the clay and shale have been drawn, was largely a result of the settling of the chert beds when the inter-bedded limestone was dissolved. The fact that the roof did not settle into this space would be explained if the solution in the blanket cherts went on by areas, portions remaining to support the roof until after the portions first dissolved and fractured had been recemented by jasperoid and rendered capable of sustaining the roof. This upper, softer sheet is in many places richer in ore than the harder ground below, but on the other hand it is here and there entirely barren.

"Below the soft ground the blanket breccia consists of greatly fractured "live" blue flint, which in the more unbroken portions shows small dark spots one-eighth to one-fourth of an inch in diameter, surrounded by a lighter border. At many points the stratification of the chert is completely obscured by the brecciation, but in general it can be made out either from the chert or from the jasperoid sheets between the broken chert beds.

"The brecciation of the chert ledges is uneven. In places the whole ledge is broken up; elsewhere it is broken into large bowlders with finer brecciation between them; elsewhere still the sheets are comparatively unbroken, with chert fragments suspended in the jasperoid interstrata. In many of the more unbroken portions of the chert strata traces of a former fine brecciation may be distinguished. The outlines of the fragments are faint, and the cementing material resembles a network of thin dark veins. These are not ore bearing and possibly correspond to the older sheet brecciation in the sheetground deposits of the Joplin district. At numerous places in the mine the chert is fractured vertically or nearly so. Some of these fractures come so close together as to constitute "sheeting" and to conceal the bedding of the chert completely. They are ordinarily not slickensided, but are usually stained dark by the circulating waters. In general they are open, containing neither ore nor jasperoid. They are probably equivalent to the sheeting in the mines of the sheet ground in the Joplin district, where also the sheeting is later than the ore deposition.

"The ore in the Mission mine consists of sphalerite and lead in the proportion of 2 or 3 to 1. The latter is found in fissures and crevices in the chert, and the former is disseminated in the jasperoid as well as in the crevices and fissures. Where both the ores occur in a pocket, the galena shows a tendency to be crystallized in the upper parts and the sphalerite in the lower parts. In the mine as a whole not much differentiation can be seen, more lead occurring in the upper portion in some places and near the bottom in others."

Condition of camp in 1911. Conditions since 1907 have not been such as to permit the low grade blanket ground ores to be worked on a small scale with profit. Besides many of the mills were built before sufficient prospecting had been done to insure a sufficiently large ore body to render operation profitable under any circumstances. Many of the mills have been removed and others have stood idle practically all the time since they were erected. From the appearance of the camp few of the mills have run sufficiently to pay for the cost of machinery and installations. Among the mills that have been removed are the Joanna, Big Squaw, J. C. L., Spring River, Lincolnville, Omaha, Hobo, Heap-O-Brien, Querera, Sunnyside, Dark Horse, Ayers-Sloan, Indiana, Mason, Ward, Lennox, and others.

In the autumn of 1911 only four mills were running. Two more were closed down temporarily and one hand jig and a few "gouging" propositions were being worked. The four mills being operated were the old Mission Mine, old M. K. & T., Big Jack, and Good Luck.

The Mission mine is operated by the Kansas City-Quapaw Company. The workings have been extended to the south and west and the new workings are at a level 8 feet lower than the old workings, and a face of 20 feet is worked. The old mill has been recently abandoned and a new 100 ton mill erected about 100 yards southwest of the old site. The ore is elevated through a new shaft at the mill. The longest drifts in the newer workings extend about 300 feet from the bottom of the shaft and there are several lateral drifts 100 to 200 feet long. The total number of headings or faces is above 60.

None of the drifts have reached the limits of the ore body and drill holes show it to continue to the south and west to the limits of the lease. No borings have been made for deeper ore but it is scarcely probable that large ore bodies are present below the blanket ground.

The "dirt" runs 30 per cent concentrates when properly culled. The concentrates average one-third galena and two-thirds sphalerite. The sphalerite concentrates are rather high grade, containing 56 to 60

per cent of zinc, and 2 to 3 per cent of iron. The galena is higher in the southern part of the workings and decreases rapidly to the north.

The mine water all seems to come from the surface and is easily handled. The mine, filled to the roof, is reported to have been emptied in four days of continuous pumping.

The old M. K. & T. (Katy) mine is owned and operated by the Petersburg Land and Mining Company, a Missouri corporation, which owns all of the SW. ¼ sec. 36, T. 29 N., R. 23 E. Borings show the blanket ground to be present under the whole 160 acres. A new 400 ton mill was erected in 1911 west of the site of the old Katy mill. The equipment consists of 2 crushers, 9 sets of rolls, 8 jigs and 6 Wilfley tables. Power is furnished by a 250 Horse Power Bessemer Gas engine.

The conditions in general are the same as those in the Mission mine to the south. The workings are on the 70-foot level and a 20-foot face is worked. About two and one-half acres have been worked out. Dirt is obtained from three shafts, 2 at a time. The ore from the shafts away from the mill is hauled in automatic end-dump cars on inclined tracks. The dirt produces about 3 per cent of concentrates which, however, are all sphalerite which assays 60 per cent zinc and between 1 and 2 per cent iron. Ordinarily 8 carloads of 30 tons each are produced each month.

The Big Jack Mining Company controls 11 acres in NE. ¼ sec. 6, T. 28 N., R. 24 E. Less than two acres have been cut out. The workings are in a soft ground containing considerable clay, on the 107-foot level. A face 14 feet high and 24 feet wide is worked. The run dips slightly to the west and becomes thicker but does not widen out. Timbering is necessary in the soft ground, and there is considerable water. The dirt runs about 6 per cent concentrates, sphalerite and galena in the proportion of 8 to 1. The sphalerite runs from 59 per cent to above 60 per cent of zinc and from 1 to 2 per cent of iron. Tiff and spar are associated with the ore. About 175 cars of dirt are handled per 10 hour shift. An upper run of 4 per cent ore 40 to 50 feet wide and 25 to 30 feet thick is not being worked at present.

The Good Luck Mine at the northeastern corner of the camp has been described in the quotation from Siebenthal. Work has continued at this mine and a large production has been made. In the fall of 1911 the mill was working ore from which 10 per cent of concentrates, all sphalerite, were recovered. The mill has a capacity of 100 tons per day.

The mill at the Lancaster mine to the south of the Good Luck burned in 1910. The Ethel Miller Mining Company is working a hand jig on the site of the old mill and has shipped several carloads of sphalerite. There is little galena in the ore, which is found in a hard ground.

The White Eagle mine and the Sweeny or McAlester mines have both been operated considerably and have produced large quantities of ore but neither mine was working during the latter part of 1911. Small productions of silicate and lead are made from some of the other mines, but the amount of this production is almost negligible.

The Miami Camp.

Geography and geology. The Miami mining camp is located from four to five miles north of the city of Miami. Most of the development in this camp is in the east half of sec. 1, T. 28 N., R. 22 E. and in the northwest corner of sec. 7, T. 28 N., R. 23 E. The village which has grown up at the mines is known as Hattonville (Post Office, North Miami). The Oklahoma, Kansas and Missouri Interurban Railway (steam)connects Hattonville with Miami and gives an outlet from the mines to the Fort Scott and Afton line of the St. Louis and San Francisco Railway at Miami.

The surface of the country is nearly flat with a very gentle slope south and slightly east to Tar Creek, a tributary of the Neosho River which joins the main stream about 5 miles south and 1 mile east of the camp. The Cherokee shale forms the surface rocks and dips at very low angles in a general northwesterly direction. Rocks of the Chester group lie a short distance beneath the surface and are exposed in the valley of Tar Creek up as far as the center of sec. 8, T. 28 N., R. 23 E., one and one-half miles north of the northeast corner of Miami. These rocks consist of sandstones and shales with some limestones. The Chestér is underlaid by the Boone formation which outcrops along Spring River 8 miles to the east, and on Neosho River south of Miami. There are unconformities between the Boone and the Chester and between the Chester and the Cherokee.

The lead and zinc ore has been found so far principally in the Chester sandstone. Along certain old solution channels the limestones in the lower portion of the Chester have been removed and the overlying sandstones have settled down on to the Boone. In this settling the sandstone has been broken and brecciated. The crevices and openings thus formed have been filled by a deposit of secondary chert, sphalerite, galena, and pyrite. Later development has shown that the brecciated condition as well as the ore continues down into the Boone so that it is probable that some of the limestone of the upper portion of the Boone as well as that of the lower part of the Chester has been removed by solution.

Nature of ores. In the Miami camp the ores are all sphalerite and galena; no oxidized ores are found. Pyrite is present in considerable quantity but so far very little tiff or spar (dolomite or calcite) has been found. A heavy oil or bitumen is associated with the ore and occurs in the same manner as the ore, i. e. in crevices and between the laminae of the sandstone. As has been mentioned, the galena and sphalerite occur in crevices in the sandstone, and in the chert. They also occur between the laminae of the sandstone and to some extent small crystals are disseminated through the sandstone. In the primary chert of the Boone the secondary chert and the ores occur in crevices and are found cementing the chert breccia. In crevices and pockets where the relation of the minerals to each other can be made out, the galena seems to have been deposited first as it occurs in large cubes next to the wall rock, the sphalerite fills in the spaces between the galena and often covers it. Pyrite occurs as small crystals on the galena and sphalerite. This successeion is plainly seen in some places but in others there is no apparent order of deposition. The ore ("dirt") runs high in concentrates, the recovery averaging about 10 per cent of the material handled, but probably not over 65 to 70 per cent of the metallic contents. In pockets of ore the recovery sometimes runs as high as 50 per cent of the dirt. The zinc concentrates on the other hand are of rather low grade on account of the pyrite and insoluble matter that they contain. In the early days of the camp, and in newly opened mines the concentrates also contain some bitumen which is penalized directly and also causes considerable pyrite to stick to the zinc concentrates, still further lowering the grade of the ore.

