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The role of geology in prospecting for lead and zinc in the Tri-state district

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THE RÔLE OF GEOLOGY IN PROSPECTING FOR LEAD AND ZINC IN THE TRI-STATE DISTRICT

BY
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THESIS

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PLATES

INTRODUCTION

The present generation has seen many changes in all phases of human endeavor, and the changes which have been made in the extraction of metals from the earth are not the least of these. The application of science to our industries has revolutionized many of them. Today quantity production in our factories is an accepted thing, and in the mines, application of the same principles has made possible the working of the low-grade copper deposits of Utah, Arizona, Chile and Belgian Congo. The mining industry has made use of almost all of the sciences in one form or another to aid it in economically extracting the ore from the earth, but this paper will deal with but one of these, the science of geology and its application to the search for lead and zinc in the Tri-State Distict of Missouri, Kansas and Oklahoma.

In the early days of mining around Joplin, Missouri, shallow shafts were sunk wherever surface indications were favorable. If ore were struck in the first shaft, drifting would immediately be started, and a 'gouge' would be in operation. If ore were not struck in the first shaft, another would be sunk some distance from the first. When the faces were worked far enough from the shaft that a long tram was necessary, the shaft would be abandoned and another sunk in the direction of the orebody. The mills in those days consisted of one or more hand-jigs, so that it was no trouble to move the mill with the shaft. Most of the early mining was done from grass-roots down to the water-level, which was usually about fifty feet from the surface. Lead ore only was taken; the zinc ore then had no value.

As the price of lead ore advanced and uses for zinc were found, it became profitable to go below the water table and mine the larger ore deposits found there. This necessitated pumping the water and made the original investment too large for the individual or small group of miners. With the advent of capital, the hand-jig method of recovering the ore gave way to mechanically operated jigs and tables. The large amount of capital put into the mills required that an orebody be blocked out with a reasonable degree of accuracy, before the mill was built and money spent for pumping equipment. This state of affairs heralded the advent of the churn drill as a means of proving the existance of an orebody before a shaft was sunk. In the Joplin district three or four holes on a forty-acre tract was considered amply sufficient to prove or disprove the existance of a mineable deposit of ore.

Fig. 1

Horse winch used for hoisting at a prospect shaft near Springfield, Mo.

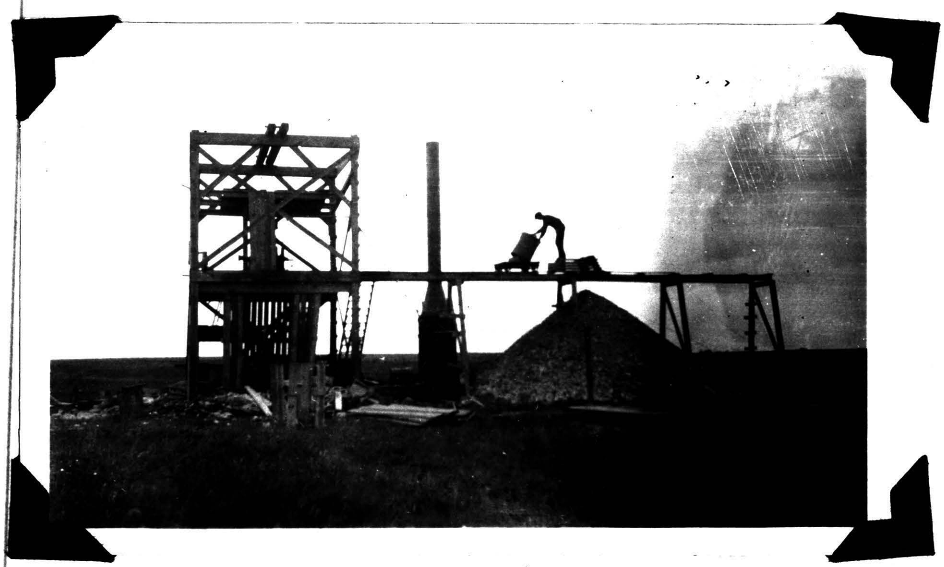

Fig. 2

Modern hoisting shaft for prospecting near Quapaw, Oklahoma.

Many of the methods in use in the old Joplin district were changed with the discovery of the unusually rich deposits of ore found in the vicinity of Picher, Oklahoma. The author is especially familiar with the deposits of this camp, and it is with the geology and methods of prospecting in this camp that the present paper will deal. The methods of prospecting are now the same in all parts of the district, but the geology, especially the type of ore deposits, is different in the several camps of the district.

With the coming of the churn drill, prospecting was put on a more exact basis, but it was not until the last few years that the operators have felt the need of more scientific prospecting. The application of geology to prospecting by the larger companies engaged in mining is only in its infancy, and it really has not had a chance to show what it can do, and how it can save the operator thousands of dollars by locating the barren areas and limiting the intensive prospecting to areas that have the best possibilities.

AREAL GEOLOGY

Ordovician

The oldest rocks penetrated by deep drilling in the Picher camp are of Ordovician age. The Roubidoux formation is penetrated at depths of around 1000 feet, somewhat less in the southern part of the camp and nearer 1100 feet in the northwest extension. The Roubidoux, as far as known from the drilling, is composed of white sandstone, quartzitic in part, but more generally loosely cemented and water-bearing. The sandstone beds are interlayered with thin beds of medium gray, sandy dolomite. The drilling does not penetrate very far into the Roubidoux, for the upper beds yield abundant potable water, so that the total thickness of the formation is unknown in this area.

The Roubidoux is overlain by the Jefferson City formation. There is about 500 feet of this in the Picher area. As the formation does not outcrop within the area, it is impossible to distinguish the several members of the group as given in Dr.C.L.Dake's paper on The Problem of the St. Peter Sandstone. It is composed of a light gray limestone

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C.L.Dake, Bull.Mo.School of Mines and Metallurgy, The Problem of the St.Peter Sandstone, Aug.1921, pp.12-14.

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ranging from crystalline to compact, interlayered with beds of white sandstone which are almost all quartzite. The beds of limestone contain thin beds and nodules of flint. The flint ranges from snowy white to gray and blue, translucent 'water flint'. There is also some oolitic flint. This is usually brown and translucent with white oolites, but some clear blue-gray with white oolites was also noted.

Mississippian

Kinderhook
- St.Joe (Chattanooga shale)

Lower Burlington

Upper Burlington (Boone formation)
- Grand Falls chert
- Limestone and chert
- Short Creek oolite
- Quapaw chert
- Glauconite

Limestone and chert

Chester (Carterville)

C.E.Siebenthal in his report on the origin of

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C.E.Siebenthal, Origin of the Zinc and Lead Deposits of the Joplin Region, U.S.G.S. Bull.606, 1916, p.25.

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the lead and zinc deposits of the Joplin region places the black shale which overlies the Ordovician rocks in the Devonian period. Later work has shown that this shale is

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R.B.Rutledge, personal communication
E.B.Branson, The Devonian of Missouri, Missouri Bureau of Geology and Mines, Vol.XVII, 2nd Series, 1923, pp.7-8

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early Mississippian in age rather than late Devonian. This shale is placed in the St.Joe formation by R.B.Rutledge. The formation consists of blue and black shale ranging in thickness from a featheredge to 40 feet where it outcrops in the vicinity of Noel, Mo. It is very thin or entirely absent over much of the mineralized area of the Tri-State District and it is on this fact that Siebenthal bases his theory of the origin of the ore deposits. A thin shale ranging from a few inches to several feet has been found by drilling in various parts of the District. At Galena, Kansas it is found at 250 feet, while north of Picher it has been found at 375 feet. Drilling in the immediate vicinity of Picher has failed to show any of this shale. Southeast of Picher in the vicinity of Noel, Mo. the shale outcrops in the banks of the creeks.

