This publication issued herewith as Bulletin 56 of the Oklahoma Geological Survey entitled "The Miami-Picher Zinc-Lead District, Oklahoma" written by Professor Samuel Weidman of the department of geology of the University of Oklahoma with chapters on Mining Methods by C. F. Williams and on Milling Practice by Carl O. Anderson, is made a co-operative publication. The Oklahoma Geological Survey paid for the field work and part of the plates in the book; however, due to lack of funds, the Survey entered into a co-operative agreement with the University Press of the University of Oklahoma whereby the latter has cast the bulletin into type, copyrighted it and will offer it for sale.

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Norman, April, 1932.

Charles E. Decker
In charge.

OKLAHOMA GEOLOGICAL SURVEY

CHAS. E. DECKER
IN CHARGE

BULLETIN NO. 56

THE MIAMI-PICHER ZINC-LEAD DISTRICT, OKLAHOMA

BY

SAMUEL WEIDMAN

WITH CHAPTERS ON

MINING METHODS

BY

C. F. WILLIAMS

AND

MILLING IN THE TRI-STATE DISTRICT

BY

CARL O. ANDERSON

NORMAN

APRIL, 1932

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CONTENTS

ILLUSTRATIONS

INTRODUCTION

LOCATION

THE Miami-Picher zinc and lead district is located in Ottawa County in the northeastern corner of Oklahoma. The producing mines are within an area of twenty-five to thirty miles centering about the mining towns of Picher, Cardin, Century, and Quapaw. Outside of these mining centers considerable ore has been produced in the past and more may be developed in the future, hence the extreme boundaries of the mineralized area in Ottawa County may be said to include some sixty or seventy square miles. The location of the producing mines in Oklahoma and in the adjoining part of Kansas is shown on the map of underground workings, Plate II and the location of the above named mining towns is indicated on the geologic map of Ottawa County, Plate I.

The Miami-Picher district is the most important part of a much larger mining area extending north into Kansas and northeast into Missouri. However, in the earlier mining history of the region, the producing mines were wholly within Missouri and Kansas, centering about Joplin and Galena.

It has been the usual practice of the United States Geological Survey to use the term "Joplin region" for the entire producing area in the adjoining parts of the three states and the term "Miami district," and "Quapaw district," or the combined "Miami-Quapaw district" for the Oklahoma portion of the region. Locally, however, the name "Tri-State district" rather than "Joplin region" has come to be generally applied to the entire mining area. The name "Picher district" or "Miami-Picher district" is now generally applied to the Oklahoma part of the producing area, hence, the latter name is used in this volume.

IMPORTANCE OF DISTRICT

The lead and zinc district of northeastern Oklahoma, combined with the producing areas in the adjoining parts of southeastern Kansas and southwestern Missouri, has been the most important zinc producing region during the past fifty years, not only of the United States, but also of the entire world.

The production of metallic zinc from this region in the past ten years has ranged from 300,000 to 400,000 tons of zinc a year, which is about seventy per cent of the zinc production of the United States and almost thirty-five per cent of the production of the world. About sixty-five to seventy-five per cent of the zinc production is mined in Oklahoma, about twenty-five to thirty per cent in Kansas, and about five per cent in Missouri.

The region is also very important in the production of lead, yielding about fifteen per cent of the lead ore of the United States. It is surpassed only by southeastern Missouri, Idaho, and Utah. The relative amount of lead production of the three adjoining states in the Tri-State district is about the same as that of the zinc production.

SCOPE OF REPORT

This work is intended only as a progress or preliminary report, and is based on geological investigations carried on during three summer field seasons, June to August, of 1927, 1929 and 1930. Previously the author had visited the district for very short periods in 1920, 1921, and 1922. The present volume is published to supply information concerning the lead and zinc mining industry of the State.

The district is one of great interest not only because of its unusual richness in zinc and lead, but also because of various important aspects of geology concerning the structural relations, distribution, and origin of the ores. The author is well aware of the incompletion of this investigation and the more or less tentative conclusions reached concerning certain phases of the geology of the ore deposits, presented in this work.

ACKNOWLEDGMENTS

The author wishes to acknowledge his indebtedness to the officers of the mining companies and to mine superintendents and foremen with whom he came in contact for valuable assistance received in carrying on his investigations. Without exception all the mining companies, both employers and employes, have given all the aid and information desired or that was available concerning explorations and geological data, including mine maps and drilling records, relative to their respective mines. Especially valuable aid was given by the Commerce Mining and Royalty Company, the Eagle-Picher Lead Company, the Federal Mining and Smelting Company and the Golden Rod Mining and Smelting Corporation.

Much information also has been available from the local branch of the United States Geological Survey at Miami, and from the Tri-State Zinc and Lead Producers Association, at Picher. Considerable aid, also, has been received from mining engineers, not directly connected with operating companies. Not all of the information accumulated in the form of maps and drill records has been used in the preparation of this report but it may be more fully utilized in further investigations of the district.

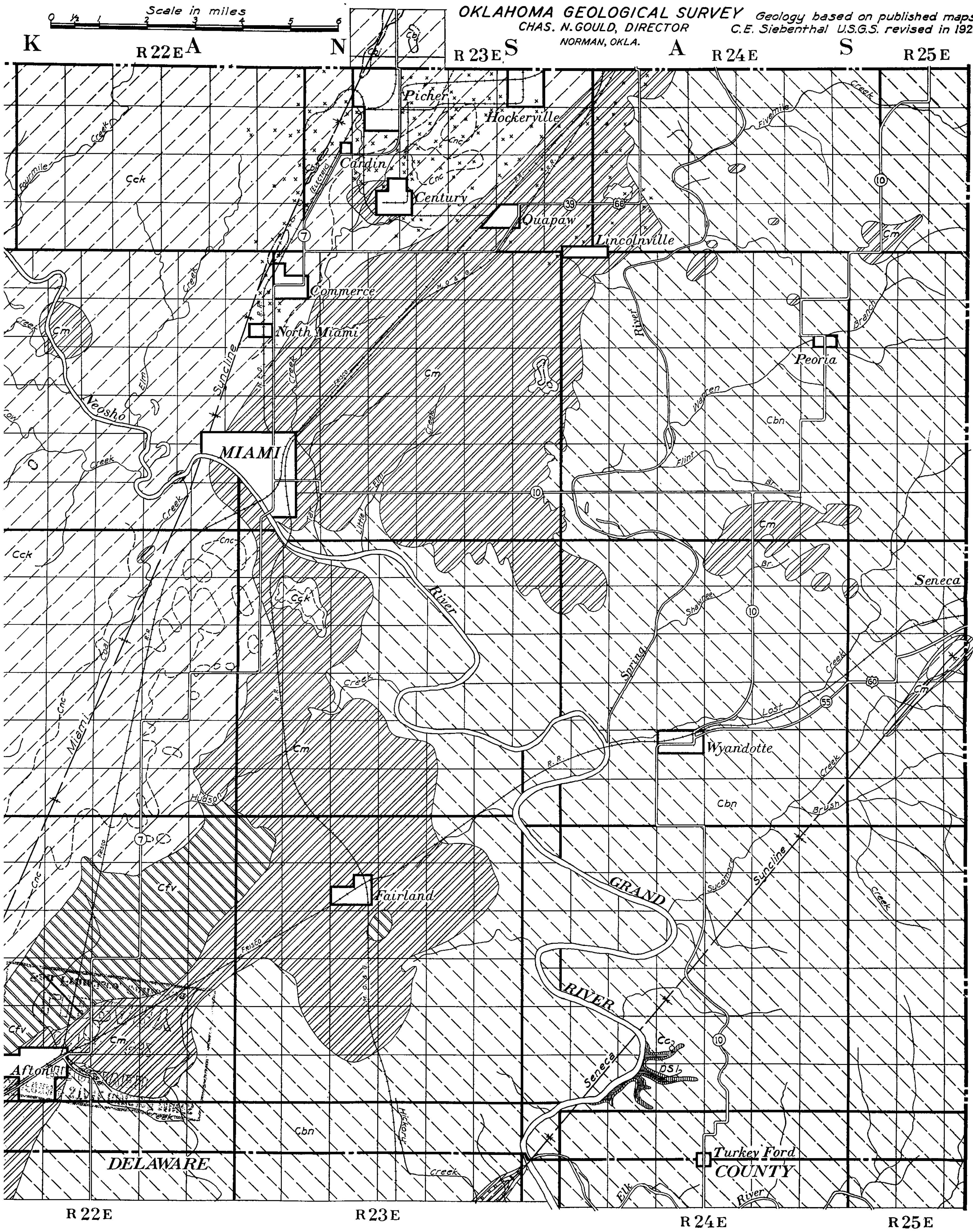
The author is especially indebted to Mr. W. F. Netzeband, formerly geologist of the Eagle-Picher Lead company, to Mr. P. W. George of the