In newly opened mines the bitumen gives rise to difficulties in concentration. The bitumen "balls up" with the ore in the first cell of the cleaner jig and settles on the grate so that the cell must be cleaned out often. It also forms a film over the particles of sphalerite, which collects the fine pyrite and holds it so tenaciously that it cannot be washed off. Besides lowering the grade of the concentrates indirectly by increasing the percentage of pyrite, the bitumen is penalized directly. The only film formed from the bitumen on the water probably has a tendency to float on the fine ore slimes.

Shape of the ore bodies. The ore bodies so far worked consist of a number of approximately parallel runs. The principal one of these runs extends from south of the center of the NW. ¼ sec. 7, T. 28. N., R. 23 E. in a direction slightly west of north through the E. ½ sec. 1, T. 28 N., R. 22 E., and into sec. 36, T. 29 N., R. 22 E. This run is from 75 to 150 feet wide and from 15 to 30 feet in thickness. As shown up to the present time the length is over one mile and a half. The run dips to the north, depths at which the ore is encountered on different leases (See fig. 10) beginning at the south end of the camp being as follows: King Jack, 90 feet; New State, 100 feet; Turkey Fat, 120 feet; Emma Gordon, 150 feet; Oklahoma, 180 feet; Carson-Dodson, 210 feet.

A number of the operators believed that the body encountered on the Oklahoma and Carson-Dodson leases did not represent the run which was being worked farther south but that it represented a deeper run.

Several drill holes were sunk on the leases to the south and a second run was found at a considerable depth below the first, and this was considered to prove that the ore on the Oklahoma and Carson-Dodson leases was not part of the original run. The depths at which the lower run was found on different leases is as follows: Swastika, 135; King Jack, 160; Turkey Fat, 200.

From an examination of these figures it seems to the writer that it is more probable that the ore on the Oklahoma and Carson-Dodson leases is continuous with the upper rather than with the lower run of the south part of the camp. This is shown by tabulating the figures as follows:

Lease	Swastika	King Jack	New State	Miami Amalgamated	Emma Gordon	Oklahoma	Carson-Dodson
Depth to top Upper run....	90	90	100	115	120	170	210
Depth to top Lower run....	135	160	....	200	200	....	300

The data are not conclusive but it seems more probable that the run which dips from 90 feet on the Swastika to 115 feet on the Miami-Amalgamated should continue to dip until it reached a depth of 170 feet in the Oklahoma shaft and 210 feet in the Carson-Dodson, rather than that the lower run should dip from 135 feet at the Swastika to 200 feet at the Miami Amalgamated and then rise to 180 feet at the Oklahoma and dip again to 210 feet at the Carson-Dodson. The latter supposition is not impossible but seems very improbable. From the data at hand, the writer believes that the run in the northern part of the camp is continuous with the upper run and that the lower run (1) may be present on the northern leases at some such depth as 280 to 300 feet on the Oklahoma and continually deeper to the north or (2) may play out to the north or (3) may turn to one side. In the last case the ore on the Chapman-Lennon leases to the northeast of the Oklahoma may represent the continuation of this lower run.

It should be borne in mind that the number of drill holes is as yet too small to draw any definite conclusions, and that the statements made above are generalizations based on rather meagre data and that the views held at this time may be greatly altered by the drilling of a few more prospect holes.

To the west of the middle part of the main run is a second run which has about the same width as the main run. It is only about 1,000 feet in length. Farther to the southwest but still within the east

½ sec. 1, T. 28 N., R. 22 E. are two more short runs or groups of runs. In these minor runs the dirt is not so rich as that of the main run but the concentrates are of higher grade. The runs farthest to the southwest are very short and so narrow that they have not been worked profitably.

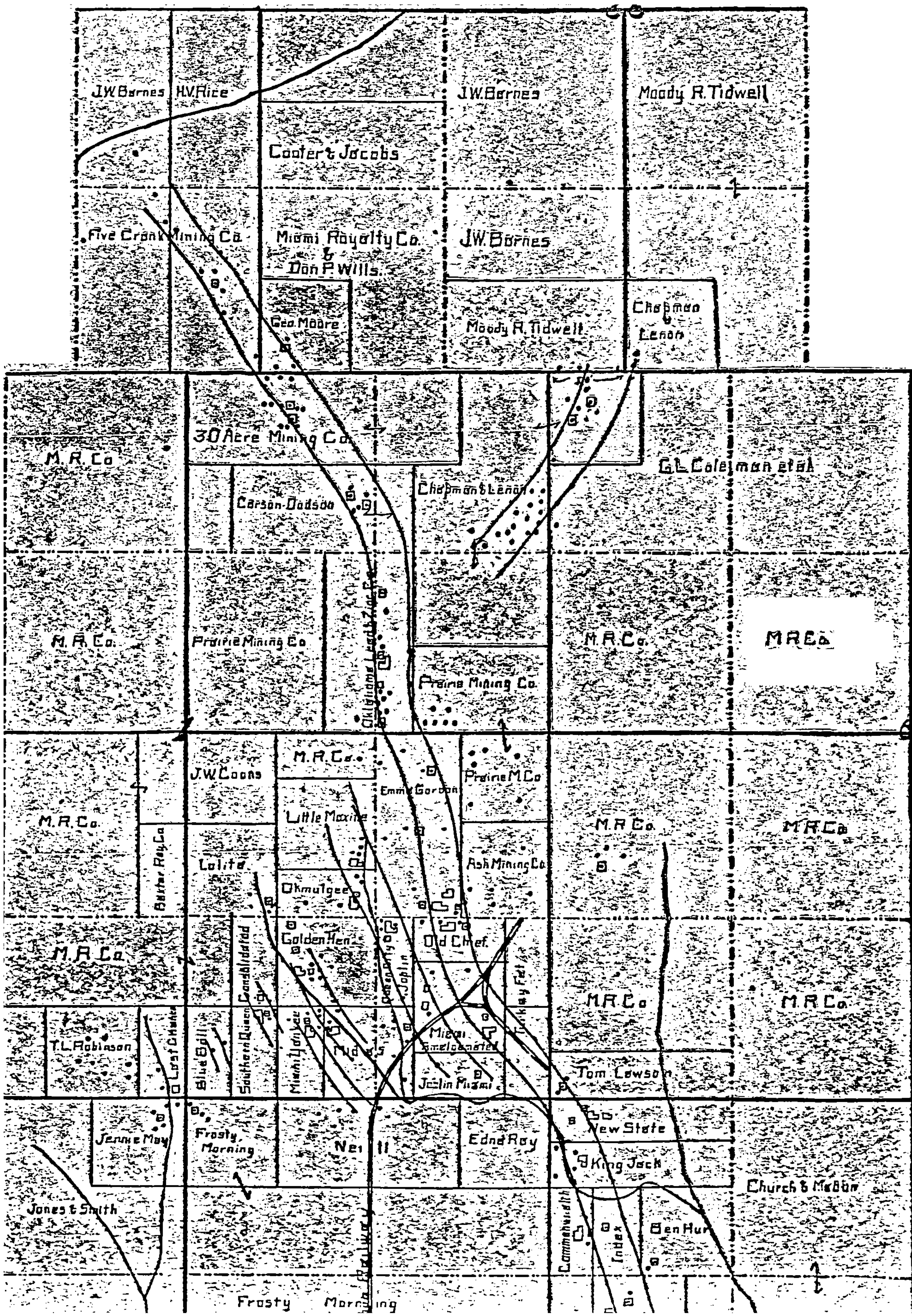
Mining methods and conditions. The mines at Miami have been developed by men from the Joplin region and the same methods which prevail there are followed. Prospecting is entirely by churn drilling. Shafts are easily sunk through the soft Cherokee shales except in cases where the water hinders operations. One shaft is usually sufficient for hoisting and pumping but a second shaft is necessary for ventilation when the underground workings become very extensive.

The water in the camp is difficult to control especially in the newly opened mines. However, the development of the camp has been from the south to the north and the dip of the ore body and of the country rock is in the same direction so that the opening of the new mines to the north has continually lowered the water level in the mines to the south. The strength of the water may be judged from the fact that 7 months pumping with two centrifugal pumps throwing six-inch streams was necessary before the 210-foot shaft on the Carson-Dodson lease could be sunk and a drift opened.

The water is a further hinderance in that it is strongly charged with hydrogen sulphide gas. In sinking shafts and in new openings the gas is so strong that the laborers can work only two or three hours at a shift, although there is much individual variation among the men in their ability to withstand the gas. Several workmen have been overcome by the gas and have been rendered temporarily blind by too long exposure to its action. After the drifts are opened and air gotten into the mine the gas gives no further trouble and in the older mines there is little or no odor of the gas.

The methods of milling and concentrating of the ore do not vary essentially from those used in other parts of the Joplin district. Fine grinding is necessary to separate the ore which is disseminated through the sandstone and this makes the use of concentrating tables necessary.