Overlying the St.Joe formation is the Lower Burlington. The Lower Burlington ranges in thickness from 75 to 100 feet. It consists of a dark gray to blue-gray fine-grained limestone interlayered with beds of flint. The flint is usually of the darker colors, blue and gray predominating, although considerable white flint can also be found. Where the white flint is present,it is usually mottled with dark gray and sometimes brown. The Lower Burlington can be distinguished from the Upper Burlington by the larger number of Spirifers it contains. The Lower Burlington is locally known as the 'Second Mississippi Lime' and is usually considered the lower limit of commercial ore deposits. Some lead and zinc has been found within the formation, but none has been in sufficient quantity to mine.

The Grand Falls chert member of the Boone formation overlies and grades into the Lower Burlington. The Grand Falls chert ranges in thickness, where distinguishable, from 15 to 60 feet. It consists of massive, thick-bedded flint beds, white, medium gray or blue-gray in color. The flint breaks with a characteristic sharp fracture which has given to it the name of 'butcher-knife flint'. The massive flint is a local phenomenon, and in many places the flint is absent and its place is taken by a fine-grained gray limestone. Where the limestone is present, it is impossible to distinguish the member for one of the chief means of identification is the massiveness of the beds of flint. In some places the limestone, where occurring as thin beds or lenses in the massive flint, has been dissolved out and replaced by a secondary black flint known as jasperoid. In many places the beds of flint have been brecciated and the fragments cemented by this jasperoid. The jasperoid is black or gray, sometimes brownish, in color, very hard and tough. The Grand falls chert is an important ore horizon in the Picher camp, being mined at depths of from 300 to 340 feet.

Between the Grand Falls chert member and the Short Creek oolite member which lies 100 feet above, there is a series of limestone and flint beds in which are included two very important ore horizons, the first occurring about 40 feet below the oolite and the second occurring about 70 feet below the oolite. The limestone of this series is usually of a massive, brown, coarsely crystalline variety. It contains numerous fossils. Some of the beds are as much as 30 feet thick without any partings. The flint occurs as beds, lenses or nodules. White or gray are the dominant colors for the bedded flints, with white, blue-gray and brown dominant for the lenses and nodules. The beds are frequently brecciated and the fragments cemented with jasperoid and in many cases with ore minerals.

The Short Creek oolite member of the Boone formation is one of the principal horizon markers of the District, when it can be found. It is fairly persistent, usually occurring as a brown or light gray limestone, locally silicified to a brown flint. It has a maximum thickness of about eight feet, but its usual thickness is around four or five feet. The Short Creek oolite can be distinguished from the younger Chester oolite with a fair degree of accuracy, because of the uniform size and degree of rounding of its individual oolites. The Chester oolites are not of uniform size and many of them are flattened to a noticeable degree.

Lying immediately above the Short Creek oolite is five to thirty feet of leached white flint or 'cotton-rock' which has been given the name of Quapaw chert by Siebenthal. It has been named after the Quapaw camp which lies to the southeast of the main Picher camp about five miles. This leached white flint is an excellent aid in locating the Short Creek oolite, for the Quapaw chert is very characteristic and the oolite lies immediately below it. In many parts of the field at the horizon of the Quapaw chert there is found a blue and white flint which is ore-bearing. This is an important ore horizon of the Picher camp, being the 200 tp 235-foot level of many of the mines.

Near the horizon of the Short Creek oolite, about forty feet above, is a stratum of limestone containing a green mineral, which the author thinks is glauconite, scattered through it. The glauconite is usually found in limestone, but in many instances it has been found in secondary flint. Where the oolite is present, the glauconite is not of much importance, but where the oolite is absent, the glauconite serves as a horizon marker. One of the ore horizons, the Quapaw chert horizon is found forty to sixty feet below the glauconite. The glauconite is very easy to distinguish and once a driller has been taught to identify it, he has no trouble in locating it in the drill cuttings. In some instances it has been found immediately above the ore horizon and in some instances it has been found in the roof and heading of several mines. There is some question as to whether the green mineral is glauconite or chlorite. Some of the operators and engineers who have worked in the lead mines of southeast Missouri are inclined to call it chlorite. To the author the mineral has more the characteristics of glauconite than chlorite. Its presence near the oolite horizon lends some weight to the glauconite theory. No analysis of the mineral has been made, but the author hopes to have this done in the near future. For the present the question of the true character is of secondary importance, the important thing is that it is a fairly persistent horizon marker which is easily distinguished.

The upper portion of the Boone formation above the glauconite consists of a series of limestone and flint beds. The limestone is gray, white or brown, the gray and white being compact to fine-grained, and the brown usually coarsely crystalline. The flint is blue, gray or white, with the blue and white predominant. The white limestone is frequently leached and is called 'cotton-rock' by some of the drillers. There are several non-persistent ore-horizons in this upper Boone. There is one at the 200-foot level and another at the 165-foot level. In some mines these horizons are mineralized all the way between and are mined as a single level.

At the 200-foot level there is a seam of black shale that is fairly persistent over much of the camp. It ranges in thickness from a featheredge to seven feet. Stringers and thin seams of this shale are found on the lower levels, but are evidently the result of local settling with the resulting crushing and movement attendant upon such phenomena. The shale has been squeezed down through fractures and cracks in the underlying rocks. Some of these stringers have been traced back to the original seam, but many of them are so thin that it is impossible to trace them for any distance.

The upper surface of the Boone is very irregular as there is an erosional unconformity of some duration between the Boone and the overlying Chester formation.

The Chester formation in this area has been called Carterville and consists of chert-free limestones and shales. The limestone is a blue flaggy rock, oolitic in part. The oolites are irregular in size, being larger than those of the Short Creek, and many of them are flattened to a noticeable degree. The oolite does not occur in any specific horizon, but promniscuously throughout the formation. The limestone is fossiliferous. The shale of the Chester is a hard, black fissile shale for the most part, and it is very difficult or almost impossible to distinguish from the Cherokee shale of the Pennsylvanian period which overlies it. The Chester is absent from much of the field, or is indistinguishable from th the Cherokee shale, where it is present only in its shaly phases. The maximum thickness of the Chester in the Picher camp is given as forty feet by C.E.Siebenthal, but the author thinks that it is thicker than this, reaching sixty and probably seventy feet.

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C.E.Siebenthal, Origin of the Zinc and Lead Deposits of the Joplin Region, U.S.G.S., Bull.606, 1916, p.28

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Pennsylvanian

The Pennsylvanian period is represented by the Cherokee shale of the Des Moines group. It is the surface rock over much of the Picher camp, although it is absent from some parts of the eastern and southern areas. It is essentially a shale, although there are some beds of sandstone and limestone present. The limestone is blue or gray, compact and contains large quantities of pyrite. The sandstone beds are as much as fifteen feet thick, though usually thinner. They are composed of rounded quartz grains loosely cemented with a calcareous or ferruginous cement. Some of the sandstones contain small quantities of oil, but never in paying quantities. The shale ranges from light gray soapstone to black fissile beds and varies in thickness from forty to eighty feet in the main Picher camp, up to 250 feet in the northwest extension of the camp in Kansas. Along the so-called Miami fault the shale attains a thickness of 330 feet. This shale has a very important bearing on the origin of the ore deposits, according to H.A.Buehler.

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E.R.Buckley and H.A.Buehler, The Geology of the Granby Area, Mo.Bureau of Geology and Mines, Vo.IV, 2nd Series,1905,pp. 78-85

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STRUCTURAL GEOLOGY

The Picher camp lies on the western slope of the Ozark Dome and has no distinct structural features. The rocks all dip away from the main uplift to the west and northwest. To the south there are some minor folds that follow the general trend of the axis of the major fold, northeast-southwest.