PLATE I

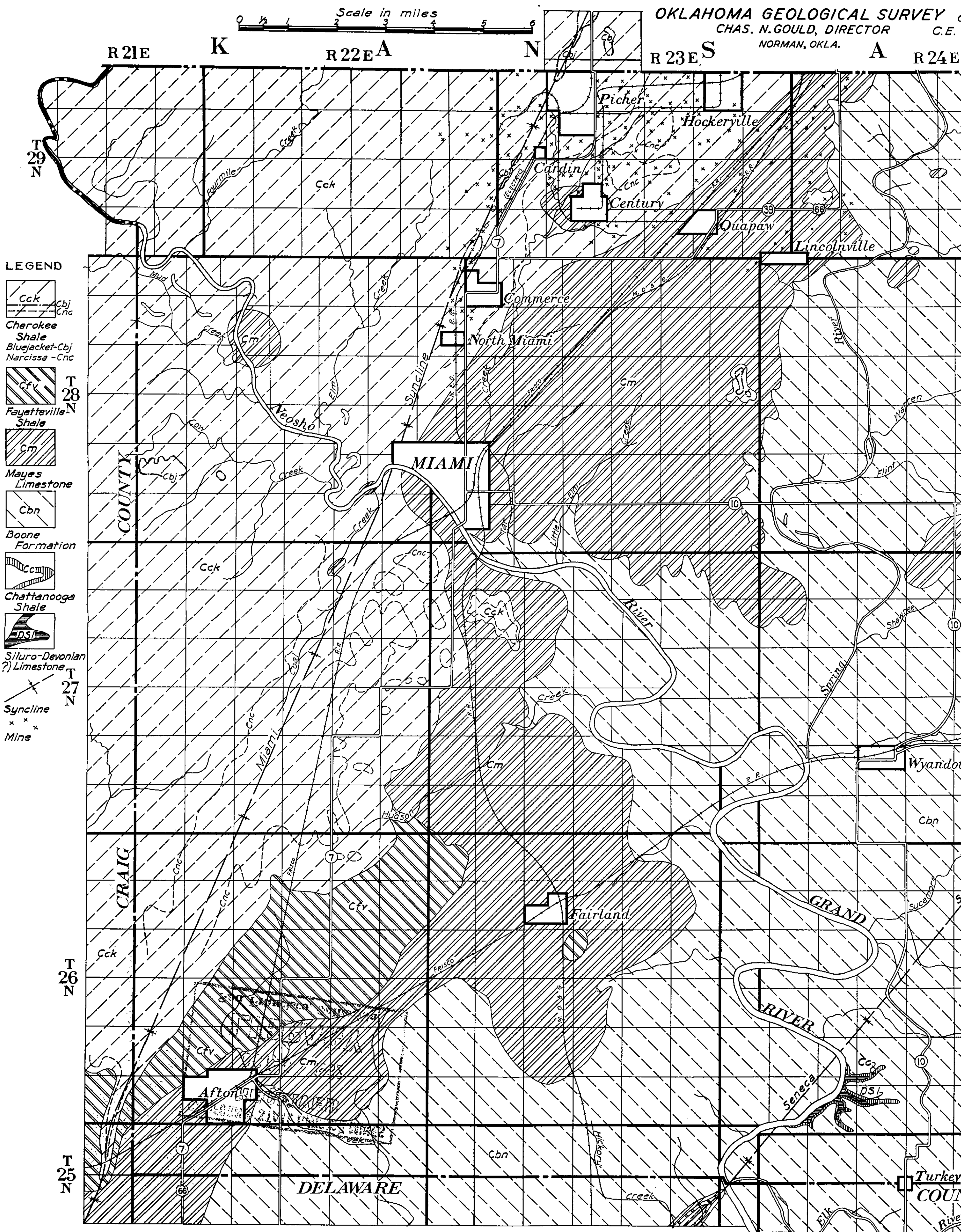
GEOLOGIC MAP OF OTTAWA COUNTY BY S. WEIDMAN

OKLAHOMA GEOLOGICAL SURVEY
CHAS. N. GOULD, DIRECTOR
NORMAN, OKLA.

Geology based on published maps by C.E. Siebenthal U.S.G.S. revised in 1929-30



GEOLOGIC MAP OF OTTAWA COUNTY BY S. WEIDMAN



Federal Mining and Smelting company, to Mr. K. L. Koelker, and to Mr. M. Fowler, mining engineers, each of whom has kindly furnished one or more maps included in this report. Mr. H. C. George, of the University of Oklahoma, formerly chief engineer, Wisconsin Zinc Company, gave valuable criticism concerning mining and milling practice. To Elmer Isern in the *Engineering and Mining Journal,* vol. 131 p. 68 credit is given for figure 10. The illustrations used in the chapter in Mining Methods are from *The Story of the Tri-State Zinc and Lead Mining District,* convention souvenir, Joplin, Missouri, September 28-30, 1931.

LITERATURE

The number of published papers specifically describing either the geology or the mines of the Miami-Picher district is not very large, although a considerable bibliography is available on the older mining district about Joplin and Galena.

The bibliography at the end of this volume is believed to be a fairly complete list of papers, not only relating to the Oklahoma part of the mining region, but including also the publications of importance on the Tri-State (Joplin) region. Although most of the publications describe both geology and mining, an attempt is made to classify them with reference to their major interest.

The meteoric water theories of origin of the zinc-lead ores, briefly mentioned on page 77, are quite fully discussed in the works named in the bibliography of Winslow, Bain and Van Hise, Haworth, Buckley and Buehler, and Smith and Siebenthal. Jenney was one of the early adherents to the magmatic theory.

GENERAL GEOLOGY

TOPOGRAPHY

THE surface of the Miami-Picher lead and zinc district is a plain. The principal drainage is through the Spring and Neosho rivers which flow southeast and unite at Wyandotte about nine miles below Miami. The area occupied by the active mines west of Spring River, altitude 750 to 850 feet, has little relief, the difference in elevation between the highest uplands and the lowest river bottoms, being less than one hundred feet. East of the mining district, however, along, and east of, the Spring River, the land is more hilly, having a relief of one hundred to three hundred feet.

The more level land west of Spring River is the area of the Cherokee shale of Pennsylvanian age. The more hilly land to the east is occupied by the older rocks of the Boone formation of lower Mississippian age. Physiographically that part of the district west of Spring River is within the Osage plains section of the Central lowland province and that part east of the river is within the Ozark Plateau province.

The area of the mining district with adjoining parts of Ottawa County illustrates an excellent example of disconformity between the southeast slope of drainage and the northwest dip of the geological strata. The elevation of the hilly uplands of the eastern part of the country is considerably higher than that of the more level plain in the western part. The highest upland, (1,130 feet) is located in the southeastern part of the county adjacent to the lowest bottom lands (750 feet) along the Grand River. The slope of the drainage is to the south and southeast, whereas, the dip of the underlying rock strata is to the west and northwest. The prevailing dip of the strata to the northwest is referred to again under the discussion of the structural features of the district.

GEOLOGY

The rock strata at the surface of Ottawa County are mainly of Mississippian and Pennsylvanian age. So far as known, only in one place, in an anticlinal area in the southeastern part of the county are formations older than the Mississippian exposed. Farther to the south of Ottawa County, however, the older formations are known to occur at the surface, which very probably are to be correlated with the strata beneath the Boone encountered in the deep water wells drilled in the district.

The stratigraphic column of the district may be tentatively outlined as shown in Table I.

PRE-CAMBRIAN

The Pre-Cambrian granite is reported to have been reached in two of the deep wells drilled in Miami, one drilled in 1900 and the other in 1904-5. No definite records of these wells are now available, but the granite is said to have been reached between 1,700 and 1,850 feet.

TABLE I. *Geologic formations in Ottawa County*

AGE	FORMATION	THICKNESS *Feet*	DISTRIBUTION
Quaternary and Recent	Alluvial	0 to 30	Along streams
Tertiary	Gravel and clay	0 to 30	On uplands and in valleys
Mesozoic?	Pegmatitic granite-porphyry	Interpreted as intrusive in Arbuckle	In Bird Dog mine well at 1183 ft.
Pennsylvanian	Cherokee formation: Bluejacket and Little Cabin sandstone	0 to 300	Mainly western part
Mississippian	Fayetteville formation; limestone and shale	0 to 40	Southwestern part only
	Mayes formation; limestone, shale, and sandstone	0 to 60	Mainly west of Spring River
	Boone formation; limestone and chert	315 to 400	Exposed in eastern and southern parts; subsurface elsewhere
	Chattanooga shale	0 to 30	Subsurface, thin or absent in mining dist.
Silurian?[1]	St. Clair limestone?		
	Tyner formation?		
Ordovician	Simpson formation (with Burgen sandstone)	1300 to 1500	Subsurface
Upper Cambrian	Arbuckle limestone (Probably with intrusives)		
Pre-Cambrian	Granite and other igneous rock	Very great	Subsurface

[1]Suggesed correlation below the Chattanooga shale

The reported depth to granite at Miami agrees fairly well with the known depth to granite, 1,772, at Carthage, Missouri, and 1,770 at Columbus, Kansas.

The logs of the deep city wells in Carthage, Missouri, and Columbus, Kansas, correlations of formations as commonly interpreted, are shown in Table II.

The strata of Paleozoic age, Pennsylvanian to Cambrian inclusive, have an approximate thickness of 1,700 to 1,800 feet in the mining district. The

TABLE II. *Deep wells in Carthage, Missouri, and Columbus, Kansas*[1]

Carthage, Mo., Well No. 6			*Columbus, Kansas, well*	
DEPTH *Feet*	THICKNESS *Feet*	FORMATION	DEPTH *Feet*	THICKNESS *Feet*
None	None	Cherokee shale	0-207	207
0-165	165	Burlington (Boone)	207-345	138
165-200	35	Grand Falls chert	345-375	30
200-373	173	Lower Burlington (Boone)	375-451	76
373-386	13	Northview shale (Chattanooga)	Missing	
386-890	504	Jefferson City dolomite	451-1038	587
890-915	25	Rubidoux sandstone	1038-1050	12
915-1610	695	Lower dolomite	1050-1674	624
1610-1772	162	Lamotte sandstone	1674-1770	96
1772-1854	82	Granite	1770-1783	13

[1]Information is lacking concerning the author of this correlation but is it quoted here as formerly representing a common interpretation in the district.

correlation of the formations from the surface down to the Chattanooga shale is well defined and generally accepted, but that of the formations below the Chattanooga is not.

PRE-CHATTANOOGA FORMATIONS

There are many deep water wells in the district drilled for the purpose of furnishing water for the concentrating mills at the various mines, and for public water supplies in the cities of Miami, Commerce, Picher, and Baxter Springs. These wells have their source of supply in water-bearing sandstone beds from 900 to 1,250 feet below the surface, and at definite horizons from 500 to 700 feet below the Chattanooga shale.