The leasing system is followed and the mines are seldom developed by the owners of the land. In Miami camp practically all the land is owned, or the first lease is held, by two companies, the Miami Royalty Company and the Emma Gordon Mining Company. These companies sub-lease the lands to the prospectors and operators. These in turn may lease all or part of their holdings to other parties, and the mines may be actually worked by companies holding the third or fourth lease. The royalty paid varies from 10 per cent where the lessee prospects and


J.W.Barnes
H.V.Rice
J.W.Barnes
Moody R.Tidwell
Cooter & Jacobs
Five Crank Mining Co.
Miami Royalty Co. & Don P. Wills.
J.W.Barnes
Geo.Moore
Moody R.Tidwell
Chapman & Lenon
30 Acre Mining Co.
M.R.Co
G.L.Coleman et al
Carson-Dodson
Chapman & Lenon
M.R.Co.
Prairie Mining Co
Oklahoma Lead & Zinc Co.
M.R.Co.
MRCo
Prairie Mining Co.
M.R.Co.
J.W.Coons
Emma Gordon
Prairie M.Co
M.R.Co.
Little Maxine
M.R.Co
M.R.Co
Baxter Roy.Co
Lolita
Ash Mining Co.
Okmulgee
M.R.Co.
Golden Hen
Old Chief
Consolidated
Joplin
Turkey Fat
M.R.Co
M.R.Co
T.L.Robinson
Lost Chance
Blue Bell
Southern Queen
Miami Jubilee
Miami Smelcometed
Tom Lawson
Joplin Miami
Jennie May
Frosty Morning
Neill
Edna Ray
New State
King Jack
Church & McBain
Jones & Smith
Commonwealth
Index
Ben Hur
Frosty Morning

develops the land if ore is found, to 50 per cent for proven mines equipped with mills.

Mining development. Under this heading a brief description of each of the mines is given with general data as to their workings, mill-

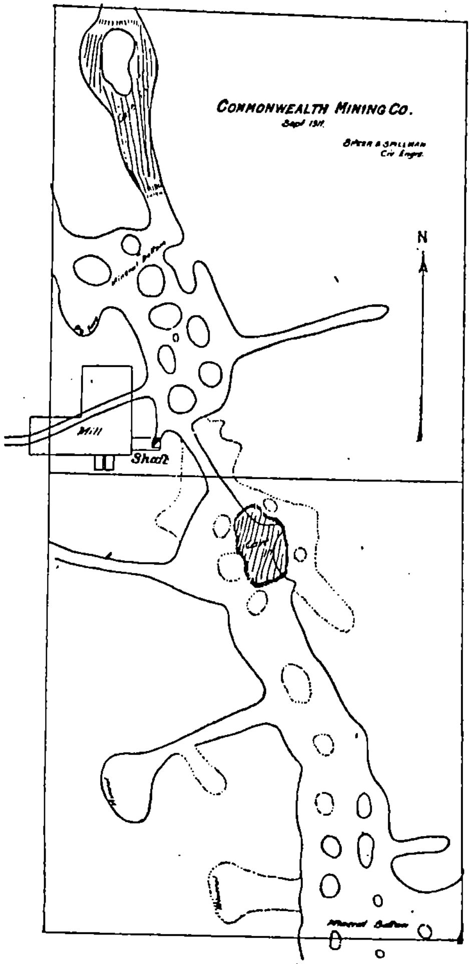


Fig. 11. Map of underground working of Commonwealth Mine.

ing equipment, output and ores. The properties on the main run are taken up in order south to north and then those on the minor runs in the same order. Finally a discussion of the prospecting outside of the developed portion of the camp is given. The arrangement of the properties is shown on fig. 10.

The *Swastika* is the lease farthest to the south that has been worked to any extent. The ore was found at a shallow depth and was worked out in a rather short time. A mill was erected but was later moved to the Sullivan lease operated by the Miami Amalgamated Company. The deeper run was found in a drill hole north of the mill site at a depth of 135 feet. If ore should prove to be present in quantity the lease will be revived.

The *Morning Star* (Commonwealth) lease has been mined out and the mill removed. The *Index* mine and mill was operated by the Kenwood Mining Company. Considerable production was made in 1908 and 1909. Operations were discontinued and the mill moved away. Both of these leases will be prospected for the deeper ore and may be revived. A shaft was sunk on the *Ben Hur* lease but apparently failed to show ore in paying quantities since there has been no further development. The nature of the underground workings in this portion of the camp is shown in fig. 11.

The *King Jack* mine was operated by the Temple and Chapman Lead and Zinc Company during 1908-09. A considerable production was made but the vein was worked out and operations discontinued for some time. The Miami Amalgamated Company now has charge of the lease and in the fall of 1911 was remodeling the mill and installing a modern gas engine. The shafts were being sunk to the lower run which was encountered in drill holes at a depth of 165 feet. The holes showed over 30 feet of good ore, both lead and zinc. The upper run was worked at 90 feet and the ore was rich and the concentrates of high grade.

The *New State* mine now operated by the Kansas Mining Company has been one of the most consistent producers of the camp. A 100 ton mill was erected in 1907 but was not in steady operation until the middle of 1908, since which time the mine has been almost a constant producer. The ore is worked from two shafts one 112 feet deep and the other 100 feet deep. The run averages about 100 feet wide and has a face of 12-14 feet. In this mine the ore is rich, the complete returns on can runs for three months showing a recovery of 10½ per cent of consentrates, of which about one-fouth was lead. About 6 per cent of blende and galena are found in the tailings from the mill and these are treated in a tailing mill equipped with six reciprocating tables. The zinc concentrates contain from 47 to 55 per cent of zinc, averaging 50-51 per cent, and 2 to 4 per cent of iron. Zinc concentrates from the tailing mill contain an average of about 45 per cent of zinc and 3 to 6 per cent of iron. The lead concentrates assay 80-81 per cent of metallic lead. Considerable ore is still in sight on the upper run and more can be obtained by removing the pillars which have been left to support the roof. Although the lower ore is also known to be present on the lease its exact extent has not been shown.

Merely the corners of the *Edna Ray* and *Tom Lawson* leases were crossed by the ore run and this was soon mined out. The mills which

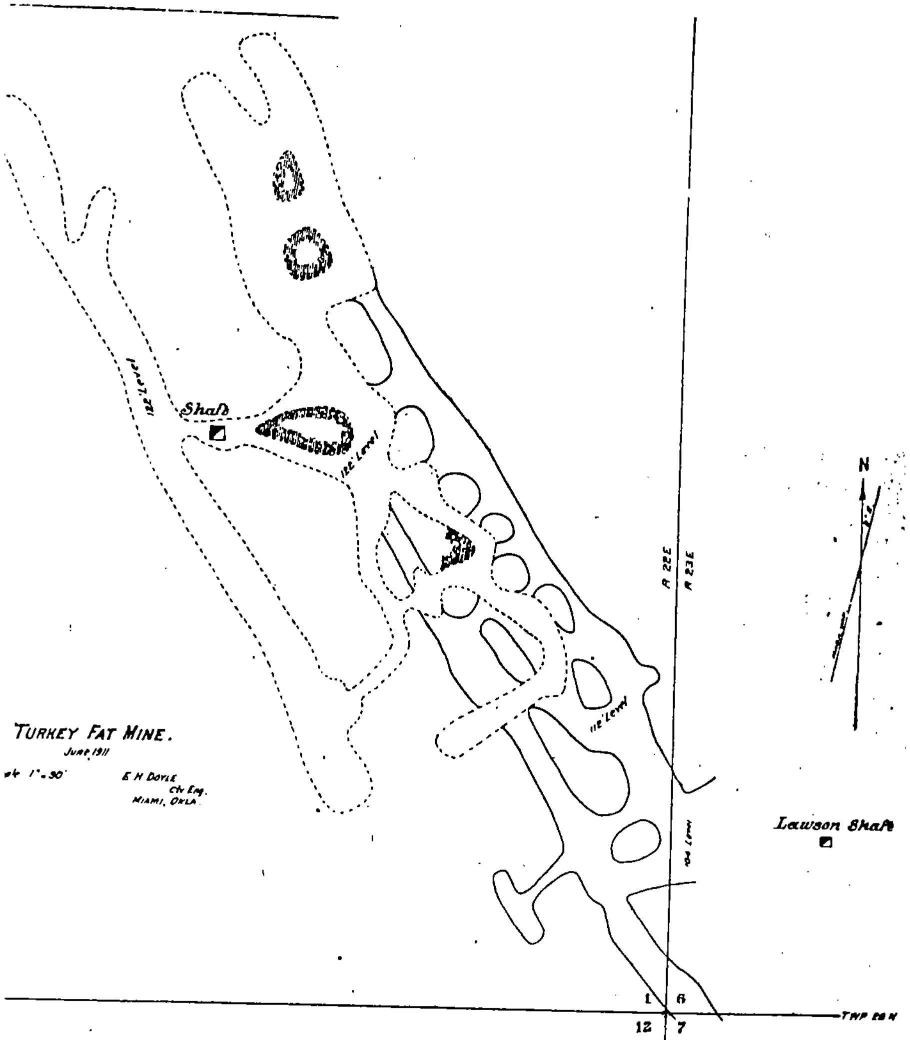


Fig. 12. Underground workings of Turkey Fat Mine.

e erected were soon removed, the Tom Lawson mill to Lincolnville the Edna Ray mill to the Oklahoma lease.

The *Turkey Fat* lease consists of 10 acres of land with the main crossing the southern end diagonally. This lease is the only one

which is operated directly by the Miami Royalty Company. The upper run of ore is found at 120 feet and averages about 16 feet thick and 20 to 50 feet wide. The one deep hole which has been put down (Nov. 1911) shows good ore from 202 to 225 feet. There is probably ore sufficient for a year's run in the upper ore body. The mill has a capacity of 100 tons of ore. In character the ore does not differ materially from that of the New State which has been described. The Turkey Fat has been second largest producer in the camp. The underground workings are shown in fig. 12.

The Miami Amalgamated Company operates the *Sullivan lease,* a square of 10 acres immediately west of the south half of the Turkey Fat lease. The upper ore run crosses the lease diagonally and is encountered at a depth of 110 to 125 feet. The ore carries about two and one-third times as much blende as galena. The blende concentrates usually carry 2½ per cent of iron. Deep holes have shown the lower run under the east side of this lease, and a good body of ore was shown from 200 to 250 feet. The cuttings assayed 30.69 per cent blende with very little galena. A shaft was being sunk to this deeper ore in the fall of 1911 when the writer visited this district.