There is no faulting in the camp showing vertical displacement, although some slickensides have been noted in several of the mines. The so-called Miami fault appears to be a very pronounced fracture zone which has allowed more than the usual amount of local settling. The Miami fault has been traced for a distance of several miles along a northeasterly course from the northern edge of the town of Commerce, Okla., to within a few miles of the town of Baxter Springs, Kansas. It is distinguished by the unusually deep shale along its course. The normal shale depth off to the side of the fault is about eighty to one hundred feet, whereas along the fault zone the shale reaches a depth of as much as 330 feet. As far as has been determined by mining along this fault zone there has been no vertical displacement. The fault zone has played a very important part in the deposition of the ore for some very rich deposits have been found just off of the zone of deep shale. The deposits all lay at nearly right angles to the strike of the fault. The strike is about N 30 E.

RESUME OF THE SEVERAL THEORIES OF ORE GENESIS

There are several very different theories advanced for the origin of the deposits of zinc and lead in the Joplin region. C.E.Siebenthal gives a very excellent resume of these several theories and his resume is quoted in toto.

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C.E.Siebenthal, Origin of the Zinc and Lead Deposits of the Joplin Region, U.S.G.S., Bull.606, 1916, pp.39-42.
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"If considered as to their genesis, the zinc and lead deposits of the Joplin district have long been acknowledged to be among the most puzzling in the whole category of ore deposits, and this statement is easily borne out by a perusal of the diverse views set forth in the following brief resume of the various theories presented to account for their deposition.

"Schmidt and Leonhard, who were the first geologists to make a detailed investigation of the zinc and

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Adolph Schmidt and Alexander Leonhard, The Lead and Zinc Regions of Southwest Missouri, Mo. Geological Survey Rept. 1873-74, pp.412-414, 1874.
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lead deposits of southwestern Missouri, concluded as the result of their studies that the ores were deposited contemporaneously with the dolomitization of the Mississippian rocks, apparently by laterally moving but not surface solutions.

"Jenney, studying the deposits 20 years later,

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W.P.Jenney, The Lead and Zinc Deposits of the Mississippi Valley, A.I.M.E. Trans., Vol.22, pp.219-224, 1894
****

held that the ores were derived from the pre-Cambrian crystalline rocks through the fissures of indefinite vertical extent and were deposited by solutions of moderate or normal temperature, cooled by their long journey from their sources. E.M.Shepard discussing the Greene county deposits

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E.M.Shepard, Geology of Greene County: Missouri Geological Survey, Vol.12, pp.169-173, 1898
****

a few years later, concurred in this view.

"F.L.Clerc, in a short description of the geology of the mines of the district, suggested that the ores were lea-

****
J.N.Wilson, Lead and Zinc Ore of Southwest Missouri Mines; authenticated statistics, with contributions by F.L.Clerc and T.N.Davey, Carthage, Mo., pp.8-11, 1887
****

ched from the sink-hole (Cherokee) shale patches which dot the region and which "may be only a small part of those that once existed".

"Haworth, writing in 1904 upon field work done in

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Erasmus Haworth, Special Rport on Lead and Zinc: Kansas Univ. Geol. Survey, Vol. 8, pp.117-126, 1904

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1898-99, concluded that the ores were in the main derived from the overlying Cherokee (Pennsylvanian) shale, and carried down and concentrated in the Mississippian limestones and cherts.

"Buckley and Buehler, in their report on the Granby

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E.R.Buckley and H.A.Buehler, Geology of the Granby Area: Mo. Bureau of Geology and Mines, 2nd ser., vol.4, pp.78-110, 1906

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area, state their belief that the metals of the present concentration were disseminated in the overlying Pennsylvanian shale, during the erosion of which the metals were oxidized and taken into solution, carried downward into the Mississippian limestones and cherts, and there concentrated and deposited by the mingling of oxidizing and reducing solutions.

"Winslow showed by the large-quantity analyses of

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Arthur Winslow, Lead and Zinc Deposits: Mo. Geol. Survey, vol.7, pp.447-487, 1894

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Robertson that zinc and lead are disseminated through the Archean, Cambrian, Ordovician, and Mississippian rocks of the Ozark region, and he argued that these rocks by their decomposition in turn furnished the metals of the succeeding rocks; that the caverns and sink-hole breccias of the prek Pennsylvanian erosion furnished favorable sites; that the solutions from the limestone land furnished the metals, and that the organic matter deposited by the Pennsylvanian sea constituted a suitable precipitant; wherefore he held that beneath the margin of the Pennsylvanian sea the conditions were the most favorable for the concentration of the ores. With this view Branner, Keyes, and Adams are in substantial

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J.C.Branner, The Zinc and Lead Region of North Arkansas: Ark. Geol. Survey Annual Rept. for 1892, vol.5, pp.15-35, 1900.

C.R.Keyes, Diverse Origins and Diverse Times of Formation of the Lead and Zinc Deposits of the Mississippi Valley:A.I.M.E. Trans., Vol. 40, pp.184-231, 1910.
G.I.Adams, Zinc and Lead Deposits of Northern Arkansas: U.S. G.S. Prof. Paper 24, pp.43-46, 1904
****

agreement, though Branner thinks that a part of the bedded deposits are of a contemporaneous sedimentation with the inclosing rocks. Branner and Keyes also lay special stress on synclinal structure as favorable to the concentration of ore bodies.

"Bain adopted the theory, previously worked out by

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H.F.Bain, Preliminary Report on the Lead and Zinc Deposits of the Ozark Region: U.S.G.S. 22nd Annual Rept., pt.2, pp.204-215, 1901
****

Van Hise for the upper Mississippi Valley region, of a primary deposition by ascending artesian currents and a secondary concentration by descending currents keeping pace with the lowering of the land level by erosion. Bain further contributed the view that the ore-bearing currents in the Joplin region ascended from the Cambrian and Ordovician rocks through fault zones cutting the "Devono-Carboniferous" shales, thus accounting for the localization of the ores and the occurrence of dolomite.

"In the Joplin district folio Smith accepted, with

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W.S.T.Smith and C.E.Siebenthal, U.S.G.S., Geological Atlas, Joplin district folio (No.148),pp.18-19, 1907
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modifications, the Van Hise-Bain idea of a primary concentration of the ores by ascending waters that had derived their metal content from either the Mississippian or the Cambrian and Ordovician limestones, although convincing evidence was not at hand to decide from which source the metals were chiefly derived. He greatly minimized the importance of sulphide enrichment by downward currents, maintaining that the vertical order, frequently observed, of galena above, next blende, with iron sulphide in depth, is one normal to primary deposition by ascending waters. In the chapters on stratigraphic and structural geology in that folio, the junior author (the present writer) showed that only minor faulting was found in the area under discussion and pointed out that the Chatanooga (Devonian) shale was not persistent and hence not a complete barrier to the ascent of solutions from Cambrian and Ordovician rocks."

Siebenthal, after further work in the district has

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C.E.Siebenthal, Origin of the Zinc and Lead Deposits of the Joplin Region, U.S.G.S., Bull.606, 1916
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enlarged upon the theory first evolved by W.S.T.Smith and himself. He maintains that the rocks of Kinderhook age, even in their more shaly phases are decidedly arenaceous and are not an effective barrier to the ascent of ore-bearing solutions from the Cambrian and Ordovician rocks. He sites the mineable deposits of ore at Springfield, Aurora, McDowell, Stotts City, Joplin, Hornet, and Galena from rocks of this age as proof of his contention. The Chatanooga (Devonoian) shale is thought to be an effective barrier, where present. The Cambrian and Ordovician limestones and dolomites are thought to be the direct or ,at least, indirect source of these ores. The ores were precipitated from ascending alkaline-saline sulphureted waters similar to those found in artesian waters in the Pennsylvanian area immediately to the west of the Joplin district.