TABLE III. *Lithologic character of Pre-Chattanooga formations in 2 deep wells.*

1. *Ottawa County well.* (*Outside mining district*)

FORMATION	THICKNESS *Feet*	DEPTH *Feet*
Limestone; dolomite 1-15%, insol. 25-67%, Ch.[b] S. Sl.	43	512 555
Dolomite, much calcite, insol. 10-30%, S. Ch.	15	570
Dolomite, much calcite, insol. 5-30%, Ch. S.	15	585
Dolomite, about 40% calcite, insol. 10-24%, Ch. Sl.	25	610
Dolomite, little calcite, insol. 10%, Ch. Sl.	5	615
Dolomite, 10-20% calcite, insol. 10-50%, S. Sl.	60	675
Dolomite, little calcite, insol. 16-35%, Ch. S.	25	700
Limestone, 10-25% dolomite, insol. 15-30%, Ch.	115	815
Dolomite, little calcite, insol. 30%, Ch. S.	5	820
Limestone, much dolomite, insol. 10-30%, Ch. S.	35	855
Limestone, little dolomite, insol. 11-33%, Ch. S.	30	885
Dolomite, much calcite, insol. 23-33%, Ch. S.	15	900
Limestone, little dolomite, insol. 33-50%, mainly Ch.	30	930
Limestone, little dolomite, insol. 5-15%, Ch. S.	15	945
Limestone, much dolomite insol. 30-50%, Ch. S.	40	985
Sandstone, calcareous, dolomitic 50% S.	10	995
Limestone, very dolomitic insol. 16-36%, mainly S.	40	1035
Sandstone, 1035-40, 1050-55, dolomitic, calcareous	20	1055

2. *Power Station well.* (*Within mining district*)

FORMATION	THICKNESS *Feet*	DEPTH *Feet*
Dolomitic, little calcite, insol. 28-44%, Ch. S.	40	505 545
Dolomite, fine calcareous insol. 20-30%, Ch. S.	45	590
Dolomite, calcite, 15%, insol. 29%, Ch. S.	10	600
Dolomite, little calcite, insol. 5-10%, Ch. S.	10	610
Dolomite, little calcite, insol. very little Ch. S.	10	620
Dolomite, calcite 5-10%, insol. 5-25%, sandy	40	660
Dolomite, some calcite insol. 10-20%, sandy	30	690
Dolomite, little calcite, insol. 5-15%, mainly Ch.	60	750
Dolomite, little calcite, insol. 20-35%, Ch. S.	50	800
Dolomite, little calcite, insol. 10-30%, Ch. S.	50	850
Dolomite, no calcite, insol. 20-25%, mainly Ch.	20	870
Dolomite, little calcite, insol. 5-15%, mainly Ch.	30	900
Dolomite, little calcite, insol. 15-30%, mainly Ch.	30	930
Dolomite, little calcite, insol. 10-20%, Ch.	30	960
Dolomite, no calcite, insol. 20-40%, Ch. S.	30	990
Sandstone, insol. 80-85% S. dolomite 15-20%	10	1000
Dolomite, very sandy, insol. 20-40%, mainly S.	60	1060
Sandstone, 70-95% fine S. dolomitic	20	1080
Dolomite, little calcite, insol. 15-30%, fine S.	40	1120
Sandy dolomite, calcareous insol. 30-40%, mainly S.	10	1130
Dolomite, little calcite, insol. 10-20%, mainly Ch.	30	1170
Dolomite, little calcite, insol. 20-30%, Ch.	20	1190
Chert, dolomitic insol. 72% Ch.	10	1200
Dolomite, little calcite insol. 20-40%, Ch.	29	1229

b—Ch., chert; S., Sand; Sl., silt.

An examination of the well cuttings of two of the deep wells of the county has been made, the Ottawa County Welfare Home well, 1,055 feet deep, drilled in 1927, and the other the Commerce Mining and Royalty Company Power Station well, 1,229 feet deep, drilled in 1929.

In determining the lithologic character, representative screened portions of each five or ten-foot sample of the well cuttings were treated with Lemberg solution and allowed to stand for a few minutes. If calcite is present it is stained violet by the solution while dolomite remains unstained. The relative amounts of calcite and dolomite represented by the stained and unstained grains were then either counted or estimated under the microscope. A weighed portion of the sample was treated with hydrochloric acid, the calcite and dolomite being dissolved out and the weight of the insoluble residue determined and later examined under the microscope and identified as chert fragments, quartz sand grains, and silt.

The lithologic character of the Pre-Chattanooga formations in the two wells is shown in Table III. The Ottawa County Home well is located seven miles southwest of the mining district, in the SW. SW. sec. 12, T. 27 N., R. 22 E. The Power Station well is within the mining district, in the NE. NE. sec. 25, T. 29 N., R. 22 E. In the table the mainly limestone or dolomite beds that have similar lithologic character are grouped together with respect to approximate content of dolomite, calcite, and the insoluble material consisting of chert, quartz sand, and fine silt. Only the sandstone beds are definitely correlated and placed opposite one another in the table. A pronounced difference in the relative amount of dolomite in the two wells is indicated. There is much greater dolomitization of the limestone within the mining district than outside. A corresponding difference in dolomitization also affects the Post-Chattanooga formations, the Boone and Mayes limestones, in the two wells as shown in Table XIX.

With respect to the relative amount of chert in the limestone of the two wells the difference is apparently only slight. However, there is distinctly more chert in the Boone and Mayes formations within the mining district than outside the district (see Table III) and hence a corresponding difference in amount of chert probably characterizes the Pre-Chattanooga in the two wells.

The dolomite as well as the chert in the limestone is probably largely of secondary origin, the processes of dolomitization and silicification having affected the limestone strata at some time after their original deposition. The forty-three feet, mainly limestone, in the Ottawa County well just below the Chattanooga shale at 497 to 555 feet is obviously at the same stratigraphic horizons as the forty feet of dolomite in the Power Station well at 505 to

545 feet. Likewise at greater depth there is mainly limestone formation in the well outside the mining district where there is principally dolomite at corresponding stratigraphic horizons in the well within the mining district.

The sandstone beds, however, not appreciably affected by dolomitization and silicification because the original sand grains are not replaceable by dolomite and chert, occur in the sections of the two wells at approximately the same depth and stratigraphic horizon. On the other hand there is little or no similarity in amount of dolomite and chert in beds at the same depth and obviously at the same stratigraphic position in the two well sections located only ten miles apart. The difference in content of dolomite and chert in beds of the same horizon is considered as indicating that the dolomite and most of the chert are of secondary origin and was introduced after the original limestone beds were deposited.

Since the dolomite and chert are largely of secondary origin, the original character of the limestone is masked and it is difficult to correlate, by lithologic means, with formations outside the region.

The upper fifty to one hundred feet of the section may represent the St. Clair formation of northwestern Arkansas, as occurrence of this formation has been recognized also in northeastern Oklahoma. The strata below this, probably of upper and middle Ordovician age, may include the Tyner formation known to occur farther south in various localities.

The sandstone beds, at 985 to 995 feet in the County well and at approximately the same depth in the Power Station well, and also the sandstone horizons fifty to sixty feet below may represent Burgen—St. Peter sandstone rather than the Rubidoux sandstone of Lower Ordovician age.

According to this interpretation the strata below the water-bearing sands, down to the pre-Cambrian granite, a thickness of 800 to 900 feet in the district, would be correlated with the lower Ordovician and upper Cambrian, as suggested in Table I.

The above suggested correlation would also be in general agreement with the tentative correlations of formations for northeastern Oklahoma as offered by L. C. Snider,[1] C. L. Dake,[2] United States Geological Survey,[3] C. N. Gould,[4] and E. O. Ulrich.[5]

MISSISSIPPIAN

Chattanooga Shale

The Chattanooga shale of lower Mississippian age is a thin bed, usually from zero to fifteen feet thick in the mining district, but increasing in thickness to the south. While reported as generally absent farther east it is known to have a thickness of thirty-five feet at the Mystic Mine shaft in Gordon Hollow, in the Joplin district.[6] This shale is called also the Noel shale and the Hannibal shale. It grades from a brown to gray sandy, dolomitic shale.

The shale outcrops in Ottawa County only along the east bluff of the Grand River three miles north of the mouth of Elk River in Secs. 28, 29, 32, and 33, T. 26 N., R. 24 E. The shale exposed on the Grand River is about twenty-five feet thick. It is overlain by the St. Joe member of the Boone formation and underlain by limestone. It is black, thin bedded, bituminous and carbonaceous, with well defined jointing, trending about N. 50° E. and N. 60° W.

The formation has been recognized in deep wells as far north as the vicinity of the Kansas State boundary, and probably occurs in a thin bed

Table IV. *Chattanooga shale in deep wells of Ottawa County.*

NAME OF WELL	LOCATION	DEPTH *Feet*	THICKNESS *Feet*
Fairland, City Well	Sec. 9, T. 26N., R. 22E.	500-535	35
Ottawa County Welfare Home	Sec. 12, T. 27N., R. 22E.	497-512	15
Walter Tyding Well	Sec. 35, T. 28N., R. 22E.	460-470	10
Miami, City Well	Sec. 30, T. 28N., R. 23E.	432-446	14
McCoys Green House	Sec. 24, T. 28N., R. 22E.	453-460	7
Bertah McGhee Well	Sec. 29, T. 28N., R. 22E.	538-550	12
Rialto Mine	Sec. 19, T. 29N., R. 24E.	370-375	5
Lucky Syndicate Mine	Sec. 17, T. 29N., R. 23E.	475-480	5
Victory Metal Companv	Sec. 16, T. 29N., R. 23E.	475-476	1

underlying much of the area of the Picher district. In many of the deep wells the drill records do not report the shale, but where samples have been examined, the horizon can usually be recognized. Table IV shows the Chattanooga shale at a depth of 370 to 538 feet in various deep wells of the county.

Boone Formation

The Boone formation, named from Boone County, Arkansas, its type locality is a cherty limestone formation, varying in thickness in the Miami district between 329 and 393 feet. The upper portion is correlated with the Keokuk, and the lower portion with the Burlington and Fern Glen of the Osage series. In the following records of deep wells the names of certain subdivisions of the Boone are given, but no attempt will be made to consider the Boone other than as a unit. The Boone is considered as including the strata between the Mayes (Chester) limestone above, and the Chattanooga shale below.

The Boone, as already stated, is the surface formation along the eastern border of the district along Spring River and in the eastern and southeastern parts of Ottawa County. Within the main part of the mining district and farther west it lies below the surface beneath a variable thickness of the Mayes limestone. Along the western border of its main area of outcrop it forms a few inliers within the area of the Mayes formation. It outcrops along the Néosho River bottom as far north as Miami. (See Plate I).

In Table V is shown the depth below the surface and the thickness of the Boone formation in various deep wells of the district, which have

TABLE V. *Depth and thickness of the Boone Formation in wells*

NAME OF WELL	LOCATION	DEPTH *Feet*	THICKNESS *Feet*	TOTAL DEPTH *Feet*
1. Fairland City Well	Sec. 26, T. 26N., R. 23E.	10-395	385	535
2. Ottawa County Home	Sec. 22, T. 27N., R. 22E.	120-497	377	1055
3. Miami City Well	Sec. 30, T. 28N., R. 23E.	50-432	382	1257
4. Walter Tyding Well	Sec. 35, T. 28N., R. 22E.	70-460	390	610
5. McCoy's Greenhouse	Sec. 24, T. 28N., R. 22E.	57-439	382	1046
6. Bertha McGhee	Sec. 29, T. 28N., R. 22E	155-538	383	1500
7. Victory Metal Co.	Sec. 16, T. 29N., R. 23E	105-475	370	1025
8. Lucky Syndicate Mine	Sec. 17, T. 29N., R. 23E.	140-475	335	1525
9. Picher City Well No. 2.	Sec. 20, T. 29N., R. 23E.	75-468	393	1066
10. Picher City Well No. 3	Sec. 20, T. 29N., R. 23E	104-450	346	1068½
11. Rialto Mine	Sec. 19, T. 29N., R. 24E.	0-370	370	929
12. Xavier Mine	Sec. 23, T. 29N., R. 22E.	110-456	346	1083
13. Goodeagle-Barnsdall	Sec. 25, T. 29N., R. 22E.	140-510	370	1025
14. B. & R. Mining Co.	Sec. 25, T. 29N., R. 22E.	140,469	329	1057
15. Blue Mound Mine	Sec. 13, T. 35 S., R. 23E (Kansas)	140,490	350	1275
16. Baxter Springs Well No. 2	Sec. 36, T. 34 S., R. 24E (Kansas)	12-355	343	1016

reached the water-bearing sandstone after penetrating the recognized horizon of Chattanooga shale.