One of the first mines opened in the camp was the *Old Chief* and this mine made considerable production in 1908, 1909, and 1910. The upper run was then exhausted and operations ceased. During 1911 the ground was prospected by the Standifer Mining Company and sufficient ore was found at a slightly lower level than the one which had been worked, to justify a resumption of mining.

The *Emma Gordon* lease, operated by the Standifer Mining Company, comprises 20 acres in a rectangle of two 10-acre squares, with the long dimension north and south. The ore run extends the full length of the lease. The ore has a face of 20 to 25 feet. Here the ore is very rich but contains much pyrite which materially lowers the grade of the zinc concentrates. The ores are treated in a 400-ton mill of the sheet ground type and the tailings from this mill in a tailing mill, equipped with 8 tables and operated by the High Five Mining Company. From February 5, 1910 to January 1, 1911 the average of the assays on the zinc concentrates from the big mill was, zinc, 45.56 per cent.; iron, 8.62 per cent. The average price received for the zinc ore was $23.34 per ton. Probably not over one-half of the upper run on this lease is worked out and the lower run is also known to be present but its exact limits have not been defined. The proportion of galena in the upper run is high but the lower run is practically all sphalerite.

The Oklahoma Lead and Zinc Company and the Carson-Dodson Company sublease from the Emma Gordon Company. A 200-ton mill has been erected on the former lease and ore is hauled by tram to this mill from the Carson-Dodson shaft. The depth to ore on the Oklahoma lease is about 180 feet and on the Carson-Dodson about 215 feet. Development of these leases has been greatly retarded by the strong head of water. Two 6-inch centrifugal pumps were kept in almost constant operation for 7 months before the water was lowered sufficiently to permit the hoisting of ore from the Carson-Dodson shaft. The first ore was hoisted in the fall of 1911 and proved to be very rich, one days run producing over 50 per cent. of concentrates, a large proportion of which was galena. The Chapman-Lennon leases are also sublet by the Emma Gordon Company. A shaft has been sunk t ore and a mill erected but as in the other leases at the north end of the camp, the water is very difficult to control and no ore has been produced. At present, (June, 1912) a pump is being installed which is reported to be the largest so

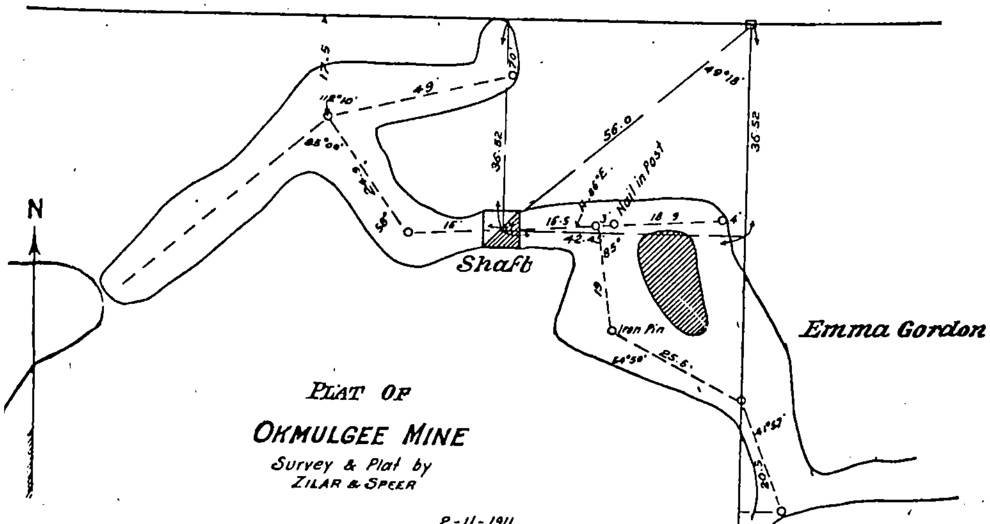


Fig. 13. Map of underground workings of the Okmulgee mine.

far installed in the Joplin district. It is hoped that this will handle the water and lower the level so as to permit the development, not only of this lease but of the other leases in this part of the camp.

Lying immediately west of the main run is a second run approximately parallel to it. The ore in this run is of the same general nature and occurs in the same conditions as that of the main run. The proportion of galena to sphalerite is somewhat less and there is less pyrite in the sphalerite concentrates. The Joplin-Miami, Queen City-Joplin, Okmulgee, and Little Maxine leases have been the principal producers from this run. The nature of the underground workings of the leases on this run is shown in the map of the underground workings of the Okmulgee mine (fig. 13.)

Still further west is a series of runs which are parallel to the main run but which are much shorter and narrower. The Golden Hen, Midas and Miami Yankee leases have produced considerable quantities of ore from the largest of these runs. On the Golden Hen lease the depth to ore is 130 feet, and the face of ore 14 feet. The run is 20 to 30 feet in width. The dirt contains about 8 per cent of concentrates, about ten times as much sphalerite as galena. The zinc concentrates average about 53 per cent zinc and 3 per cent iron.

The smaller runs to the southwest have not been successfully worked. The ore run is narrow and the dirt not very rich. The workings on the Donna (Southern Queen) and Consolidated leases are shown in figure 14.

No systematic drilling in search of deeper ore bodies has been done in the southwestern part of the camp.

PRODUCTION OF THE NORTHEASTERN FIELD.

The total production of the different camps in tons and its value from 1907 to 1911[33] is given below.

Quapaw camp.

Year	Galena	Value	Sphalerite	Value	Zinc carbonate	Value	Total production	Total value
1907	647	$43644	3062	$118400	97	$1631	3806	$163675
1908	504	26076	3539	109779	19	300	4062	136155
1909	244	12545	5015	207585	38	586	5297	220716
1910	270	13727	3921	152166	....	....	4191	165183
1911	329	18202	2245	82571	6	85	2580	100858

Miami camp.

Year	Galena	Value	Sphalerite	Value	Total tons concentrates	Total value
*1907						
1908	1730	$92177	6475	$139595	8205	$231772
1909	4056	210586	11569	361029	15265	571615
1910	3364	174134	10055	294877	13419	469011
1911	2848	152527	8391	247530	11039	400057

*Small production from one mine included in Quapaw camp.

33. Statistics from Mineral Resources of the United States, United States Geological Survey.

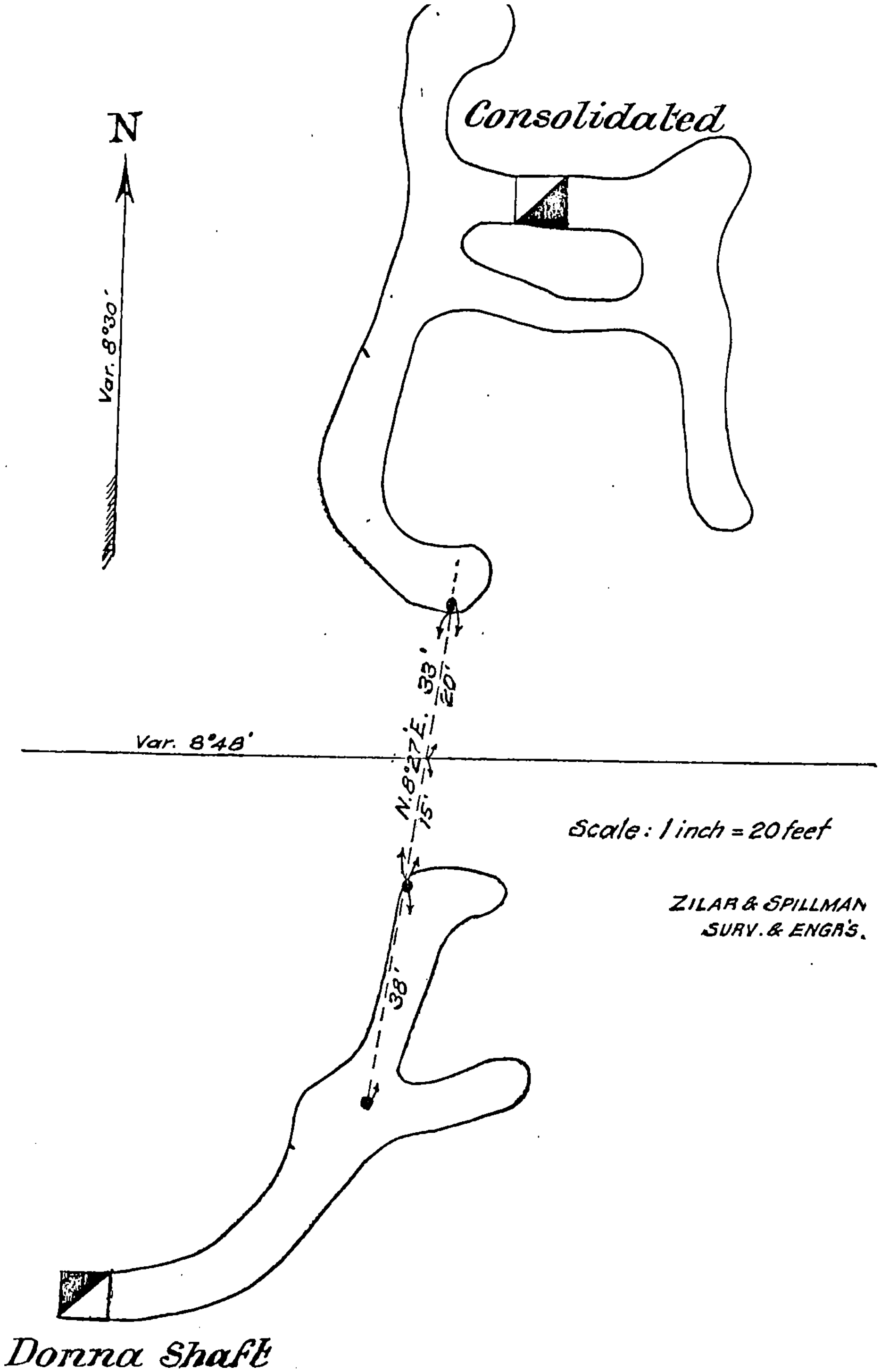


Fig. 14. Underground workings of the Donna and Consolidated leases.