The present writer holds with Siebenthal in his opinion that the primary ores are the result of precipitation from ascending alkaline-saline sulphureted waters, but does not agree with him as to the relative abundance of secondary deposits. The writer is of the opinion that secondary enrichment plays a very important part in the origin of the present ore-deposits. The sheet ground deposits in the Grand Falls chert seem to be entirely primary, but all the deposits above the sheet ground horizon show indications of secondary enrichment. The writer believes that the rich deposits found with an abundance of calcite are the result of a secondary concentration, as are the numerous narrow runs of unusual richness found in the Hockerville and Century sections of the camp. The writers theory of origin would be a combination of Siebenthal's and Van Hise-Bain's taking the new evidence in support of ascending waters advanced by Siebenthal and combining it with the Van Hise-Bain idea of enrichment by descending waters.

City of Picher Deep Well #3 NW 1/4 of NW 1/4, Sec.21, Twp.29N, Rge23E. Finished 11/24/24

0-55	soil, clay and shale	Cherokee
55-90	white lime	Chester
90-104	coarsely crystalline brown lime with seams of green shale	Chester
104-132	white lime, little light blue flint	Upper Burlington
132-136	tan lime, ca 1/3 blue-white flint	Upper Burlington
136-150	fine-grained brown lime, blue & white flint	Upper Burlington
150-154	brown & white lime, some white flint	Upper Burlington
154-169	gray & white flint, jasperoid, good jack shines	Upper Burlington
169-173	gray & white flint, jasperoid, jack shines	Upper Burlington
173-177	gray & white flint, glauconite in leached jasperoid	Upper Burlington
177-181	crevice, lost cuttings	Upper Burlington
181-183	jasperoid, white flint, chatty jack shines	Upper Burlington
183-190	snow white flint, gray & white water flint, little jasperoid, jack shines mostly free ore.	Upper Burlington
190-216	cottonrock, some unleached white flint in upper 6'.	Quapaw Chert
216-219	cottonrock & light blue flint	Quapaw Chert
219-223	white, blue & dark gray flint, glauconite in leached white flint	Quapaw Chert
223-227	crystalline brown lime, 1/3 light blue flint	Middle Upper Burlingtom
227-231	crystalline brown lime, 1/3 white flint	Middle Upper Burlingtom
231-250	crystalline brown lime, little white flint	Middle Upper Burlingtom
250-258	crystalline brown lime	Middle Upper Burlingtom
258-278	snow white flint & cottonrock	Middle Upper Burlingtom
278-286	white lime, little gray flint	Middle Upper Burlingtom
286-300	light brown flint	Middle Upper Burlingtom
300-325	brown jasperoid, gray flint fragments, 1/2 tan lime	Grand Falls Chert
325-350	dark gray fine-grained lime, gray & white flint	Grand Falls Chert
350-360	dark gray fine-grained lime, some gray flint	Grand Falls Chert
360-396	dark gray fine-grained lime, 1/3 gray flint	
396-412	dark gray compact lime, 1/4 gray flint	

412-420	dark gray to white flint, compact gray lime	Lower Burlington
420-430	dark gray, light gray and brown flint, gray to tan lime	
430-440	white to light gray lime, light gray to brown flint	
440-450	compact light gray lime, a little blue and gray flint	
450-460	crystalline white dolomite, streaks of green shale	Jefferson City
460-500	crystalline brown dolomite, gray and white flint	
500-580	light gray sandy lime, white chert, streaks of green shale	
580-620	calcareous sandstone, brown oolitic flint	
620-640	compact brown dolomite, clear blue-gray oolitic flint, brown flint	
640-660	soft white lime, white sandstone, white chert	
660-740	white to tan dolomite, clear white sandstone, thin seams of oolite, white chert	
740-770	brown flint, a little oolitic white flint, white sandstone	
770-800	gray flint, brown oolitic flint, some clear white sandstone	
800-820	compact light gray dolomite	
820-848	sandy brown dolomite, white chert, gray flint, a little oolitic brown flint, a little clear white sandstone	
848-856	gray flint, white chert, white sandstone, brown dolomite	
856-872	white sandstone, brown oolitic flint, some brown dolomite, gray and white flint	
872-896	gray sandstone, some brown dolomite, white chert	
896-920	dark gray sandy dolomite, little white chert	
920-944	white to gray sandstone, clear gray flint	
944-952	compact gray dolomite, white sandstone, some white chert	
952-1000	gray sandy dolomite, some gray, white and clear bluish flint, flint makes about 1/2 of volume in last 16 feet.	

1000-1040	white sandstone, clear quartz grains loosely cemented	Roubidoux
1040-1068	gray sandy dolomite, quartzite, some gray and white flint	

Note: The Kinderhook is missing in this locality.

PROSPECTING

In the early days of the Joplin camp, prospecting and mining were practically synonomous for wherever surface indications were favorable, a shaft was sunk and if ore were found a few drifts would be cut. When the underground haul became too great another shaft would be sunk.

With the advent of capital, the churn drill came into universal use for prospecting from the surface. Within the last year or two a method of underground prospecting has been developed by the use of a heavy duty drifter supplemented by jointed steels for drilling holes horizontally to depths of 150 feet or more. The present writer has already described this method of prospecting in a previous paper.

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W.F.Netzeband, Underground Deep-hole Prospecting at the Eagle-Picher Mines, A.I.M.M.E., Pamphlet No.1583-A, Nov.1926.
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Surface Prospecting

The early day churn drill was almost exclusively powered by a single-cylinder, vertical steam engine, but with the perfection of the four cylinder gasoline engines the steam engines have been practically all replaced by such engines. The Fordson tractor has led the way in this revolution and the majority of rigs are powered by Fordsons, but lately a four cylinder Hercules engine mounted by the Keystone Driller Company has found much favor with the drill-men in the district. A few International Harvester engines are being introduced and so far have had very good success.

There are several types of rigs used in the field. The Keystone 5 1/2 Missouri Special mounted with either a Fordson or Hercules gasoline engine is by far the favorite. There are a number of Sparta rigs mounted with single cylinder kerosene engines and Star rigs with vertical steam engines. A few Armstrong and Clipper rigs are in use, but no new ones are being brought into the field. The Keystone mounted with either the Fordson or Hercules engine makes an ideal rig for work down to 400 feet, but with the development of orebodies below 400 feet in some of the outlying areas, the Star rig has been found more satisfactory. The Keystone rig has been developed to give the greatest effieiency with depths above 400 feet and has been developed to meet the needs of this field, which is probably one of the reasons for its great popularity in this field. The Keystone rig is purely a spudding machine whereas the Star and Armstrong rigs drill on the screw after the tools are buried.

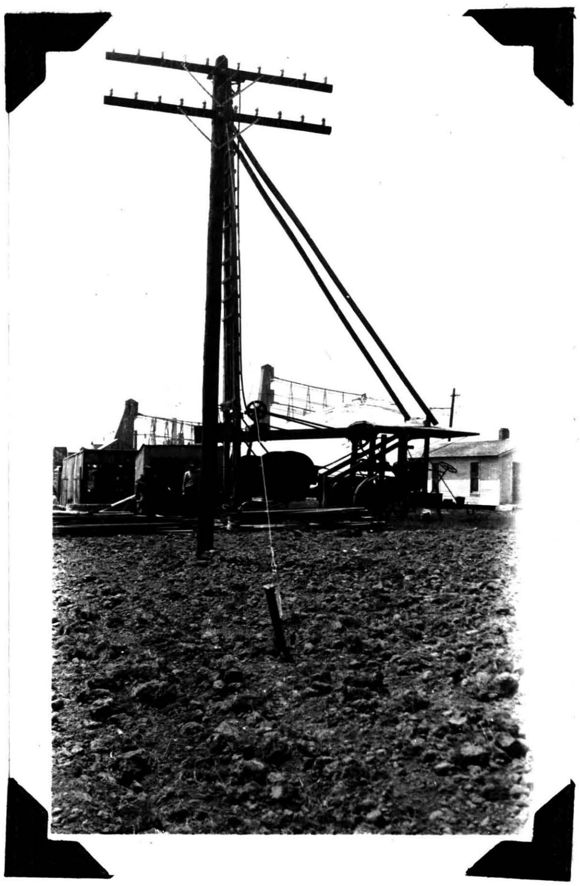

Fig. 3
Keystone drill rig.