Table V shows the thickness of the Boone to range from 329 to 392 feet, an average of 362 feet. In most of the wells listed the upper and lower limits of the Boone are well-defined, but in a few the stated thickness is interpreted from driller's logs and may vary slightly from the true thickness. The thickness shown in each of three of the deep wells, numbers 2, 5, and 11, is 377, 382, and 370 feet. The samples of drill cuttings were examined and interpreted by the author, W. F. Netzeband and J. M. Thiel. The foregoing indicated thickness also agrees closely with that in the two deep wells at Carthage, Missouri, in one of which (see Table II) the thickness is 375 feet, and the other, quoted by Smith and Siebenthal[7] is 355 feet. The sixteen deep wells cited are distributed over a considerable area and show a fairly close agreement in thickness. There is only about thirty-two feet above or below the average thickness of 362 feet for the formation.

The writer has not found the Cherokee shale lying directly upon the Boone formation in Ottawa County. There may be some exceptions, but so far as observed along the western border of the Boone, the overlying rock was the lower limestone portion of the Mayes formation.

The slight variation in thickness of the Boone beneath the Mayes limestone or where the Mayes has only recently been removed by erosion may be due to two causes; first, unequal thickness of the Boone formation developed during its initial deposition; and second, unequal erosion developed on the exposed surface of the Boone after it was formed and before the Mayes formation was deposited upon it. A certain amount of the variation in thickness is probably due to unequal sedimentation during the initial deposition of the Boone and since the difference in thickness of the Boone from place to place is not very great, the amount which may be attributed to erosion (or solution) is obviously not very important.

The Boone, as determined from samples of the deep well of the Ottawa County Welfare Home outside the mining district shown in Table VI, is a limestone formation containing a variable but usually large content of flint or chert. The amount of residue insoluble in hydrochloric acid in various horizons ranges from sixteen to eighty per cent. The insoluble residue consists mainly of quartz in the form of chert or flint, a small part being mainly clastic quartz grains and fine clay particles. The quartz grains and the clay particles are considered of primary origin being deposited with the limestone strata, but the insoluble residue in excess of ten or fifteen per cent of the strata was apparently introduced as secondary chert, a product of silicification.

Black shale, in thin seams and in lense-like beds from one to five or six feet in thickness, occurs at several horizons in the Boone formation. Black or dark shale was observed in the Netta, Golden Rod No. 8, Golden Rod No. 9, Blue Goose, Anna Beaver, and Domado-Bethel mines. Thin shale beds are reported as occurring in the Boone in many of the drill records of the district. Thin seams and beds of black shale are also known to occur where the Boone is quarried for lime[8] in various localities in Missouri as at Carthage, Clarksville, and other localities.

The shale observed in the mines is usually much folded and crumpled by pressure between the more resistant cherty limestone beds associated with it.

Black shale obviously in place in the Boone has often been referred to as of Cherokee age, and its occurrence erroneously described as due to slumpage or other forms of transportation from the overlying Cherokee horizon.

In Table VI the Boone in the Ottawa County well is separated into several zones or horizons having a general similarity with respect to chert content.

The Boone formation consists of about equal amounts of limestone and chert, varying considerably at different horizons. In four of the sub-divisions

TABLE VI. *Lithologic character of Boone formation. Well of Ottawa County Welfare Home*

FORMATION	THICKNESS *Feet*	DEPTH *Feet*
Limestone gray; 35 to 40 per cent of insol. residue, mainly chert	35	120 to 155
Limestone gray; 50 to 66 per cent of insol. residue, mainly chert (Devils Promenade Chert)	45	200
Limestone dark gray; 43 per cent of insol. residue, mainly chert	20	220
Limestone gray; 50 to 60 per cent of insol. residue, mainly chert	20	240
Limestone light gray; 16 to 40 per cent of insol. residue, mainly chert	60	300
Limestone light gray; 56 to 80 per cent of insol. residue, mainly chert (Grand Falls Chert)	105	405
Limestone dark colored; 50 to 73 per cent insol. residue, mainly chert	55	460
Limestone greenish, shaly; 30 per cent insol. residue, mainly chert and fine silt. (St. Joe Member)	37	497
Total	377	

shown, there is more limestone than chert, and in three there is more chert than limestone. The Boone formation is usually called the "Boone chert" rather than the Boone limestone. The samples of the formation in the Ottawa County well contain very little or no dolomite and in this respect are not like those of the Boone containing the ore deposits in the mining district. There is also a smaller amount of chert in the Boone formation outside the mining district than within the district. The lower half of the Boone in this well contains more chert than the upper half, the upper half being mostly limestone, and the lower half mostly chert.

Complete drill samples have been obtained from the Power Station well and the Bird Dog mine well located in the central part of the mining district. (See under Chert Silicification and Table XVII).

It was the intention of the writer to make a detailed lithologic study of the formations in the three wells, one of which is located outside and the other two within the mining district. The investigation involved the determination of the relative amount of dolomitization and silicification developed in the two localities. Because of the difficulty and time involved in making accurate determinations of the amount of dolomite as distinct from calcite, this investigation could not be completed. However, sufficient work was done to indicate that the formations within the mining district contain a much larger amount of dolomite and chert than outside. The increase in dolomitization and silicification not only affects the Boone formation in which the ore occurs but also influenced the Pre-Chattanooga formation below the Boone. (See under dolomitization and silicification.)

St. Joe member. No attempt has been made by the writer, in this report, to divide the Boone into various subdivisions for mapping or correlation purposes except with reference to the oolite and green lime horizons in the upper half of the formation and the well defined St. Joe member at the base. The St. Joe member overlies the Chattanooga black shale and forms the basal beds of the Boone. It consists of shaly and sandy dolomitic limestone with little chert within the mining district. Outside the district it contains little or no dolomite. It is usually thirty to forty feet thick with no apparent break in sedimentation either with the underlying Chattanooga shale or the overlying more cherty limestone beds of the Boone. It is exposed in only one locality in Ottawa County, namely along the east side of Grand River in sections 29 and 32, T. 26 N., R. 24 E.

Short Creek Oolite. The Short Creek oolite is a thin bed of oolitic limestone, usually from one to ten feet in thickness. It is a fairly persistent horizon especially in the eastern part of the district and is about one hundred to 125 feet below the top of the Boone. It has considerable value as a datum plane because of its wide distribution and its distinct lithologic character permitting its identification from other beds in the Boone. In places the oolitic member has been silicified into chert; the oolitic spherules, however, are well preserved and easily recognized.

Table VII data furnished by W. F. Netzeband, shows the thickness and depth below the surface of the oolite member at various mines. Additional data are available but only those records showing the general range in depth for each mine or lease are given in the table.

Green limestone. The green limestone (glauconite) member has a thickness of five to twenty feet. Its position in the Boone is usually twenty-five to thirty feet above the oolite although in a few places a bed of similar character has been described as occurring immediately overlying the oolite. It consists

TABLE VII. *The depth below surface and thickness of the oolite bed in the Boone*

MINE	LOCATION	DRILL HOLE	DEPTH Feet	THICKNESS Feet
Martha B	NE NW 17-29-24	F22	115-120	5
Martha B	NE NW 17-29-24	56	115-121	6
Crawford Lease	NW 36-29 23	6	95-100	5
Crawford Lease	NW 36-29-23	13	105-110	5
Crawford Lease	NW 36-29-23	39	110-119	9
Lucky Syndicate	N SW 17-29-23	8-12-F13	240-245	5
Lucky Syndicate	N SW 17-29-23	8-12-F14	255-260	5
Lucky Syndicate	N SW 17-29-23	8-12-F25	260-264	4
Tri-State Mining Co.	NW NW 19-29-23	121	235-260	25
Foch	NE NW 19-29-23	1006	215-220	5
Foch	NE NW 19-29-23	1008	200-205	5
Netta	NW NE 20-29-23	1102	246-251	5
Perin W20	NE NW 20-29-23	133	230-235	5
Otis White	NW SE 17-29-23	F3	245-250	5
Otis White	NW SE 17-29-23	F10	220-230	10
Otis White	NW SE 17-29-23	F12	255-260	5
Otis White	NW SE 17-29-23	F25	260-264	4
Swift	NW NW 16-29-23	18-67-5	225-230	5
Swift	NW NW 16-29-23	18-66-11	235-240	5
Netta-White	SW SE 17-29-23	A22	225-230	5
Netta-White	SW SE 17-29-23	A25	220-230	10
Netta-White	SW SE 17-29-23	A27	235-245	10
Mabon	S 32-29-24	26-68-34	165-175	10
Mabon	S 32-29-24	26-68-58	195-204	9
Mabon	S 32-29-24	26-69-1	140-150	10
Indiana	NW NE 21-29 23	C41	205-215	10
Indiana	NW NE 21-29 23	141	185-190	5
Indiana	NW NE 21-29 23	167	225-230	5
Waxahachie	SW NE 33-29-23	20	125-130	5
Waxahachie	SW NE 33-29-23	63	123-130	7
Blue Bonnett	NE NE 23-29-23	32	155-160	5
Blue Bonnett	NE NE 23-29-23	39	150-170	20
Pliler Lease	NW SE 20-29-23	2	30-35	5
Cosmos (Jeff City)	SE NE 21-29-23	129	205-210	5
Hunt E40	NE SE 16-29-23	53	230-235	5
Hunt E40	NE SE 16-29-23	56	230-235	5
St. Louis #6	SW NE 17-29-23	F4	275-285	10

of medium to fine grained, grayish to brownish crystalline limestone containing a small and variable amount of greensand or glauconite. A sample submitted to the writer contained one to five per cent of glauconite, the grains ranging in size up to one-twentieth inch in diameter.

Other subdivisions. The upper part of the Boone is often referred to as the upper Burlington and the lower part the lower Burlington, the two being separated by the Grand Falls chert. However, the writer has not found it practical to apply this classification in the stratigraphic subdivisions of the Boone because of the very irregular distribution of the chert.