Peoria camp.

Year	Galena	Value	Lead carbonate	Value	Sphalerite	Value	Zinc carbonate and silicate	Value	Total production	Total value
1907	15	$1157	5	$275	14	$568	583	$14036	587	$16006
1908	2	80	....	....	24	617	261	6325	287	7012
1909	6	246	....	....	....	....	267	7348	273	7594
1910	3	160	1	42	....	....	65	1406	69	1608
1911	12	628	....	....	....	....	311	8330	323	8958

OTHER OCCURRENCES OF LEAD AND ZINC IN NORTHEASTERN OKLAHOMA.

The Sycamore Creek District.

The prospects along the Seneca fault, which has been described under structure, are included in this district. These prospects were visited by Siebenthal in 1906 and as practically nothing has been accomplished since that time his description is given without further remarks:

"South of Seneca the Seneca fault cuts diagonally across the divide between Lost and Sycamore creeks, striking the latter 1½ miles west of the Missouri-Oklahoma line. At this point considerable prospecting has been done in and along the fault block, though without developing any paying bodies of ore. The first prospecting, which yielded some silicate, was done by means of a drift under the south bluff of Sycamore Creek a few feet above water level. Here the fault block is about 180 feet in width, and the throw is not sufficient to bring the sandstone of the Chester down to the present level of the surface. The limestones of the block, probably opened up more or less by the faulting, have been subjected to much solution, with the result that the space between the side faults, as exposed in the bluff, consists of a great mass of chert blocks lying topsy-turvy, the interstices being filled with tallow clay and residual clay. In the ravine just south of the bluff, near the southeast edge of the block, is a shaft from which drifts at the 75-foot and 104-foot levels extend southwestward for about 100 feet each. Thin ore was encountered in the lower drift, and better ore in the upper one. The ore consists of galena, sphalerite, and silicate. The silicate was too heavy to be separated from the sphalerite on hand jigs, and the ore could not be sold at a profitable price. Another shaft, 250 feet southwest of the deep shaft, encountered some large chunks of galena, which had to be broken up before they could be brought to the surface. Southwest of this point the displacement by the fault is greater, and at a distance of 400 feet sandstone and sandy shale of Chester age are present to a depth of 65 feet, with some galena and sphalerite in crevices in the sandstone and in the secondary limestone cement of associated chert breccia."

Ottawa Prospects.

Some prospecting has been done near Ottawa, in SE. 1/4 sec. 36, T. 28 W., R. 23 E. NE. 1/4 sec. I. T. 28 N., R. 23 E. Galena and sphalerite are reported to occur under the same general conditions as in the Quapaw-Lincolnville district. No oxidized ores are found. One shaft has been sunk to 60 feet but no large body of ore is in sight at this horizon. Drill holes are said to show a disseminated ore carrying 2 to 3 per cent of concentrates, at a depth varying from 90 to 120 feet. The thickness of the ore is from 4 to 10 feet.

McCuddy Land.

Some lead and zinc has been obtained from pockets by shallow workings on the McCuddy land in sec. 14, T. 28 N., R. 22 E. To the end of 1911 over 35,000 pounds of galena and 10,000 pounds of sphalerite had been sold.

PROSPECTS FOR THE EXTENSION OF THE NORTHEASTERN FIELD.

All the commercial deposits of lead and zinc ore so far found in the Joplin district are intimately associated with the effects of the underground solution which took place between the deposition of the Mississippian rocks and the overlying Pennsylvanian shales. As has been noted the principal deposits are found in a basal "breccia" around old sink holes in the Boone which were filled by the Pennsylvanian shales. The effects of the inter-Mississippian-Pennsylvanian underground solution are found only to the northeast of a line passing through Miami, Wyandotte, and Tiff City, so that, in general, commercial deposits of ore are not likely to be found south and west of that line. Nothing in the geologic conditions of the area occupied by the outcrop of the Boone formation in Delaware, eastern Mayes, and northern Adair and Cherokee counties indicates the presence of lead or zinc in paying quantities.

The conditions at the Miami camp are different in some details from those in the other camps of the region. Here the principal ores so far worked occur in rocks of Chester age and the underground solution has acted upon the limestones lying immediately above the Boone chert.

The writer regards it as possible that the conditions at Miami may be duplicated at other localities along the contact of the Pennsylvanian

and Mississippian rocks for some distance to the southwest of the present productive region. The surface rocks give no indication of the location of areas affected by underground solution and therefore prospecting will be entirely a matter of chance and the chances for encountering narrow ore bodies like the one at Miami, even if they are present, which is by no means certain, will be very small. The prospects, then, for any great extension of the field are not at all favorable but if there is any such extension it will almost certainly be along the Missippian-Pennsylvanian contact to the southwest of Miami.

CHAPTER III.

OTHER OCCURRENCES OF LEAD AND ZINC IN OKLAHOMA.

THE ARBUCKLE MOUNTAIN REGION.

Location and Area.

The Arbuckle Mountains occupy an area 60 miles long and 10 to 30 miles wide in the south-central part of Oklahoma. The area includes southern Murray, northern Carter, the greater portion of Johnston, south-central Pontotoc, and a small portion of south-western Coal counties. The mountains are divided into two unequal portions by the Washita River.

Structure and Stratigraphy.

The Mountains consist of cores of granite, porphyry and associated igneous rocks all probably of pre-Cambrian age, surrounded by strata of paleozoic rocks dipping steeply away from the igneous cores. The simple dome structure is much complicated by minor folding and by thrust faulting which produces a typical Appalachian structure.

The section as exposed shows the following general succession of rocks:

Age.		
Pennsylvanian	Franks conglomerate (North of Mountains)	
	Glenn formation (South of Mountains)	
Mississippian	Caney shale	1600′
Mississippian (?)	Sycamore limestone	0- 200′
Devonian (?)	Woodford chert	650′
Siluro-Devonian	Hunton limestone	0- 300′
Silurian	Sylvan shale	60- 300′
Ordovician	Viola limestone	500- 700′
	Simpson formation	1200- 2000′
Cambro-Ordovician	Arbuckle limestone	4000- 6000′
Cambrian	Reagan sandstone	50- 500′
Archean	Tishomingo granite	—— ——

The formations from the Reagan to the Caney were apparently laid down in a horizontal position over the granite, but in middle or late Pennsylvanian time were elevated into a dome and eroded. The Franks conglomerate and later Pennsylvanian rocks were deposited and still lie almost horizontally on the upturned edges of the older rocks.

Up to the present time the Arbuckle limestone and in less measure the pre-Cambrian rocks have been the only formations in which metallic minerals in notable quantities have been found and lead and zinc seem to be confined to the Arbuckle limestone. In view of this fact and also because the higher formations have no apparent connection with the origin or deposition of the ores the discussion will be confined to the Arbuckle limestone.

The Arbuckle limestone is exposed in three large areas in the Arbuckle Mountains as follows: (1) the major portions of Tps. 1 N., and 1 S., in Rs. 5 and 6 E., and smaller portions of the townships surrounding these; (2) an area of about one and one-half square miles in the southern part of Tps. 2 and 3 S., R. 5 E.; and (3) west of Washita River, a roughly triangular area consisting of the south part of T. 1 S., in Rs. 1 E., and 1 W., and the northern parts of T. 2 S., in the same ranges and the central portion of T. 2 S., R. 2 E.

The description of the formation as given by Taff[34] is as follows:

"Beginning at the base there are thin-bedded siliceous limestones 50 feet thick. There is a gradual change upward from these thin beds into the succeeding member, 300 to 400 feet thick, which consists chiefly of heavy-bedded dull-bluish and cream-colored dolomites. Many of these massive beds are indistinctly bedded and weather into very irregular brown and sometimes nearly black bowlders. Others are more crystalline, marble-like and of pinkish or gray colors. Succeeding these come about 250 feet of thin-bedded granular limestone and compact blue limestones which pass gradually into the main body of the formation, consisting of 3500 to 4000 feet of massive, compact magnesian limestone, the lower half of which contains chert in places. These limestones on weathering usually present smooth white surfaces of practically the same color as the fresh rock. As the top of this thick member is approached the limestone beds become less magnesian and thinner and are succeeded by the highest member, which is composed of limestone interstratified with occasional sandy beds and strata of red, yellow, and green clays."

The age of the Arbuckle limestone has hitherto been expressed by the term Cambro-Ordovician. In his new classification, Ulrich[35] places the upper half of the formation as certainly the age of his Canadian system, while the basal 700 feet is regarded as late upper Cambrian. Above this portion comes 400 feet of pink and white marble interbedded with massive cream-colored, black-weathering dolomite that is probably Ozarkian if that system is represented in the section. Succeeding this is a thickness of 2000 feet of massive, interbedded pure and magnesian lime-

34. Tishomingo folio (No. 98), Geol. Atlas U. S., U. S. Geol. Survey, 1903, p. 3.

35. Bull. G. S. A., vol. 22, p. 641.

stone in which no fossils have been found but which are lithologically similar to the succeeding 2300 feet which contain Canadian fossils and are therefore regarded as probably Canadian but possibly as Ozarkian.

The Davis Zinc Field.