Fig. 4
Sparta drill rig.

Fig. 5

Star drill rig.

It is the general practice in the district to drill 6 1/4-inch holes because the type of rigs used are best adapted to handle this size of tools, and this size of hole gives an accurate enough idea of the formation passed through. In bad ground where several strings of casing will be necessary, the hole is started at 8 1/4 or 10 inches, and, when necessary, is finished at 4 7/8 inches. The drillers do not like to use the 4 7/8-inch tools unless absolutely necessary for they lack weight, making for slow drilling; and if trouble is encountered the driller, does not have much chance to finish the hole.

The drilling is done almost entirely by contract, very few of the operating companies owning their own rigs. There are a number of large contractors in the field owning from 3 to 20 rigs and these men usually have as partner some man in the larger companies who is in a position to keep the rigs at work. It is sometimes the case that one contractor will have partners in several of the large operating companies, each partner owning an interest in one or several rigs. In this way the contractor is assured that his rigs will be kept at work. The majority of rigs are owned by the men who run them and like the larger contractors they often secure as a partner someone within an operating company, usually the field man. This system has developed only within the last year or two, and it is questionable how far it can go without serious results to the drilling industry.

The drilling contract price is very low in the district. During ordinary times, drilling can be contracted for at the price of $1.00 a foot for depths down to 350 feet, if the drilling is average. Where drilling is bad due to hard or caving ground, the price ranges from $1.10 to $1.50 a foot depending on the time it will take the driller to finish the hole. Below 350 feet a sliding scale is put into effect, the usual scale being 10¢ a foot additional for every 50 feet below 350 feet; that is, for average drilling the price from 350 to 400 feet would be $1.10 a foot, from 400 to 450 feet the price would be $1.20 a foot. Average drilling over a period of time costs the driller about 70¢ a foot so that if he can keep his drill busy, he makes a fair profit.

The field man is guided in spotting his holes by the various theories that have been developed, and are discussed in detail under the heading "Application of Geology to Prospecting". When a new tract is taken over, the drilling is begun at one corner either 50 or 100 feet from both boundaries and a string of holes drilled east and west or north and south across the tract at intervals of 200 or 400 feet. If nothing indicative is found in this first row of holes, another row is drilled 200 or 400 feet from the first and paralleling it. Some companies drill a row of holes around the periphery of the tract and then use that as the base for further drilling. When an indicative hole or series of holes is found the drilling is then centered around that particular spot until an orebody is drilled out or the absence of an orebody proved. This drilling is much closer than the preliminary drilling and often holes are spotted on 25-foot centers, although usually 50 or 100 feet, its is considered sufficiently close. One company drills their holes on the fractions of 1/3; that is, their holes are spotted 33, 66 or 100 feet apart.

The details of sampling and keeping records of the holes are discussed later.

Underground Prospecting

Recently it has been found that many small pockets and narrow runs of ore were missed that could very well be mined at a profit from the present workings. Driving prospect drifts, more or less blindly, into unknown territory proved to be a rather expensive undertaking and the percentage of discoveries was rather small. This problem was solved by the Denver Rock Drill Manufacturing Company bringing into the district a heavy duty drifter equipped with jointed steels that could drill horizontal holes up to a depth of 250 feet. Many of the larger companies have adopted this type of machine for prospecting ahead of faces that showed signs of going blind, or for prospecting along the walls of abandoned drifts to pick up any stray pockets or narrow parallel runs that might otherwise be overlooked. In the writer's experience the machine has more than paid for itself many times in locating these isolated pockets and runs, and in saving money that would be spent driving prospect drifts into barren territory. In one mine recently these two phases of the machine's usefulness were excellently illustrated. In one instance it disproved the presence of an orebody that the ground boss was positive was just a few feet ahead, and thus saved the company the cost of an expensive prospect drift or carrying the working drift in dead ground. Later it found a very rich cave just thirty feet from the face of an abandoned drift. This drift had been driven by a former operator and no indication of a cave could be seen from the dust covered walls. This one find alone paid for all the prospecting done at this particular mine, not to mention the money saved by not driving a drift into barren territory on the strength of a ground boss' hunch.

Since the earlier paper was written describing this machine the cost of operation has been cut to $1.14 a foot. This is quite different from the cost of driving a prospect drift, for the usual contract price for this type of work is $5.00 to $7.50 a foot and the company furnish the machine, steel, air and powder over and above the contract price.

Diamond or shot drills are impractical in this district because of the character of the ground. No shot drill could be effective in hogchaw ground and the diamond loss alone would be more than the present contract price for churn drill work. It is, of course, true that core drilling gives more accurate results, but to men who are familiar with the district, the churn drill records can be interpreted fairly accurately for all practical purposes, and a further degree of accuracy is not necessary.

SAMPLING

The methods used for sampling drill holes, like the methods used for mining, are considered very crude by men outside the district, but the results obtained are sufficiently accurate, when intelligently interpreted.

The sample is taken by dumping one or two bailerfuls of cuttings into a tub or half barrel. A sample of these cuttings is panned, and if any values are found that are considered worthy of assay, the cuttings are allowed to stand and settle. The clear water is then decanted off, and all of the cuttings, both slimes and coarse, are poured into a hole dug into the ground to receive them. A sample weighing about five pounds is taken from the cuttings so saved by the field man and assayed for lead or zinc, or both. If it is found that no values are present worthy of assay, the cuttings are thoroughly washed free from all slimes, and an adequate sample piled on the ground and properly tagged with its respective depth.

A five-foot screw is the usual sample taken until ore is reached, and then either a two and one-half-foot or a three-foot screw is taken. Some might think that a smaller screw should be taken so as to place more accurately where the values lie. This is an unnecessary refinement for mine faces are carried anywhere from 8 to 70 feet high, and the exact location of the values within a given face is of no consequence. No selective mining is practiced in this field for it has been found that alarge tonnage of medium grade ore with consequent low mining cost pays bigger dividends than high cost selective mining would.

Some engineers in the district have tried drying all of the cuttings in a given sample instead of allowing the cuttings to settle and decanting off the clear water. The added cost and loss of time entailed in this procedure more than offsets the added degree of accuracy obtained, which as will be shown later is an unnecessary refinement.

A field man after some experience in the field acquires a fair degree of accuracy in estimating the values of lead and zinc in a sample by panning. The dividing line between samples worthy of assay and those not worthy of assay has been arbitrarily fixed by most companies at two per cent zinc sulphide and one per cent lead sulphide. Anything below this value is designated as shines or traces.

It has been found that an ore body mills out about ten per cent higher than the recovery estimated from drill holes and a s a general rule the total tons of concentrates recovered is higher than the value estimated from the drilling. This, of course, is not always the case, but under ordinary circumstances an ore body which can be made to show a profit on paper by a careful analysis of the drill records can be mined at a profit by a competent group of men.

DRILL RECORDS

There are two types of drill records used in the district: the one is the record made out by the man who runs the drill; and the other is the record made out by the field man employed by the company having the drilling done. The records are essentially the same, but the record written out by the field man is usually the more complete of the two. Some of the drill men are very competent and make a very creditable record; but others are shiftless and their records are practically worthless for correlation purposes. Examples of the three types of records are shown.

1) A record worthless for correlation purposes.

0-16	soil & clay
16-75	soapstone
75-90	flint
90-125	lime
125-140	lime & flint
140-160	cottonrock
160-175	lime
175-180	flint
180-220	lime & flint
220-230	blue flint, lead shines
230-240	lime
240-270	white flint
270-290	flint, jack shines
290-300	lime & flint

2) A record made by a competent driller.