The Grand Falls chert is usually described as composed mainly of chert, varying in thickness between thirty and eighty feet. This cherty member of the Boone has been mapped by C. E. Siebenthal[9] in the Joplin district, where it is described as a chert zone about 100 feet below the Short Creek oolite horizon.

In the Miami district there is considerable irregularity in the distribution of highly silicified or cherty zones in the Boone. In some places there is no well defined single zone of chert and in other places there are several zones characterized by abundant chert. It is the writer's belief, like that of A. Winslow,[10] and others that the cherty portion of the Boone varies greatly in its thickness from place to place, and does not form a definite stratigraphic horizon.

A thick body of cherty limestone in the upper part of the Boone formation is exposed along the Spring River ten miles below Baxter Springs at "Devils Promenade," in the SE. ¼ NW. ¼ sec. 5, T. 28 N., R. 23 E. The right bank of the river consists of a wall of flint rock, overlying a floor of flinty limestone holding many flint concretions, the so-called "biscuits" in the "Devils Kitchen." This cherty limestone has been referred to as the "Lincolnville chert" and the "Quapaw chert" as it was approximately from this zone that the lower runs of ore at Lincolnville and Quapaw were mined.

The silicified limestone at Devils Promenade has much the same character as the Grand Falls chert. It varies greatly in thickness, usually from twenty-five to fifty feet. It usually occupies a position between twenty or thirty feet and fifty or sixty feet above the oolite horizon. In places, therefore, it occupies the same zone as the green lime horizon, and where it is very thick it may include the oolite horizon.

CHESTER SERIES

Overlying the Boone formation in northeastern Oklahoma is the Chester series (upper Mississippian) which is represented in Ottawa County by the Mayes and Fayetteville formations. The Mayes formation consists of limestone at the base followed by shale and sandstone. It has been described by L. C. Snider[11] as the basal formation of the Chester series and is correlated mainly as the equivalent of the Moorefield shale and the Batesville sandstone of Arkansas. Farther south the Mayes is overlain by younger members of the Chester consisting of the Fayetteville shale and Pitkin limestone. While the Pitkin limestone[12] is not known to occur farther north than southern Mayes County, the Fayetteville shale was recognized by L. C. Snider[13] near Fairland, Ottawa County. In the summer of 1930 the Fayetteville was mapped as shown in Plate I as extending as far north as Narcissa.

Mayes Formation

The Mayes formation is quite variable in character and thickness, and is correlated with the Carterville formation in the Joplin district.[14] The Carterville formation, considered as of Chester age, is described by Smith and Siebenthal as consisting of shaly and oolitic limestones, calcareous, arenaceous shale, shaly sandstone, and massive hard sandstone.

The principal surface exposures of the Mayes formation (See map, Plate I) are west of Spring River. The formation, however, occurs to some extent in isolated areas on the hilly uplands of the Boone chert east of the river. Its main area of outcrop is in a belt or zone extending northeast across the county, between the area of the underlying Boone formation on the southeast and the overlying Cherokee shale on the northwest. It is apparently everywhere present underneath the Cherokee shale in the western part of the county.

Although the map by Snider[15] derived from an earlier one by Siebenthal[16] shows the Chester or Mayes as terminating in northern Ottawa County, it is the writer's interpretation that the Mayes overlies the Boone chert in the vicinity of Baxter Springs, and is exposed farther north along Spring River and Brush Creek in Cherokee County, Kansas. The basal limestone member of the Mayes can also be recognized in the driller's logs of the Kansas mining field. The Mayes formation is mapped therefore as extending into Kansas.

No detailed description of the various phases of the Mayes formation will be attempted, but the general character of the limestone, shale and sandstone members will be discussed.

The basal limestone is well exposed along the Neosho River below Miami and on the lower slopes of uplands east of the city. Southeast of Miami, where the K. O. & G. Railroad crosses the Neosho River, about fifteen feet of the Mayes is exposed overlying the cherty limestone of the Boone. The contact between the two formations is about fifteen feet above the low-water level of the river. The base of the Mayes is a thin conglomerate consisting of a limestone matrix inclosing pebbles of chert derived from the weathering and erosion of the underlying Boone. The pebbles are irregular in shape, but usually have smooth surfaces. The size of the pebbles vary from less than one inch to two and three inches in diameter. Above the basal conglomerate portion much of the limestone is partly siliceous and platy, but the greater part is a coquina-like mass of comminuted fossils.

Thin sections, examined under the microscope, show that the conglomerate at the base contains, in addition to the limestone matrix and chert pebbles, abundant clastic grains of coarse quartz and a small amount of feldspar, glauconite, and iron oxide. A thin section of the very fossiliferous limestone bed, about ten feet above the conglomerate at the level of the railroad track, shows about twenty-five to thirty per cent of clastic quartz, with some feldspar. The beds, therefore, are not pure limestone but contain considerable clastic material, indicating a tendency to grade into sandstone and shale.

The Mayes limestone is very much silicified and dolomitized in the vicinity of the ore deposits in the mining district. The cherty phase associated with the ore is not exactly like the Boone chert, but closely resembles it in many places. A relatively distinct and easily recognized phase of the formation, called "sandspar" by the miners, is apparently formed by the silicification of the limestone containing an appreciable amount of clastic grains of quartz, feldspar, and fine silt. The silicification of the nearly pure limestone develops fine grained chert much like the Boone chert; the silicification of the nearly pure sandstone develops quartzitic sandstone and quartzite; and the silicification of the sandy limestone apparently develops the "sandspar" rock.

The shale is dark colored or black, usually quite calcareous and sandy. In places it contains lenses of shaly limestone and sandstone. The shale is brown or yellow to a depth of ten or fifteen feet where exposed to surface weathering. The shale of the Mayes in many places resembles the black fissile shale of the overlying Cherokee formation. For this reason the shales of the two formations can not be distinguished easily from one another, either in well records or surface outcrops, unless distinctive associated rocks are present. The shale phases grade into limestone and sandstone both parallel and normal to the bedding, indicating great variability in conditions of sedimentation.

Sandstone generally occurs overlying the shale where the formation attains a thickness of thirty to sixty feet. The sandstone is found on the tops of many of the hills within five or six miles south and southeast of Miami. A hill of Mayes formation two miles east of Miami in the northern part of sec. 33 is formed of about twenty-five feet of crinoidal limestone below with ten feet of shale, followed by about ten feet of sandstone capping the hill. The upper bed contains abundant bryozoa of the Archimedes type. In the vicinity of Century and Lincolnville the sandstone occurs along the stream bottoms, the underlying shale and limestone being below the surface.

The sandstone is usually fine grained and friable except in the vicinity of the ore deposits where it is extensively silicified into hard quartzitic sandstone. Thin sections of both friable and quarzitic phases contain a variable amount of clastic feldspar grains. Analysis of the sandstone from the top of the hill two miles east of Miami shows seven per cent soluble calcareous material, sixty-seven per cent quartz sand, and twenty-six per cent feldspar sand. In addition a few grains of tourmaline, zircon, and muscovite are present.

The thickness of the Mayes formation is quite variable, probably ranging between ten and sixty feet. Variation in thickness seems to characterize each of the limestone, shale, and sandstone phases of the formation.

A fairly complete section of the Mayes formation is exposed as an outlier on the Boone, east of Spring River in the NE. NE. sec. 35, T. 28 N., R. 24 E. The formation is exposed along a road on the north side of a hill. The Boone is exposed in the creek bed, above which there is about sixty-one feet of Mayes formation, as follows:

MAYES FORMATION	*Feet*
Sandstone at top of hill, Archimedes abundant	10
Shale	10
Limestone	3
Shaly zone, unexposed	9
Limestone, thin-bedded	6
Shale, brown, weathered	8
Limestone, thin-bedded, conglomerate at base containing chert pebbles	15
Total	61
BOONE LIMESTONE	
Limestone cherty in creek bed 6 feet.	

The thickness in the above section is in accord with that of the sixty feet of Mayes in the Ottawa County well.

It is probable that the maximum thickness of the formation is about sixty feet in the district. In some places much of the entire formation may consist of limestone as already indicated. Usually, however, it consists of alternating shale and sandstone, with fifteen to thirty feet of limestone at the base.

An examination of drill cuttings and drill records has led W. F. Netzeband and P. W. George to estimate the maximum thickness of Mayes limestone as ranging between thirty and fifty feet in the mining district.

In the logs of exploration drill holes little or no attention is paid to the character of the formation above the limestone, and no samples are preserved for inspection. A section of the Mayes formation like that above referred to in the outlier east of Spring River, if encountered in a drill hole probably would be described in the logs as "shale" or "soapstone" down to the fifteen-foot bed of limestone at the base of the formation. That portion above the limestone has been usually interpreted as Cherokee shale.

The variation in thickness of the shale and sandstone of the Mayes formation appears to be the basis, to a large extent, for the erroneous belief in the widespread occurrence of "shale holes" and "shale depressions" in the surface of the Boone formation. These so called "shale holes" are then described as due to underground solution developed before the shale was deposited upon the Boone, when the latter is supposed to have had a surface characterized by "sink hole" or "Karst topography." The present exposed surface of the Boone, however, is not characterized by "sink hole" topography, and the very insoluble character of the cherty Boone is obviously an adequate explanation for the failure to develop such a solution type of topography.

The cherty character of the Boone had been developed (first period of silicification) before the Mayes was deposited and hence similar unfavorable conditions for solution, or Karst, topography affecting the Boone probably existed in both pre-Mayes and pre-Cherokee time, just as it persists today.

The maps of the sub-shale surface in the mining district are valuable in supplying certain geological information, but the sub-shale surface contoured does not represent any definite stratigraphic horizon. The contours indicate only the very irregular surface between the shale and underlying limestone within the Mayes formation. The variable thickness of the shale, sandstone, and limestone is due to variable conditions of original sedimentation and is not confined to this locality, but appears to be characteristic of the Chester series throughout a large part of the Mississippi Valley region. In addition to the variable thickness of shale in the Mayes formation the contoured sub-shale surface is uneven because of warping and folding of the strata as referred to under structural features.

Fayetteville Shale

Although the Fayetteville shale formation is not present in the mining district, it is known to occur in the southern part of Ottawa County, where it overlies the Mayes and underlies the Cherokee as far north as the vicinity of Narcissa. The Fayetteville formation consists of shale interbedded with limestone and sandstone. Certain shaly horizons are characterized by abundant Archimedes types of bryozoa. The maximum thickness of the formation in the southern part of the county is probably between forty and fifty feet. Its absence in the northern part of the county is probably due to lack of deposition rather than subsequent erosion.