While a great deal of the area underlaid by the Arbuckle limestone west and south of the Washita River has been prospected for minerals, the only area which has been developed to any extent or which gives any immediate prospect of such development is that known as the Davis zinc field.

Geologic conditions. The portion of the Arbuckle Mountains west of the Washita River is composed of a porphyritic granite core which forms two hills known as the East and West Timbered Hills, with the Reagan sandstone, the Arbuckle limestone and the younger formations dipping steeply away from these granite outcrops. Along the east side of East Timbered Hills the Reagan is faulted out and the Arbuckle is in contact with the granite.

The productive horizon is the member of the Arbuckle limestone which is composed of marbles and dolomites and which is regarded by Ulrich as probably representing his Ozarkian system. The whole outcrop of this member is called the "mineral belt" and is all claimed to carry various minerals in considerable quantities by some of the prospectors of the district but so far only a small area in secs. 17, 18, and 21 in T. 1 S., R. 1 E. has been proven to bear any metallic minerals in commercial quantities and sphalerite and smithsonite are the only valuable minerals so found.

The dolomites and limestones in this area dip to the northeast generally at from 40° to 50° but this general dip is considerably complicated by minor folding and by faulting. Several minor faults cross the outcrop at about right angles to the strike. The displacement of these faults varies from a few feet to 20 rods and in all observed cases the block on the northwest side of the fault is displaced to the east. All the rocks are very much broken by jointing but this is especially true of the dolomite. A sharp blow of the hammer breaks a large block into small angular fragments very few of which are over one inch in any dimension. The concentration of the zinc in the dolomite is probably due to this broken condition, the small seams forming channels for the passage of circulating waters carrying zinc in solution and at the same time affording small cavities for the deposition of the ore.

Nature of the ores and associated minerals. In this region the zinc ore occurs as the carbonate from the surface to a depth of 5 to 8 feet. Below this level the zinc is in the form of the sulphide, sphalerite or zinc blende. The carbonate contains large proportions of dolomite. The blende is usually finely disseminated but in some cases seems to have largely replaced the country rock in irregular masses which are confined to the dolomite layers so that the blende makes up the larger portion of some of the strata. The largest mines that have been opened, the Hope-Sober, the Ben Frankin mine of the United Mine and Milling Company, and the Goose Nest mine of the Arbuckle Mining and Milling Company, show two layers of the blende bearing rock each 3 to 4 feet thick separated by a layer of "dead rock," 5 to 6 feet thick, carrying only thin seams of blende. A well drilled on the property of the United Mining and Milling Company is said to have shown the rich ore to a depth of 30 feet and to have encountered a similar body 15-20 feet thick at 125 feet below the surface.

The prospectors of the region report very good assays on material from practically all the prospect holes, although the appearance of the material does not indicate that much metallic material is present. Analyses of surface samples of carbonate showing as high as 47 to 50 per cent zinc are commonly reported and approximately average sample of blende ore are reported as showing 58 to 60 per cent zinc. However, the highest assay reported on a carload of blende ore is 38.5 per cent zinc.

Some of the samples collected by this Survey show the following results: Four samples consisting of chips from surface blocks in different parts of the field show respectively, trace; .17 per cent; .77 per cent; samples of carbonate from near the surface and from shallow prospects in different localities show respectively.55 per cent, .45 per cent, .77 per cent, and 5.4 per cent. A sample composed of chips of a large number of blocks in a pile of blende ore selected for milling show 25.46 per cent; a sample of blende from one of the deeper prospects shows 8.88 per cent; a sample from all parts of one of the most widely advertised mines shows 8.08 per cent. The concentrate from the only mill which has been installed shows 45.96 per cent. The mill was not run long enough to get the tables and grinding machinery properly adjusted so that the showing of the concentrate is probably not so good as can be obtained.

Other metals occur in small quantities with the zinc. An interesting feature is a narrow belt of iron ore (hematite) seldom over one rod in width, which lies near the middle of the dolomite member throughout the length of the outcrop. Bowlders of hematite, in part altered to limonite, are strewn thickly along the surface of this belt. Some of them are as much as 10 feet in diameter. In only a few cases does the iron ore extend as much as 10 feet beneath the surface. The richest portion of the zinc ore so far seems to be in close proximity to this iron-bearing horizon.

The cause of this segregation of the iron ore into so narrow a belt is problematic but it is entirely possible that it is due to a small fault parallel to the strike of the rocks. Such a fault would be almost impossible to trace in the dolomite unless the belt of ore itself be taken as evidence of its existence. The localization of the ore took place before the formation of the small faults perpendicular to the strike previously mentioned since the iron ore belt is offset by them.

Pyrite is practically absent from the zinc blende in the body of ore near the surface. The cuttings from the deep body encountered in the well previously mentioned show some pyrite but it is apparently in small quantity.

Lead occurs in small quantity very near the surface as the sulphide and as the carbonate or sulphate. It is absent from the deeper ore and has not been observed in sufficient quantity to make its separation profitable. Copper stains are often present and some pieces of malachite and azurite have been discovered in different parts of the field. So far no large body of copper ore is known to have been found although there are rumors to the effect that such bodies exist. Yellow stains of greenockite, cadmium sulphide, are common on the rock and ore near the surface.

Present development. The development in the Davis field at present consists principally of shallow prospect holes, of which there are a great number scattered over the hills, especially in the region east of the East and West Timbered Hills.

In two localities steps toward further development have been taken. Immediately east of West Timbered Hill the United Mining and Milling Company has erected a 4-table mill at their Ben Franklin mine near the center of sec. 21 T. 1, S., R. 1 E. The machinery is on the ground to erect a 4-table mill on the Arbuckle Mining and Milling Company's property in the SW. ¼, sec. 17, T. 1 S., R. 1 E. In the NW. ¼ sec. 18, T. 1 S., R. 1 E. the Rumley or "Incline" mine consists of an inclined shaft or tunnel. The track in the tunnel dips at about 20° to the southeast, while the rocks dip at 30° to 35° to the north. In the summer of 1911 the tunnel had reached a length of about 150 feet. A sample selected from the dump was analyzed but showed no metallic value.

Some prospecting has been done two miles east of East Timbered Hill. One drill hole 160 feet deep is reported to have encountered a body of ore 14 feet thick at a depth of 67 feet, which shows 19 to 26 per cent of sphalerite, and another body 27 feet thick at 140 feet which is also very rich. The writer has not seen any cuttings from this hole and the authorities for the analyses are not known to him.

One great hinderance to the development of the filed is the lack of adequate water supply for milling operations. The best prospects are situated on the divide between Colbert and Honey creeks, and the small branches flowing into these streams do not carry any water during the greater part of the year. The mill at the United Mining and Milling Company's mine was idle almost all of 1911 on account of lack of water.

Prospects for future development. Although there is undoubtedly considerable ore present in the field there are several factors which combine to make the value of the field somewhat problematical and to render any prophecy along this line a matter of guess work. Some of those factors are as follows:

1. The question as to the extent of the ore. While the prospectors admit that the richest ore is near the outcrop of iron ore which has been described, they claim that good values are present practically to the edges of the dolomite outcrop. The samples so far collected from prospect pits near the edges of the dolomite and analyzed in the Survey laboratories do not bear out this claim but the number of samples collected is too small to warrant a definite conclusion.

2. The depth to which ore occurs. The first body of ore does not exceed a depth of 40 feet over most of the area which has been the most thoroughly investigated. The only investigation at a greater depth than 50 feet is the well which has been mentioned. Some ore was found at about 125 feet, but neither the exact thickness nor the percentage of zinc was accurately determined. Thorough prospecting by drilling is the only methods of settling this question and until this is done, any statement as to the probable value of the field must be founded on mere supposition.

3. The absence of pyrite is favorable to the production of concentrates very low in iron, but on the other hand the extreme fineness of grain of much of the ore will render complete separation very difficult and the concentrates will probably run high in lime.

4. The question of adequate water supply is unsolved. The portion of the region which is being developed lies near the headwaters of a small creek and there is not sufficient water through most of the year to supply the one concentrating mill already installed. The limestone and dolomite are too badly fractured to form a reservoir for any water which might be impounded during the wet season. The problem may be solved by the deep wells which are proposed, but the high dip of the rocks, the small catchment areas, and the presence of numerous sinkholes renders it improbable that an adequate supply will be encountered at a reasonable depth. A possible solution is to pipe water from Honey Creek near Turner's Falls. The distance is about 4 miles from the mines in section 18, and the mines are approximately 250 feet above the creek. Water for the northern portion of the field can probably be secured from Colbert Creek, about 2 miles below the stream from the mines.

5. The ore or concentrate must be hauled to Davis, a distance of 7 miles over roads which at present are very bad. This of course is not prohibitive, but should be borne in mind in trying to arrive at any estimate as to the value of the field.

WICHITA MOUNTAIN REGION.

The Wichita Mountain group lies to the northwest of the Arbuckles and extends from Lawton on the southeast to Granite on the northwest a distance of 65 miles. The mountains are 30 miles wide at the middle and narrow rapidly toward both ends. They are divided into groups known as the Wichita, Quana, Raggedy, and Devils Canyon mountains.

The Wichita Mountains include the largest area and are composed principally of a medium to coarse-grained pink to red granite. The Quana Mountains are principally of porphyritic granite; the Raggedy Mountains are isolated peaks of anorthosite, black and gray granite, gabbro and diorite; and the Devils Canyon Mountains to the west consist of peaks of medium to coarse grained red and pink granite.

The general structure of the group is apparently the same as that of the Arbuckle Mountains, but the Redbeds more nearly covered the Wichitas than they did the Arbuckles and the great series of paleozoic sedimentaries which surround the Arbuckles are buried under the Redbeds, except for an outcrop of the Reagan sandstone and a range of hills of Arbuckle limestone along the north side of the mountains, and three knobs of Viola limestone near Rainy Mountain Mission.