0-10	soil & yellow clay
10-40	soapstone
40-45	soapstone & lime boulders
45-50	gray lime
50-60	gray lime, white flint
60-85	gray lime
85-95	gray lime, white flint
95-130	white lime, white chalky flint
130-135	white & blue flint
135-165	white flint, gray lime
165-175	blue flint, green lime
175-180	blue flint, few lead shines
180-195	gray & brown flint, few lead & jack shines
195-225	brown flint, jack shines, lead traces
225-230	gray brown & black flint, good zinc
230-232 1/2	blue white brown & black flint, fair zinc
232 1/2-235	gray & brown flint, jack shines
235-240	gray & brown flint, fair jack
240-245	gray & brown flint, few jack shines
245-255	brown flint

3) Field man's record.

0-69	soil, clay & shale
69-124	gray lime, white flint, lead traces
124-144	white flint, white lime
144-154	white & blue flint, lead traces
154-174	white, blue & brown flint
174-177	white, blue & brown flint, lead
177-183	white & brown flint, tiff, lead traces
183-202	white, blue & brown flint
202-207	white, blue & brown flint, glauconite
207-226	white & blue flint, jack traces
226-236	white flint
236-256	cottonrock
256-262	white & brown flint
262-268	white & brown flint, gray lime

An explanation of some of the terms used by the drillers might not be amiss at this time.

The term "soap" or "soapstone" has been borrowed from the coal miner and is used to describe a massive, non-gritty shale. To one who has handled this type of shale when it was moist, the aptness of the term is readily recognized.

Shale is used by some drillers to denote the harder and more fissile varieties. Slate is sometimes used to describe a very hard, black, fissile shale. This, of course, is not a true slate.

Selvage is a rather confusing term and one cannot always be sure in what sense it is used. To most drillers, selvage is applied to all non-gritty shales which are found interbedded within the lime or flint strata, especially the thin seams of green shale found within the ore horizons. To the miners, selvage means a soft black mud, which Smith and Siebenthal think is an early stage in the formation of jas-

W.S.T.Smith and C.E.Siebenthal, U.S.G.S.,Geological Atlas, Joplin folio No.148, p.14

peroid. This meaning has also been used by some drillers, especially those who have spent some time working in the ground.

Tiff is the local name given to calcite, of which there is an abundance in the district. This term is confusing to one who has spent some time in the lead belt of Southeast Missouri for there the term is applied to barite.

Hogchaw, at one time had a very definite meaning to the drillman, but with the great influx of more or less experienced men due to the great demand for drillers, this term has lost some of its original meaning. To the drillers who have come down from the old Joplin camps the term means a much fractured chert that will run like quicksand when it is wet. It has been known to come in under casing and push a string of tools back up the hole as much as thirty feet. To many of the new men, any loose caving chert ground is hogchaw regardless of whether or not it will follow in under the casing.

Cottonrock is another term that has two meanings. To most drillmen, cottonrock is a soft, porous white flint that has resulted from long sustained leaching. To some it means a soft white lime. The true meaning is really a combination of the two, for a more careful analysis of the leached flint shows it to be very calcareous. Most field men are agreed on using the term to mean the leached white flint rather than the straight soft lime. There are two recognizable cottonrock horizons; one the Quapaw chert and the other a stratum lying immediately above the Grand Falls chert.

Mundic has avery definite meaning. It is used to denote the pyrite or marcasite, both of which are present, which occurs very abundantly in some parts of the district. There is some chalcopyrite present in the orebodies and the same term is applied to it; but, as the chalcopyrite is not abundant enough to be of commercial value, and no critical value is attached to it in the analysis of a drill log, its definition as mundic is of no consequence.

Spar to the driller and miner means dolomite. There are two varieties recognized, the pink crystalline and the massive gray variety. The drillman distinguishes these as pink and gray spar.

Green lime may be found in the logs of the more observant drillman. This term applies to a lime or porous flint that contains numerous small grains of glauconite shot through it.

Shines is a term in which the personal equation plays a large part. This term is applied to the values of lead or jack, and theoretically applies only to values below two per cent zinc sulphide and one per cent lead sulphide; that is, to values not worthy of assay. To all values above this a series of terms has been applied. These terms are given below with their estimated values.

Fair jack shines	2.0 to 3.5% ZnS
Good jack shines	3.5 to 4.5% ZnS
Jack	4.5 to 6.0% ZnS
Fair jack	6.0 to 7.0% ZnS
Good jack	7.0 to 10.0% ZnS
Very good jack	10.0 to 25.0% ZnS
Extra good jack	Above 25.0% ZnS

These values are arbitrarily fixed and they are so understood when analyzing a drill log. The personal equation plays a very important part in estimating these values and what one man may call shines another would call jack. "Jack," by the way, is the local designation of sphalerite. Any one man at two different times may apply a different term to the same value, depending on whether or not he has been getting values in the holes he is drilling at that particular time. A drillman who has been unfortunate enough to drill in a number of blank holes may call a two per cent screw jack, whereas after drilling in several holes with high values, he may call a four per cent screw shines.

From the fact that many of the terms used by drillmen have several meanings, it can readily be appreciated that interpreting drill logs is not without its difficulties. In making a drill log the personal equation plays a large part, but in analyzing and interpreting a log this personal equation always remains an unknown factor. In any group of holes drilled by a number of men the correlation is difficult, for the brown lime of one may be gray lime to another. Lime or flint to the careless driller may be lime and flint to the more observant man. On very few of the logs written by drillers are there any notes made of the oolite or green lime. In many cases the logs are merely skeletons, reporting only lime or flint with no further description as to color. Very often values are reported merely as ore with no description of the kind of rock it occurs in or whether the ore is lead or zinc. All the above factors make correlation difficult over a very large area, and at no time can one be sure of the absolute accuracy of a correlation.

THE APPLICATION OF GEOLOGY TO PROSPECTING

The geology of this district is so difficult of solution that to date no satisfactory methods have been found whereby a geologist can go into the field and intelligently prospect for orebodies.

There have been several theories developed which can be used with reservations. The best known of these is the "shale theory". An outgrowth of this is the "lime theory", or more accurately, a theory based on the contact between the Chester and Boone formations. There are several criteria that have been used with more or less success in guiding prospecting. Among these are the relation of the Short Creek oolite to the ore horizons and likewise the green lime, also the relation of lime bars and solution channels to the orebodies. As the shale theory and lime theory are based on the relation of the orebodies to the lime bars and solution channels, it would perhaps be best to discuss this relation first.

Relation of Orebodies to Lime Bars and Solution Channels.

It will be readily noted from the resume of the various theories of the origin of the ore deposits that almost all of them consider that open ground is one of the essentials for the deposition of the ore. Carrying this idea a little farther, it will be seen that the ore-bearing solutions were further aided in depositing their burden by being impounded against an impermeable bar of some sort. Within the district there are many bars of limestone that are impermeable to the free passage of underground waters and act as a barrier to the flow of such waters. It would be expected that rich orebodies would be found around the edges of such barriers, and such is the case. It is very often found that in drilling a given tract an area of very open ground is found, which in subsequent mining proves to bear all the criteria of an ancient solution channel. In drilling away from this area of open ground, the ground will become noticeably tighter until an area of lime is reached. Usually between the area of very open ground and the area of lime the orebody will be found. Of course, wherever you have the above conditions you will not always find an orebody, but here the conditions are the most favorable.

In wildcat drilling the drills are spotted from two to four hundred feet apart until the nature of the ground has been determined and then closer drilling, sometimes as close as thirty feet, is tried to thoroughly test out the area that shows the most promise.