PENNSYLVANIAN

Cherokee Formation

Only the lower half of the Cherokee formation occurs in Ottawa County. The formation is a black fissile shale, containing relatively thick sandstone beds, several thin seams of coal and at least one thin bed of limestone.

The Cherokee shale occupies the northwestern part of Ottawa County, the eastern boundary (see map, Plate 1) extending southwest through the mining district to the vicinity west of Afton. The general thickness of the Cherokee formation in the district increases from the southeast to the northwest in conformity with the dip of the underlying strata to the northwest. The thickness varies from a knife edge along the eastern margin of its area of outcrop to nearly 300 feet in the northwestern part of the county.

The places of greatest thickness recorded within the mining district are in Blue Mound just north of the State line in Kansas, where it is 235 feet thick, and in places in the deep shale trough of the Miami syncline extending in a northeast direction through the central part of the mining district where it reaches 285 feet thick.

Beyond the western margin of the district the Cherokee gradually increases in thickness to about 450 feet ten or fifteen miles west in northern Craig County where it is overlain by the Fort Scott limestone. It thickens rapidly to the southwest, reaching 960 feet in the vicinity of Claremore.

The true thickness of the Cherokee formation in the mining district can not be accurately determined from drillers' logs except where the Cherokee shale rests directly upon the basal limestone of the Mayes formation. Where the Cherokee rests upon sandstone or shale of the Mayes, the thickness of the two formations can not be determined. In many of the logs of deep wells of the district, the thickness of the two formations therefore, can not be interpreted. If the drillers were required to report the thickness and depth of sandstone as distinct from shale, and also to report the chert conglomerate at base of the Cherokee, much valuable information concerning the geology of the Cherokee and Mayes formations could be obtained. The structural features of the Cherokee formation, mainly the folding of the "Miami syncline," are discussed more fully under structure.

A conglomerate is known to have been encountered in exploration drill holes at the base of the shale, in the area of the Cherokee, but is rarely or never recorded by drillers in the logs of wells. In sinking the North Field shaft of the Scammon Hill mine in July and August, 1929, careful attention was paid by the writer to the character of the formations penetrated. The shaft was sunk through 180 feet of Cherokee shale and a bed of chert conglomerate three to four inches thick was found at the contact with the underlying Mayes limestone. The miner in charge stated that in sinking other mine shafts in the district a gravelly shale, varying in thickness from a few inches up to a few feet, was found usually on the underlying limestone, the thicker beds of gravel containing pebbles up to two and three inches in diameter.

The source of the chert or flint pebbles in the Cherokee basal conglomerate is apparently from the underlying Mayes formation which contains relatively abundant pebbles not only throughout the basal limestone of the Mayes but to some extent also in the overlying shale and sandstone. The chert pebbles in the Mayes formation are obviously derived from the underlying Boone chert which unconformably underlies the Mayes. The source of the chert pebbles can therefore be traced back through their secondary source in the Mayes to their original source in the Boone chert.

In some places there are thin seams of coal, and in other places some bitumen. As a result of the presence of bitumen a few tar springs occur in the district, the most notable of which was the Tar Spring on Tar Creek now covered with debris from the mines in the village of Cardin. In several mines of the district considerable tar is encountered, the source of which is in the Cherokee shale, overlying the ore-bearing formation as described later.

Several coal seams occur in Cherokee shale, one of the most persistent, a foot thick, occurring about thirty feet below the "Blue Mound sandstone" exposed in the slopes of Blue Mound, in "Dawes Hill" (sec. 30, T. 28 N., R. 22 E.) and in the hill a mile to the east in sec. 29 once used as a triangulation station. Other thin coal seams, lower in the Cherokee, were encountered in the sinking of the North Field shaft of the Scammon Hill mine at 120 feet (two to three inches thick) and at one hundred feet (eight to ten inches thick) above the base of the Cherokee.

Little Cabin sandstone. The Cherokee formation includes two well defined sandstone members, the lower about fifty feet and the upper about 200 feet, above its base. The upper is the Bluejacket sandstone, well exposed at Bluejacket in northern Craig County. The lower member was named the Cabin Creek sandstone[17] by D. W. Ohern in an unpublished manuscript for exposures along Little Cabin Creek near Vinita, Craig County.

The sandstone is medium to coarse grained grading into shaly beds and has a usual thickness of ten to fifteen feet. It is well exposed in the vicinity of Narcissa in Ottawa County. It forms the cap rock of the flat-topped hills, fifty to one hundred feet high, south of Miami and also caps the low mounds south and southwest of Baxter Springs. As the Cherokee formation dips to the northwest it appears on lower ground along Tar Creek near Commerce and in Century. Its approximate distribution is indicated on the geologic map, Plate I, under the name of Narcissa sandstone.

As stated, its position is about forty to fifty feet above the base of the shale. No fossils have been found in it except that of plants. It is approximately at the same horizon in the Cherokee as the "Burgess sand" in the oil fields.

Bluejacket sandstone.[18] The Bluejacket sandstone is a well defined sandstone member about 200 to 250 feet above the base of the Cherokee. It attains a thickness of ten to forty-five feet in various places. The sandstone has resisted erosion somewhat better than the shale and forms the cap rock of several mounds such as "Dawes Hill" in sec. 30, T. 28 N., R. 22 E., and

TABLE VIII. *Section through summit of Blue Mound showing thickness of Cherokee formation*

DRILL HOLE	63A	60A	57A
Cherokee			
Bluejacket sandstone	25	25	25
Shale	210	195	205
	235	220	230

the hill used as a triangulation station a mile east in sec. 29. One of these mounds is Blue Mound, a short ridge trending north from the Oklahoma-Kansas boundary, north of Picher, capped with about twenty-five feet of this sandstone and having a relief of about one hundred feet.

At the West Side Webber mine, located on the west side of Blue Mound, E.½ SW. ¼ sec. 7, T. 35 S., R. 24 E. (Kansas), three holes drilled on the top of the mound show the following thicknesses of the formation shown in Table VIII.

In the section at Blue Mound the driller's logs show a uniform thickness of twenty-five feet of sandstone, underlaid by 195 to 210 feet of shale above the Mayes.

Drill records of the Kansas Exploration Company show a thickness of 266 feet of the Cherokee formation in the deep shale trough about one-half mile west of Blue Mound in the NE. cor. SE. ¼ NE. ¼ sec. 12, T. 35 S., R. 23 E. (Kansas). In the middle of the trough there are five to twenty feet of the sandstone underlaid by 176 to 205 feet of shale. The relative position of the sandstone and the shale on Blue Mound and in the deep shale trough, shown in fig. 7, is further discussed in the chapter on structural features.

At the Scammon Hill mine, logs of drill holes of the Commerce Mining and Royalty Company, penetrating the deep shale of the "Miami trough" show a thickness of sandstone and shale shown in Table IX as follows:

TABLE IX. *Section showing Cherokee formation in Miami Syncline at Scammon Hill mine*

DRILL HOLE	97E	101B	102B	104B	105B	106B	114B
Cherokee							
Surface	0	10	0	0	8	8	8
Bluejacket sandstone	20	30	27	38	30	29	42
Shale	230	210	228	247	197	248	200
	250	250	255	285	235	285	250

There appears to be a slightly increased average thickness of both the sandstone and the underlying shale within the syncline at the Scammon Hill mine as compared with that outside the syncline at the Webber mine on Blue Mound, apparently due to the infolding and crumpling of the shale in the syncline.

The Bluejacket sandstone has been provisionally correlated with the well-known Bartlesville sandstone of the oil fields. At Bluejacket the sandstone is usually fifty to sixty feet thick, forming either a single thick bed, or more usually separated into several beds by intervening shales. It is at the same horizon as the sandstone at Blue Mound, being about 200 to 250 feet above the base of the Cherokee formation.

The name Blue Mound sandstone is probably more appropriate for local use in the mining district as the position of the sandstone on Blue Mound is well understood and its continuation into the surrounding locality can be traced in surface outcrops.

"Elm Creek" limestone. A six- to ten-inch bed of limestone, containing abundant fossils, is present in several places within the Cherokee formation in the northwest part of Ottawa County and in the adjoining area of Kansas. It occurs along Elm Creek, south of the road, in NW.¼ SE.¼ sec. 10, T. 28 N., R. 22 E.; along Fourmile Creek in the central part of sec. 30, T. 29 N., R. 22 E.; and along the east bank of the Neosho River in the east part of sec. 15, T. 29 N., R. 21 E. It was also found on the south slope of a hill in the west part of sec. 15, T. 35 S., R. 3 E., (Kansas) a short distance north of the Kansas State line.

The exact horizon of the limestone could not be definitely determined but where developed it probably occurs ten to twenty feet below the Bluejacket sandstone. However, it was not found in sections where the Bluejacket is known to occur. The limestone is such a thin bed that it may not have been developed except in a few places, and it is also possible that the above occurrences may not represent the same horizon. Limestone is well known in the Cherokee at several horizons farther south, and the above thin bed of limestone may be correlated later with one of them.

There appears to be no decrease in the original thickness of either the Mayes or the Cherokee formations along their present border of outcrop. The Mayes preserves its maximum thickness of sixty feet on uplands east of Spring River, and its normal thickness is indicated in the synclinal fold south of Seneca. The Cherokee formation is represented along the border by the Little Cabin and Bluejacket sandstones, which are respectively correlated with the "Burgess sand" and "Bartlesville sand" in the oil fields farther west. It appears quite probable that upper Mississippian and Pennsylvanian strata once extended over a large part, if not the whole, of the Ozark plateau region and were subsequently eroded.

IGNEOUS INTRUSIVES

Igneous rocks intrude the Carboniferous rocks of the surrounding region. Some forty miles to the south of the mining district is the Spavinaw[19] pegmatite granite, the intrusion of which has arched up the overlying Boone formation in the vicinity. About seventy miles northwest of the district occurs the granite pegmatite intrusive and basic sills of the Rose Dome[20] area in Kansas. About eighty miles northeast of the district are intrusive rocks on the border of Laclede County and Camden County[21] Missouri.

In May, 1930 granite was struck at a depth of 1,245 feet in drilling a water well at the Bird Dog mine west of Picher, in the SE ¼ of sec. 13, T. 29 N., R. 22 E. The granite is interpreted by the writer as of intrusive origin because of its porphyritic pegmatitic texture, marked silicification of the sandstone at the contact, and the absence of granitic material deposited as sediment in the overlying sandstone. The pegmatitic granite, apparently, projects up through the lower part of the Cambro-Ordovician some 500 to 700 feet and has arched the overlying strata adjacent to the Miami syncline as indicated in Figure 7. It is the opinion of the writer that the intrusion of the granite arched the overlying strata and formed the adjoining syncline.