No metallic minerals have been reported from the Arbuckle limestone of the Wichita Mountain region but a great deal of time and money have been spent in prospecting the various areas of igneous rocks.

All of the granites are cut by dikes of varying composition, but principally of a basic nature. The dike rocks are usually fine-grained and green to black in color. In general the contacts of the dikes with the granite or gabbro country rocks are very sharp and show very little or no mineralization. The igneous rocks are manifestly much older than the oldest sedimentary rocks of the region which are Middle Cambrian (Upper Cambrian of Ulrich). They are therefore almost certainly pre-Cambrian and from the nature and relation of the rocks are more probably Archeozoic than Proterozoic (Algonkian). The coarse-grained character of the granites and gabbros indicates that they were formed at considerable depths below the surface. It seems, therefore, that the granites now at the surface were intruded into pre-existing surface rocks and were later cut by the dikes, and that all the activity took place long before the beginning of the Cambrian. The rocks into which the granites were intruded and which must have formed a great

thickness above the present surface, were then eroded during the long interval before the deposition of the Reagan sandstone in middle Cambrian times. If there was any mineralization by hot solutions from the granites or dikes, it must have taken place in the rocks nearer the surface, which were eroded before the deposition of the Reagan.

The geologic conditions, therefore, are not such as to lead to the expectation of finding notable deposits of metallic minerals in the igneous rocks of these mountains and so far the developments have been in line with the indications of the geologic conditions. Thousands of dollars have been spent in prospecting in this region and so far there has been no return. Hundreds of prospect holes may be found in the mountains, most of them along the dikes but some of them in the ordinary granite or gabbro country rock where there is no indication whatever of metallic minerals.

Prospecting was extremely active after the opening of the country to white settlers and great excitement resulted in 1902. In October, 1903 the region was visited by H. Foster Bain of the United States Geological Survey who visited many prospects and collected samples from the prospects, 71 of which were assayed in the laboratory of the Survey at Washington. Of these 71 were assayed for gold, 10 for silver, 2 for copper, and one for lead. No trace of gold was found, two samples showed 0.14 and 0.92 ounce per ton of silver, respectively; the two samples assayed for copper gave 0.35 and 10.81 per cent respectively, and the sample assayed for lead gave 3.36 per cent. The sample showing 10.81 per cent copper was picked material from a vein about one and one-half inches wide.

The claim from which the sample showing 3.36 per cent lead was collected is located in sec. 16, T. 3 N., R. 14 W. It is described as follows by Bain[36]:

"CLARK AND BENNET MINE.

"This is also known as the Galena mine. It is located a short distance northwest of the Gem and Diamond mines, and shows a greenstone dike about 2½ feet thick cutting through the red granite. This dike has been faulted and considerably broken up. There has been a development of white quartz in the interstices of the broken rock. Accompanying the quartz is galena and some chalcopyrite. The sample taken from here (W-48) was from the dump and represented the best material which could be found. It showed on assay, as noted below, no gold, 0.92 ounce of silver, and 3.63 per cent of lead. The silver value is unimportant. The lead is not enough to give the material rank as an ore. In its present form and in order to make mining pay, it would be necessary to

36. U. S. G. S., Prof. Paper. No. 31.

erect concentrating machinery and produce an ore carrying a larger amount of lead. The development work so far accomplished does not show enough lead to warrant this, and while the matter is one of personal opinion, it is not believed that further development work would give any better results."

The conclusions which were reached by Bain in regard to the mineral possibilities are as follows:

"In view of the precautions taken in collecting the samples, and the great care with which they were assayed, the absolutely uniform absence of even a trace of gold and only the occasional presence of a small quantity of silver, copper, or lead allows but one conclusion to be drawn, namely, that none of the prospects examined shows any ore in the proper sense of the term, nor does any one of them have any present or probably future value. The possible exceptions in the case of copper and lead have already been discussed in detail.

"Whether future prospecting may reveal other occurrences which do have value cannot, it is true, be stated. It is believed, however, that the prospects examined were fully representative and have, in many cases at least, been developed enough to allow a proper judgment as to their value to be made, and in no case do they offer any encouragement whatever for additional prospecting.

"In the granite mountains near Lugert there are certain coarse pegmatites showing crystals of quartz 3 inches or more in length. With the quartz crystals are some small, black, semi vitreous crystals recognized by Doctor Hillebrand as belonging to the columbite-tantalite group. It is hoped that further investigations may show the presence of some of the rare earths.

While the results of the investigations were disappointing in so far as they failed to show the presence of the expected ore bodies, the region is one of other valuable resources. The granite, which is so abundant, is suitable for building purposes, and is at many points excellently situated for quarrying. The limestones are available for the manufacture of lime and are of suitable composition for the manufacture of Portland cement if fuel and industrial conditions ever change so as to warrant investment in that industry. The small asphalt springs found near the east end of the Fort Sill Reservation are possibly indicative of larger deposits of oil and gas, and the excellent soil of the prairies and valleys, combined with good water resources, afford the basis for a large and thriving population."

A considerable amount of work has been done since that time but the conclusions reached have been borne out so far. No shipments of ore are known to have been made which have repaid expenses. Very

little development or prospecting is going on at present in the greater portion of the mountains but in a few of the more promising prospects some attempt at development is being made.

LAWTON AREA.

One of these localities is a few miles northwest of Lawton. On petition, these prospects were visited by D. W. Ohern, Director of the Oklahoma Geological Survey in March, 1912, and a report was made to the petitioners. This report is given in full:

General geology. "The region is underlain by complex series of igneous rocks, that is, rocks that were once in a molten state. These consist largely of a pink granite. This granite is widely exposed not only in the immediate region examined but throughout the Wichita Mountains in general from near Lawton on the southeast to Granite on the northwest, a distance of 50 miles. The rock is always hard and compact and is therefore very difficult to work in.

Intruded into the pink granite are numerous masses of dark rock (usually called trap) which varies considerably in mineral composition and texture from place to place. But the variations are not important. The bodies of this rock are also extremely variable in size. Some are only an inch or two, or even less, in width while others are several hundred yards wide or even more.

Quartz stringers are very common in the entire region especially in the granite. These are very small, few exceeding a half inch or an inch in width. The granite hills are in many places stripped clear of all soil and rock debris, and such places offer excellent opportunity for observing the stringers. They are observed to run for short distances and then thin out, others often appearing and then likewise disappearing.

The best observations lead me to the firm belief that faults are common. Faults are fractures or breaks in the rocks, along which movement of rocks has taken place.

There are several zones along which the rock is badly weathered, or rotted so to speak, to a considerable depth. In other places small streams run along the zone made weak by the breaking of the rocks. Without doubt these faults play an important part in the origin of the ores.

Prospects examined. Very much to my regret, it was impossible for me to enter all the various prospect shafts. This was owing in part to the presence of water and also to the fear of encountering gas. Only one of the prospects visited is being worked and in this only was I able to go to any depth. So that this report is not as full as is desirable on my part.

The Starley Mine. This prospect was examined pretty thoroughly and numerous samples taken from which assays were made. The shaft at present is down about 70 feet deep. All drilling is being done by hand, and is an extremely slow process, the only rock encountered being the pink granite which is very hard.

The foot wall is here rather sharply defined, being evidently formed by a fault. Some mineralization has taken place in the country rock on the foot wall, but it is too slight to be considered. On the hanging wall the pink granite has been mineralized in some places to a considerable extent. The massive granite is impregnated chiefly with galena, this being the only mineral visible to the naked eye with the exception of small amounts of iron sulphide. Several samples taken at various depths gave the following assays, lead being the only metal determined except in No. 7:

	Lead.
No. 1, 5 ft. from surface	3.32%
No. 2, 12 ft. from surface	3.11%
No. 3, 22 ft. from surface	3.84%
No. 4, 34 ft. from surface	4.87%
No. 5, 44 ft. from surface	12.45%
No. 6, 65 ft. from surface	12.87%
No. 7, 70 ft. from surface	5.86%; gold $.85

silver tr.; copper none; zinc trace.

These assays show a downward enrichment of the ores which is a good omen. The last assay seems to be an exception but does not in my judgment detract from the other values. If the last of the assays be taken as the average, lead is the only thing to be taken into account. But when other things are considered the assays give but little promise.

As already noted the shaft is being sunk in the granite. The expense connected with mining this impregnated rock is very high. In some places the feldspar of the granite is almost entirely lacking so that the mass of the rock is made of quartz. This makes the work even more difficult.

An all important factor here, as in similar cases, is the amount of ore in sight. This cannot be determined with anything like precision. At present the ore body is exposed for about 6 or 7 feet from the foot wall. There is no way of ascertaining further measurements.

Should extensive work be undertaken water will soon become an important matter. There is very little near at hand and certainly not enough for jigging if the process should be instituted.

Should the ore be hauled to railway it will be rather expensive as is evidenced by the condition of the road in the first 3 of the 8 miles to

shipping point. Hauling under these conditions will cost at least $2.00 a ton.

If operations should be undertaken by machinery, the source of power is important. There is some wood near at hand but it would be unsatisfactory as a fuel as experience in other similar regions has shown. Coal would have to be hauled 8 miles by wagon. No water power is to be had in the immediate vicinity. Probably the most satisfactory source of power would be had by installing a dam at some of the sites in Medicine or Cache creeks and converting the power into electricity, transporting the same by wires to the scene of mine operations.

When all these factors are considered it appears that the outlook for this prospect is not bright unless the ore body is much larger than present conditions indicate and unless there is a marked downward enrichment of the ores.