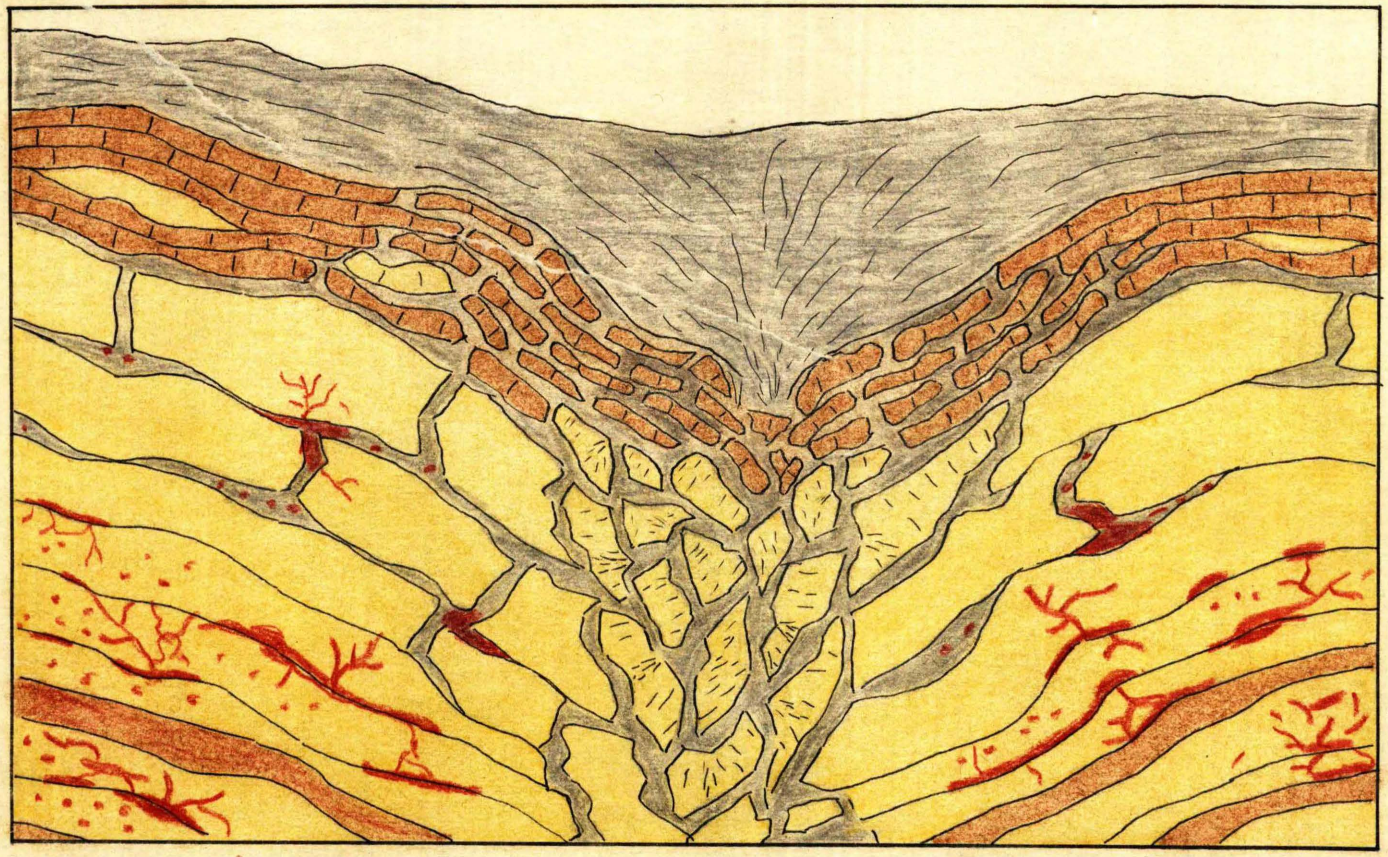

Fig. 6

A Typical Section Showing Relation of Solution Channel to Orebodies.

Shale Theory

The shale theory is also based upon this relation of the orebodies to the solution channels and lime bars and is a rapid method for locating these channels and bars.

Before the Pennsylvanian shale was laid down in this area, the Boone and subsequently the Chester formations were exposed to a long period of weathering. An unknown thickness of Chester was deposited upon the induced karst topography of the Boone and most of it subsequently eroded. Upon this post-Chester erosion surface the Pennsylvanian shales and sand stones were laid down filling in the old pre-Pennsylvanian channels and covering the hilltops.

To use the shale theory, a tract of land is systematically drilled on a definite pattern that will best show the contours of the base of the Pennsylvanian shale. As stated earlier in the paper, the shale varies in thickness from zero to 330 feet, although not within a small area. A difference in elevation of 100 feet within a forty-acre tract is very common.

After plotting the contours of the base of the shale, the pre-Pennsylvanian valleys and hills will be defined. Deep drilling within the pre-Pennsylvanian valley usually discloses a solution channel and drilling on the old pre-pennsylvanian hilltops shows tight ground, usually a lime bar. The practice is first to shale drill a given tract and then deep drill between the deepest and shallowest shale. This should locate the area most favorable for ore deposits.

The theory is sound as far as it goes, but the fact remains that in many parts of the district the ore deposits have the perverse habit of locating under shallow and deep shale indisciminately. Certain parts of the district, as for instance the Crestline, Kansas area, seem to prove out the advantages of this method of prospecting, but on the whole the method must be used only in conjunction with other knowledge.

It has been used by some large operators in drilling very large acreages in wildcat territory where nothing is known of the formation. It has great advantages in such cases for at a very small expense one can determine whether or not the underlying rocks are sufficiently fractured to be favorable for ore deposition.

Lime Theory

The lime theory is a modification of the shale theory, in that it tries to use the old original post-Boone erosion surface. A more detailed study of the shale theory will show that there is this inaccuracy involved. No consideration is taken of the remnants of the Chester formation which overlies the Boone in many parts of the

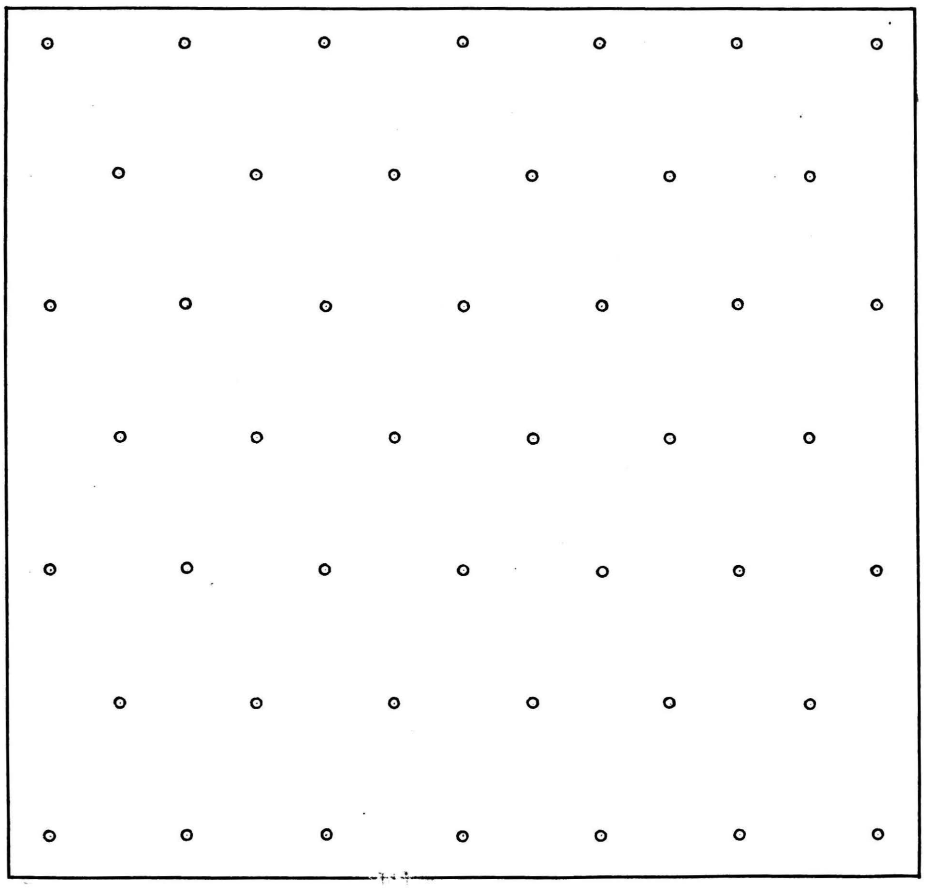

Fig. 7
One of t e sveral patterns used in shale drilling a forty-acre tract.

district. The Chester is a series of limestones and shales and in the drill records the limestones of the Chester are very difficult to distinguish from the underlying Boone limestones and the Chester shales are almost impossible to distinguish from the overlying Pennsylvanian shales. It can readily be seen that, in some cases at least, the Chester limestone might be filling a post-Boone depression and be sufficiently thick to obscure all trace of such a depression. It is conceivable that in some cases the post-Chester surface would so obscure the post-Boone surface that the post-Chester surface would show valleys overlying the hilltops of the post-Boone surface. This is not very likely, however, for Siebenthal places the thickness of the Chester at 40 feet, although the writer is of the opinion that it is thicker in the Picher area.