The evidence in support of the intrusive origin of the granite is described more fully in connection with the discussion of the origin of the ore, page 78.

TERTIARY AND QUATERNARY

Surface formations, mainly unconsolidated deposits, and much younger than the bed rock of shale, sandstone, and limestone of Carboniferous age are widely distributed over the mining district. Two distinct surface formations may be recognized: an older composed of sandy clay, much chert gravel at the base, and found on both uplands and lowlands of the district, and a younger deposit found only in the valley bottoms.

The older deposits are probably of Tertiary age, presumably Pliocene or older, like much of the Tertiary of western Oklahoma, Kansas and Nebraska, although no definite correlation has been made. The younger deposits, confined to the stream bottoms, are apparently of Pleistocene and Recent origin.

Tertiary gravel and clay. The most conspicuous of the gravel deposits are found upon the highest hills and ridges, from fifty to one hundred feet above the present stream levels. The gravels vary from less than an inch to four or five inches in diameter. They are composed largely of chert, the original source of which is partly in the chert of the Boone and partly from chert pebbles in the Mayes formation and from the basal conglomerate in the Cherokee. The gravel deposits vary greatly in thickness, usually from one to ten feet. The thicker deposits are utilized extensively for concrete and road material. Gravel pits on the uplands have been extensively worked at Ottawa, six miles east of Miami, at the south end of the ridge in sec. 13, T. 28 N., R. 23 E., and on the sandstone-capped mound south of Baxter Springs. While only the gravel composing the basal part of the deposit is found on the uplands, the overlying clay having been eroded, the clay showing the gravel beneath is found extensively on the lowlands of the Cherokee shale area, especially along the Neosho River farther to the west.

Although some of the gravel on the Mayes formation may represent remnants of the conglomerate formed at the base of the Cherokee formation, yet most of it, as well as all of that overlying the Cherokee shale and sandstone should be correlated with the Tertiary gravel of the region which is a modification of the view earlier expressed by the writer[22] concerning the age of the gravels.

The sandy clay portion of the deposit lying above the gravel in the lowland areas is usually yellow or brown in color. It contains more sand and silt than the Cherokee shale and its yellow color is largely due to oxidization and leaching. It is generally reported as "yellow clay," "soil and clay," or "clay" from ten to thirty feet thick in the drillers' logs of exploration drill holes that penetrate the Cherokee formation in the mining district. Below the "yellow clay" is the dark colored "soapstone" or "shale" of the Cherokee formation.

Both the clay and underlying gravel are well developed in the City of Miami where the gravel, usually five or six feet thick, rests directly on the Mayes limestone. The overlying yellow clay is usually five or ten feet thick in the south part of the city but increases to twenty and thirty feet farther to the north away from the river.

Probably the best exposures of the Tertiary gravel and clay are to be seen along the Neosho River above Miami. In places along the river, as at Prairie Riffle in sec. 6, T. 28 N., R. 22 E., the basal gravel, from five to ten feet thick, is firmly cemented into a hard conglomerate, making vertical walls on the river bank and causing riffles in the river bottom.

At other places along the river, as in the north-central part of sec. 15, T. 29 N., R. 21 E, (west side of river in Craig County) the conglomerate resting on Cherokee shale is overlaid by thick clay strata having a distinct dip of ten to twenty degrees to the southeast, conforming in general to the dip of the underlying Cherokee shale.

The Neosho River cuts indiscriminately across both the Carboniferous and Tertiary strata. the contact of the Tertiary basal gravel with the underlying Cherokee shale alternately extending above and below the river level. The thickness of the Tertiary deposits below river level may reach fifty or one hundred feet. The present course of the river is therefore entirely out of harmony with the drainage system that developed the Tertiary erosion of the Carboniferous strata and subsequently deposited the Tertiary gravel and overlying sandy clay.

It is the opinion of the writer that the deposits of upland gravel and associated clay of the region were formed by drainage flowing to the westward and northwestward. This favored the transportation of abundant chert gravel of the Boone from the Ozark region far out into the area of the Cherokee and other Pennsylvania formations to the westward. At that time, during the Tertiary and earlier, the drainage was apparently consequent on the northwestward dip of the Carboniferous strata, a period which long preceded that of the present system of southeastward drainage of the district.

Pleistocene and Recent. The Pleistocene and Recent deposits consist of gravel, sand, silt, and clay, mainly of alluvial origin in the river and stream bottoms. Much of it, especially along the Neosho River, may be reworked material from the Tertiary. The Recent alluvial deposits, in places at least, lie unconformably upon the eroded and slightly dipping strata of the Tertiary formation and owe their distribution to the present southeastward drainage system.

STRUCTURE

The structural features discussed include a description of the general or regional dip of the strata, erosional uncomformities, folding, fracturing and faulting, and brecciation.

The rock strata of the district dip to the northwest, although the surface drainage flows to the south and southeast as already stated. The dip of the strata is relatively slight but is sufficient to carry the Boone and Cherokee formations down to the northwest at the rate of fifteen or twenty feet to the mile. The northwestward dip in this district gradually changes until it acquires a nearly westward dip about eighty miles to the west, in the Osage Reservation,[23] where the general westerly dip averages about thirty feet to the mile.

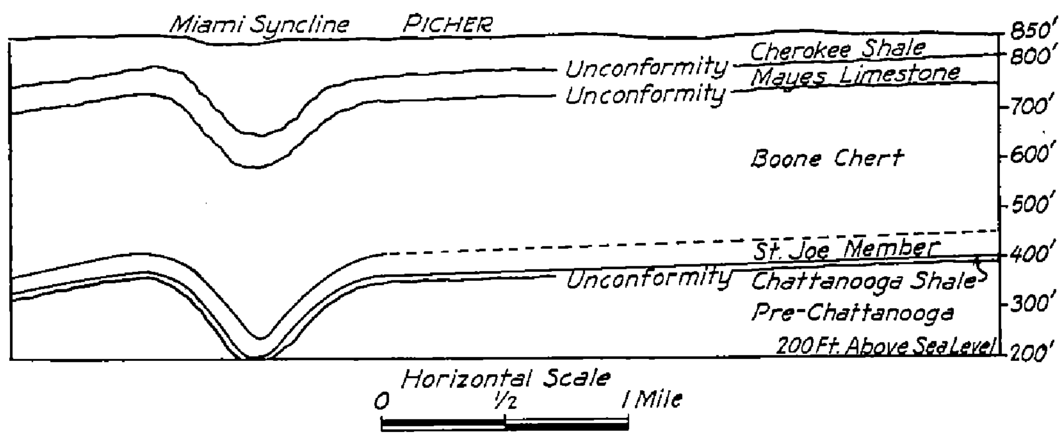


FIGURE 1. Geologic section through Miami-Picher district showing unconformities and the Miami syncline

The northwestward dip of the strata in the lead and zinc district is the same as that of the Mississippian and Pennsylvania strata farther south in east-central Oklahoma, as far south as the Arbuckle Mountains. North of the Joplin region, however, the dip changes to the northwest to conform to the structure of the shallow basin occupied by the Pennsylvania strata in northwestern Missouri.

Two erosional periods marked by distinct unconformities affect the strata of Mississippian age. The earlier occurred during the period of post-Boone emergence, after the deposition of the Boone and before the deposition of the Mayes formation. The later occurred in the period after the deposition of the Mayes formation and before the deposition of the Cherokee formation. The earlier may be referred to as the "post-Boone unconformity" and the later as the "post-Mayes unconformity." See Figure 1.

Post-Boone unconformity. After the Boone formation was deposited, with probably an original thickness of 350 to 400 feet, it was uplifted above sea level. During the period of emergence it was subjected to surface weathering and erosion. The emergent interval was of sufficient duration for the upper beds of the Boone to be worn away by erosion. The evidence of unconformity between the Mayes and Boone formations is shown in many localities by the usual development of a chert-pebble conglomerate in the basal beds of the Mayes lying on the eroded surface of the Boone. While the amount of erosion developed in the Boone before the deposition of the Mayes is not fully determinable, it is not thought to have been excessive in the Miami district and probably was much less than that developed on the higher slopes of the Ozark region.

The general thickness of the Boone as indicated in various deep water wells appears to be 329 to 393 feet. A certain amount of variation in thickness should be considered as due to unequal original deposition. Considering a part of the difference in thickness as original, the amount due to erosion is measured only in tens of feet, probably nowhere exceeding forty or fifty feet. Erosion may have been sufficient, however, to develop a fairly uneven surface of the Boone before the Mayes limestone was deposited upon it.

Post-Mayes unconformity. After the Mayes formation was deposited upon the eroded surface of the Boone, there followed another period of emergence during which the Mayes formation was subjected to much weathering and erosion. The post-Mayes emergent interval was long enough for much of the formation to be eroded away before the occurrence of the next period of submergence when the Cherokee shale was laid down upon it.

The erosional unconformity between the Mayes and Cherokee formations is not only indicated by gravel conglomerate at the base of the Cherokee shale, but also by the fact that the Cherokee, to the southward overlies successively younger members of the Chester series such as the Mayes formation in northern Ottawa County, the Fayetteville shale in southern Ottawa, and Mayes County, and the Pitkin limestone in Wagoner County. The original thickness of the Mayes formation was probably fifty to eighty feet, and the overlying Fayetteville shale in the southern part of the county, forty to fifty feet. The absence of the Fayetteville in the northern part of Ottawa County is believed to be due, not to erosion, but to nondeposition. However, considerable erosion of the Upper Mississippian formations probably occurred before the Cherokee was deposited.

The statement has been made that the Cherokee shale rests directly upon Boone chert in various places in the region, indicating complete removal by erosion of the Mayes limestone before Cherokee time, but the writer is disinclined to accept such an interpretation until a more complete investigation of the geology of the district has been made.