A few hundred yards north of the prospect just discussed lies another opening of but a few feet in depth. The site was evidently suggested by the presence of a fault which has caused a zone of rock 2 to 3 feet wide to become deeply weathered. The country rock here has been mineralized to a very small extent, a few very small masses of galena being visible. From what can be seen there is nothing to give warrant for further prospecting. No vein or lead is visible which would give promise.

Coal Lode. About one and one half miles west of Dr. Starley's prospect lies the Coal Lode prospect. At the time of my two visits this prospect was partly filled with water and hence I was unable to gather information upon which to base an opinion of very much value. The shaft has been sunk to a depth of 70 feet or more. On the dump is considerable material containing lead ore of some promise. Assay from such material however would be of no avail amounting to nothing better than a guess. It was impossible to ascertain exactly what is the nature and size of the ore body; but from the material on the dump I am disposed to think the prospect is very much like that of Dr. Starley, that is, that the country rock has been mineralized along a fault. I can give no opinion of the value of this property.

Copper Eagle Prospect. This prospect lies about five miles west of the Starley prospect. It is sunk to a depth of 70 feet in the hard fresh pink granite, no trap being directly associated. I examined carefully the walls of the shaft to some depth, being unable to go to the bottom on account of water and gas. The material on the dump showed some stainings of the green hydrous carbonate of copper (malachite) but no other evidence of ore was seen. It is difficult to understand why this was sunk here, there being, so far as I can see, absolutely nothing to give promise of encountering anything of value. There are no veins or leads to be seen in the shaft that are not common to the region in general. I see no wisdom in pursuing this project further.

The American Girl. This prospect lies between the Coal Lode and the Copper Eagle. Here also water and gas prevented entrance into the shaft. I am informed that the shaft has been sunk to a depth of 170 feet. The material in the dump contains considerable jack (sphalerite) and it is not impossible that it may be and is found in paying quantities.

Of the prospects examined only the Starley, Coal Lode and American Girl show promise. In the first, unless the body of ore proves very large soon and unless the ore grows much richer downward, further work would be unwise on account, chiefly, of the very high cost of working in the country rock. As above stated, nothing definite could be learned concerning the Coal Lode and American Girl."

In regard to the Wichita Mountain region as a whole it may be said that there is little or nothing to indicate that it will ever be a producing region of lead, zinc, or other metals. A few small areas show some prospects of development but even in these cases the appearances are not altogether favorable and their future value is problematic.

THE OUACHITA MOUNTAIN REGION.

Many reports have been current as to the occurrence of lead in the Ouachita Mountains of southeastern Oklahoma. Most of these are based on stories of the Indians having obtained lead for bullets from some place in the region. So far nothing definite is known as to the localities in which it is supposed to occur and no samples from the region have been seen. The mountains consist of a great thickness of sandstones, shales, and cherts, ranging in age from Ordovician to Pennsylvanian. The only metallic mineral known to occur is manganese which occurs in small lumps and nodules in the Arkansas novaculite (upper part of Talihina chert) of Ordovician age. So far no bodies of sufficient size to serve as an ore of manganese have been found. The formations exposed in this region have been pretty thoroughly prospected in Arkansas and no metallic deposits of value have been found. This is, of course, not to be taken as proof that there are no such deposits in the rocks of Oklahoma, but it renders their occurrence improbable, since, so far as can be seen, the conditions are altogether similar in the two states.

MINOR OCCURRENCES.

Samples of a sandstone with disseminated crystals of galena have been sent to the Survey office from Ada and the same material has been on exhibit in the Mineral Building at the State Fair. From the appearance of the material it should be easily worked and probably contains

sufficient lead to make it profitable, if it should occur in sufficient quantities. So far as is known, however, the amount available is small, although detailed work in the locality may reveal commercial deposits.

Lead or zinc or both have been reported from a great many other localities in the eastern part of the State and several very rich samples have been sent to the Survey office for identification. In every instance the mineral, usually galena, is of the type and appearance of that from the Joplin region and can usually be traced to that locality. Many of the inhabitants of eastern Oklahoma have visited the Joplin field and have brought samples back with them. These specimens lie around until their true origin is forgotten, or are lost and then found by parties who do not know their origin, and are regarded as indicating large bodies of ore in the immediate vicinity. While it is not impossible that workable deposits of lead and zinc may be found in other localities it is fully believed that the localities previously discussed, viz:, the extreme northeastern corner of the State, the Arbuckle and Wichita Mountains and possibly the Ouachita Mountains, are the only ones in which there is a reasonable expectation of finding either lead or zinc in commercial quantities.

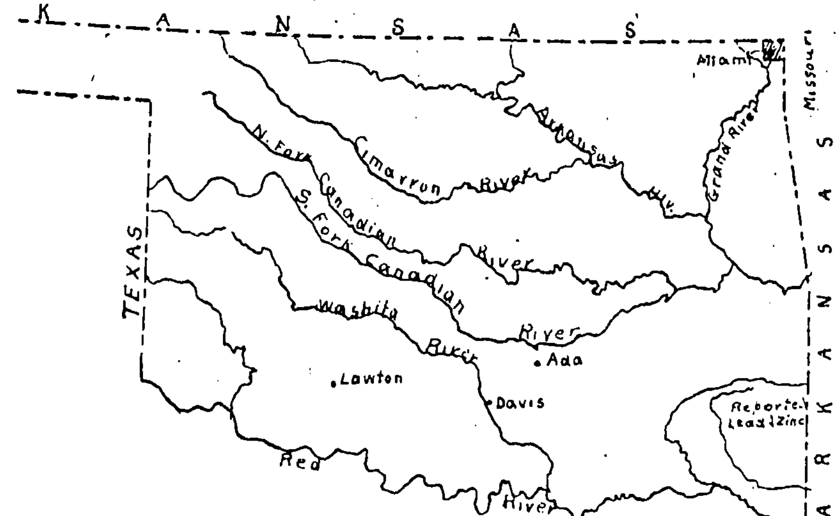


Fig. 15. Sketch map of Oklahoma showing lead and zinc localities.

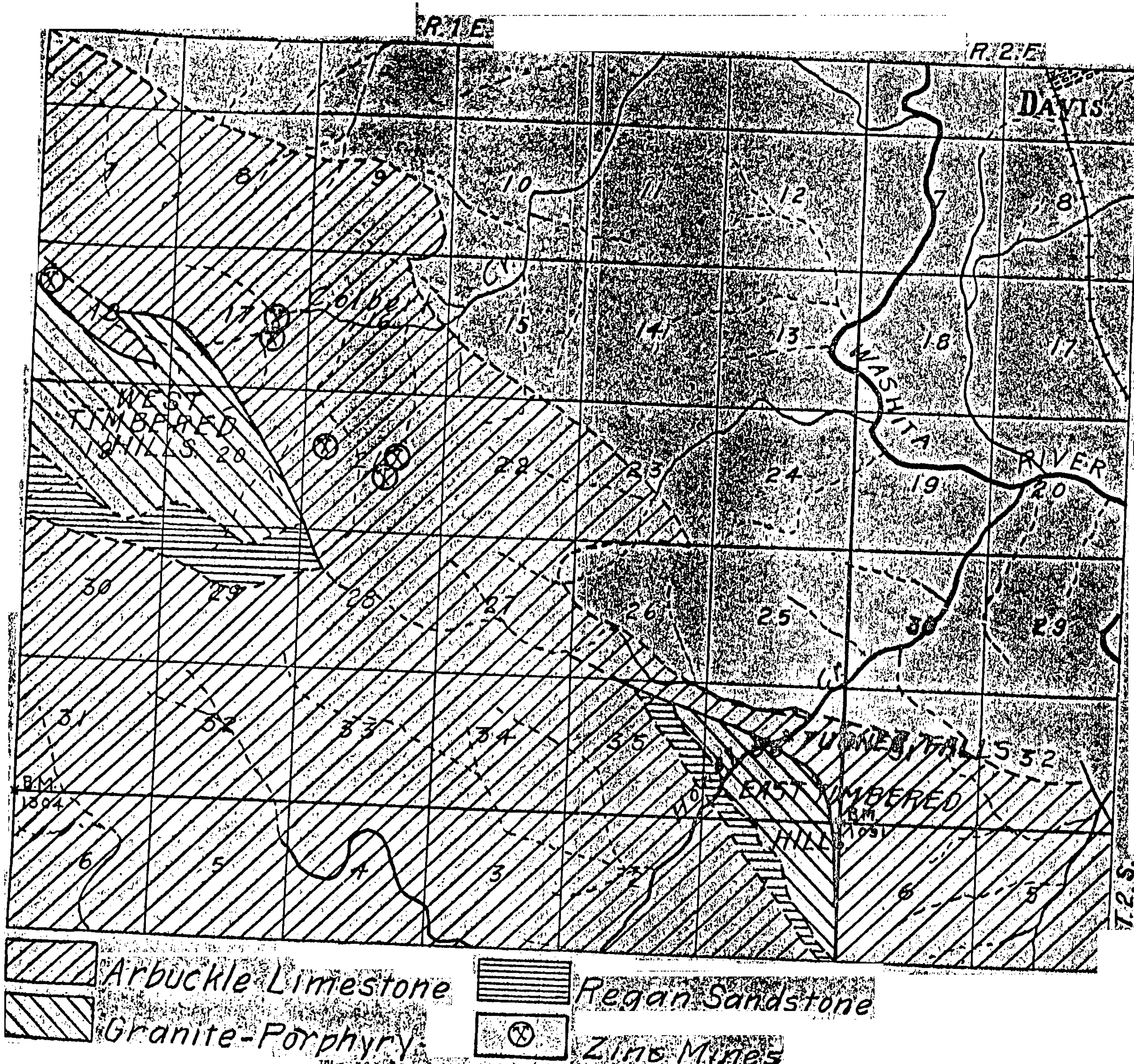


Fig. 16. Map of region near Davis showing zinc mines.