On the other hand the fact that it is almost impossible to distinguish the Chester from the Pennsylvanian shales would affect any interpretation made from contours based on the base of the shale for the true post-Chester surface might not be the contact between the limestone and shale.

The writer tried to use this method on several tracts of land, but the logs were too poorly written to place any great confidence in the resulting map. It is of interest to note, however, that contour maps using the shale and the lime theory on the same tract show up valleys and hills in nearly the same position.

An instance of where the shale theory worked fairly well is shown by the accompanying map.

Relation of the Short Creek Oolite to the Ore Horizons.

The Short Creek oolite is an important stratum in the Boone formation because of its relation to the the several ore horizons within the Boone.

Immediately overlying the Short Creek oolite is the Quapaw chert. This chert is usually distinguished by the cottonrock which in many places is the dominant rock, but in many other places this flint has not been leached and a live blue and white flint is found in place of the cottonrock. This flint is ore-bearing and one of the most important ore horizons in the Picher camp. The oolite is found from 235 to 245 feet from the surface at Picher, and the 235-foot level is in the Quapaw chert just above the oolite.

About forty feet below the oolite is another important ore horizon. This horizon is dominantly jasperoid breccia and was thought by some to be the Grand Falls chert. Later work has shown the true relation of the ore horizon to the oolite. This ore horizon is worked as the 260 to 275-foot level around Picher. This level has been very extensive and very rich. It has produced a very large proportion of the lead and zinc which has been shipped from the

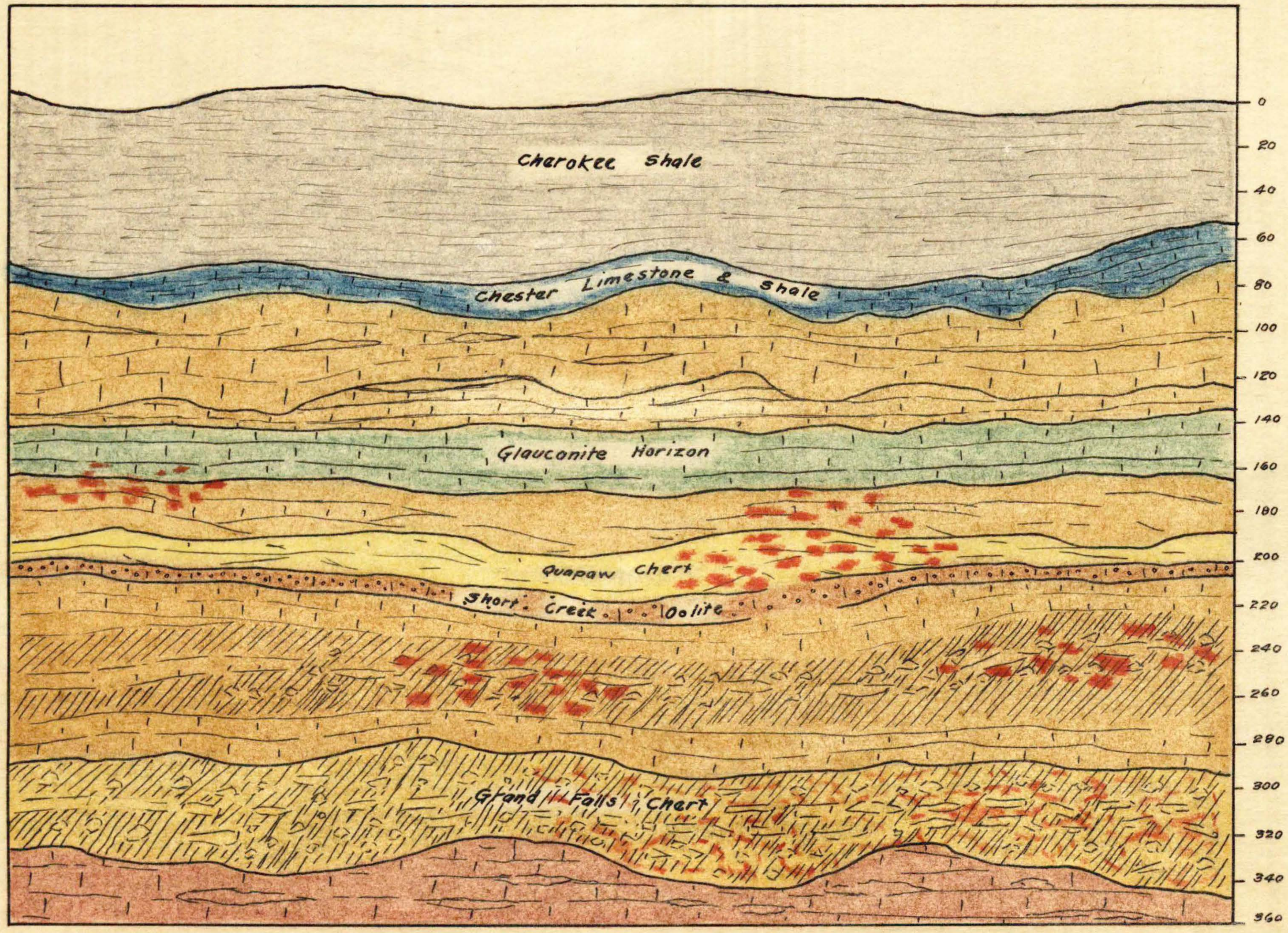

Fig. 8

Typical Section Showing Relation of Recognizable Horizons

Picher camp.

There is another minor ore horizon about 70 feet below the oolite. This is the 300-foot level at Picher. It is not very extensive, existing for the most part, as pockets leading off from the 275-ffot level. In other parts of the district this horizon is more important.

The sheet ground of the Grand Falls chert is found 100 feet below the oolite. This level is not very important in the immediate vicinity of Picher, although it has been mined in a few places at 350 feet. In the Baxter Springs area the sheet ground is being developed by drilling at about 360 feet, but to date little mining has been done on this level. In the old Webb City-Carterville camp the sheet ground was a very important ore horizon and while it was low grade, its unusual persistence made for very low mining costs.

Relation of the Glauconite to the Ore Horizons.

The glauconite is important only in those places where the oolite is missing. The most important relation of the glauconite is to the ore horizon that occurs in the Quapaw chert. It very often happens that silicification has removed all traces of the oolite and in such cases drilling is haphazard until some recognizable horizon is found. It is also very often the case that where the oolite has been obliterated the glauconite is very prominent.

It has been found that the glauconite occurs about 40 feet above the Quapaw chert. Many times this interval is as much as 60 feet, and in several instances it has been found within the Quapaw chert immediately over the oolite. As a general rule though, one can accept the interval as being 40 feet, and if drilling does not show either the ore or a silicified horizon at that depth, it can be safely assumed that the ore horizon is entirely absent from that particular area.