FOLDING

The low dip of the Mississippian and Pennsylvanian strata to the northwest in the district is not uniform but is characterized by local warping and folding, forming undulating depressions and elevations of the beds, most of which are small and have no marked regularity of arrangement. There

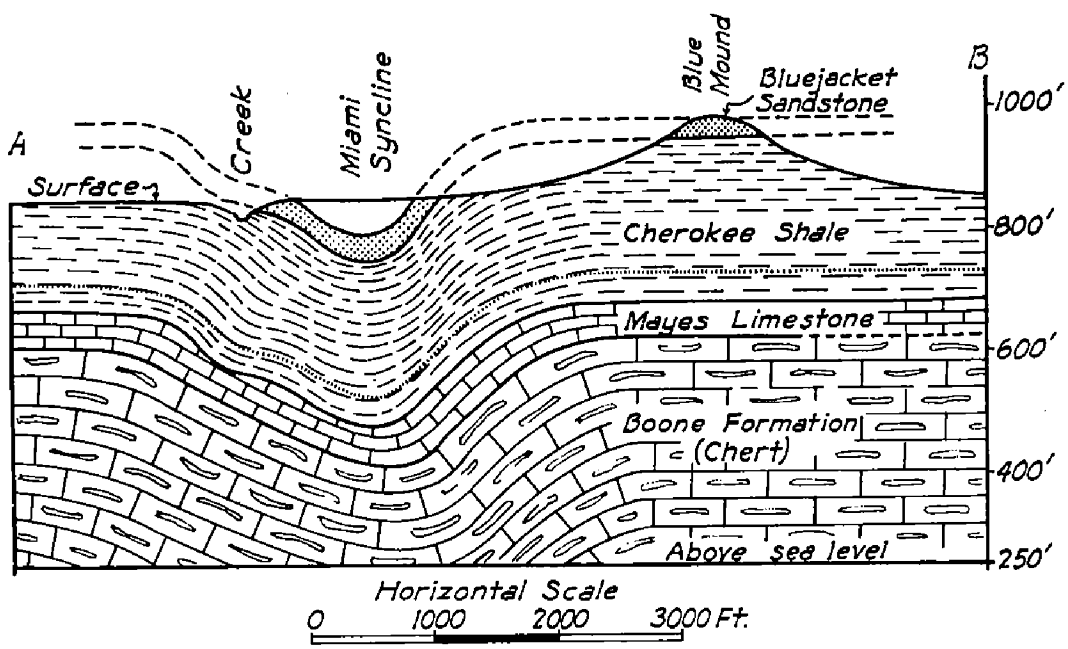


FIGURE 2. Cross section through Blue Mound showing folding of the strata in the Miami syncline.

is, however, one distinct feature of the district which has attracted considerable attention, namely, the well-defined depression or trough which has been variously named the "Miami fault," "Miami trough" and "Commerce trough." This feature is believed to be a structural fold in origin and will be described in this volume as the "Miami syncline."

Miami Syncline

A cross-section through Blue Mound and the trough located a short distance to the west, based upon drill records given in Tables VIII and IX is shown in figure 2. The cross-section is drawn to the scale indicated and shows the Bluejacket sandstone capping the mound at an altitude of 950 feet with about 200 feet of the Cherokee shale underlying it in the mound. In the middle of the trough there is a corresponding thickness of the Bluejacket sandstone and of the underlying shale.

The sandstone in the trough is about 200 feet lower in elevation than that upon the mound. Although at a much lower elevation in the trough the sandstone member obviously maintains the same stratigraphic position in the trough as in the adjacent mound.

The marked difference in elevation of the sandstone member is very apparently due to the folding of the Cherokee formation into a trough by an orogenic movement which at the same time must have folded the underlying Mayes and Boone formations. The trough filled with thick Cherokee formation—its youngest beds, the sandstone member, in the middle—is interpreted, therefore, as a synclinal fold affecting both the Cherokee and underlying formations, and figure 2 is drawn to illustrate such a structure. In the figure, also, the continuation of the sandstone (indicated by the dotted line above the present land surface), is shown as extending from the top of Blue Mound into the trough and beyond, in order to show the complete structure at the time of its origin, before that part of the Cherokee containing the sandstone was eroded away.

A different explanation[24] has been offered concerning the origin of the deep shale trough, namely, that it is due to underground solution, but this interpretation need not be discussed here.

If the shale trough is a synclinal folding of the Cherokee formation it should contain the sandstone member in the middle of the trough overlying about 200 feet of shale, wherever it is deep enough. This relationship is shown to be true of the trough on the Scammon Hill lease as indicated by the drill records in Table IX.

Since the only record of the Cherokee formation required of the driller is the total thickness, no satisfactory information is now available in the logs of drill holes concerning the two sandstone members (the Bluejacket or Little Cabin, either within or outside the trough.

If the trough is a synclinal fold, the strata underlying the Cherokee shale should indicate an appropriate dip as the trough is approached. In each of several mines located adjacent to the deep trough, which were visited by the writer, the strata and likewise some of the ore runs in both the Mayes and Boone formations dip down under the bottom of the trough. (See description of the Scammon Hill, Beaver, Blue Goose, and Crystal mines.)

The synclinal folding of the Boone and Mayes formations below the shale is indicated by the results of some deep drilling in the trough at the Scammon Hill mine. A generalized record of drill hole 79 B is shown in Table X.

The correlation in Table X of sixty feet of Mayes formation under the Cherokee shale is warranted by the occurrence of fifty feet or more of this formation observed in the Scammon Hill mine. Only the upper portion of the Boone was penetrated in this drill hole. Ore was first encountered in the Mayes and then the Boone down to a depth of 495 feet, about 245 feet below the top of the latter, indicating the ore-bearing horizon (upper half of the Boone) to continue under the bottom of the shale trough. The formations, including the ore deposits apparently maintain the same stratigraphic position in the trough as elsewhere in the district in full accord with the view that the trough is a synclinal fold involving the Boone, Mayes, and Cherokee formations.

TABLE X. *Drill hole 79 B, Scammon Hill mine*

FORMATION	THICKNESS *Feet*	DEPTH *Feet*
Cherokee Shale	190	190
Mayes Formation		
Brown lime and flint	40	230
"Sandspar," lead ore	20	250
Boone Formation		
Flint, white	30	280
Ore-bearing rock, mainly lead	10	290
Brown lime and flint	15	305
Flint and ore, mainly zinc	30	335
Lime and flint	25	360
Flint and ore	10	370
Brown flint	45	415
Ore-bearing rock, mainly zinc	80	495
Flint, selvage and open ground	5	500
Brown lime	10	510

It has not been the usual practice in exploration work to drill deeply into the formations below the bottom of the trough. However, when the bottom of the trough is more fully explored by deeper drilling, the downfolding of the Boone formation into a synclinal fold will very probably be shown as indicated in figure 2.

The syncline within the active mining district (See map, Plate I) extends in a nearly straight line for about six miles from the NE. ¼ sec. 1, T. 28 N., R. 22 E., in a direction 25° east of north to the NE ¼ sec. 12, T. 35 S., R. 23 E. (Kansas). While the general trend is N. 25° E., the direction varies locally, generally between N. 20° E., and N. 30° E.

The width of the trough in the mining district is somewhat variable but is usually about one-half mile. The depth is also variable, ranging from one hundred to two hundred feet below the general level of the sub-shale surface. The bottom of the trough is also quite uneven, probably due to minor undulating folds or possibly to small faults that cross the axis of the syncline.

The dip on the limbs of the fold, indicated by the slope of the sub-shale surface, is quite variable, ranging from a low angle up to as much as 70°, the latter high dip being shown on the west limb of the fold on the Angora mine lease. The slope of the western side of the trough may be somewhat steeper than that on the eastern side, but an examination of drill records within the area of the trough has not been sufficient to warrant any final conclusion. See also the discussion of the occurrence of granite in the well of the Bird Dog mine, page 79.

The trough extends to the northeast at least fifteen miles, to the vicinity of the mining district about Crestline, Kansas. The syncline was

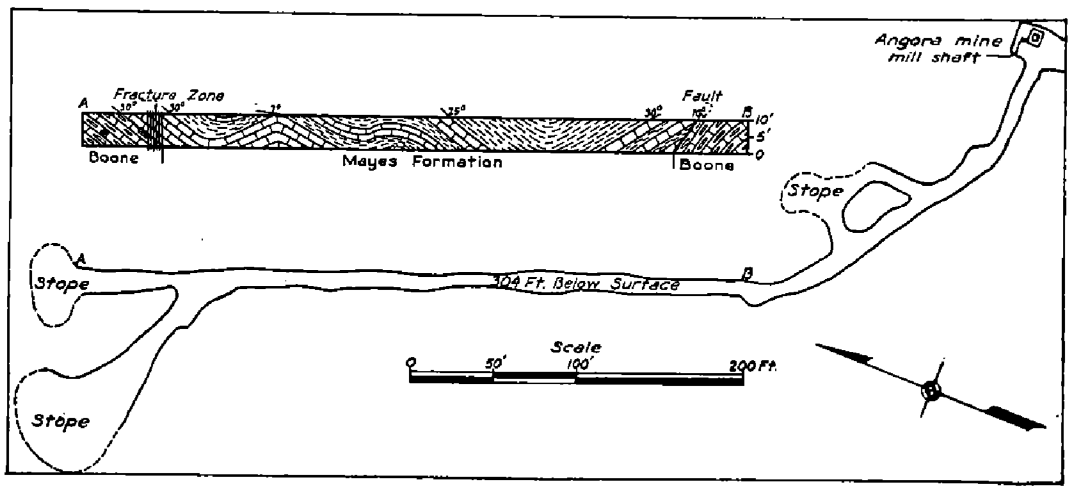


FIGURE 3. Ground plan and section of cross cut along A-B through Miami syncline in Angora mine.

traced, during the field season of 1930, and found to extend to the southwest, (see map, Plate I) across Ottawa County and for some distance beyond.

The structural features of the syncline are well exposed, about two and a half miles southwest of Afton, along the Frisco railroad, in sec. 1, T. 25, R. 21 E., in Craig County. The formations exposed, are the Mayes, Fayetteville and Cherokee, the latter being in the middle of the fold. The strata on the southeast limb dip to the northwest, and that on the northwest limb to the southeast. The Fayetteville shale, on the southwest limb, near the railroad, has a variable dip of 30° to 60° N. W., the Little Cabin sandstone in the overlying Cherokee having a dip of 75° to 80°. On the northwest limb, adjacent, the Little Cabin sandstone is crumpled up and in direct contact with the underlying Fayetteville, the intervening forty-five or fifty feet of Cherokee shale being faulted out or squeezed out by compression.

The section of the syncline exposed at the surface near Afton, is believed to be like that of the trough in the mining district near Picher, as shown in the section through the trough in the Blue Goose-Angora mine (Fig. 3), at a depth of 304 feet below the surface.

The pronounced folding near Afton is apparently confined to a section of the syncline about two miles in length. In conformity with the trough in the mining district it trends about N. 30° E. and is about one-half mile in width. The intervening section between Afton and the mining district is marked only by slight but distinct synclinal folding as indicated in the distribution and dip of the Little Cabin member of the Cherokee. The syncline was traced about ten miles southwest of Afton as far as sec. 15, T. 24 N., R. 21 E., where it crosses the Horse Creek Anticline. So far as determined it gradually converges towards the Seneca fault (or syncline) through its entire southward extension from the mining district.

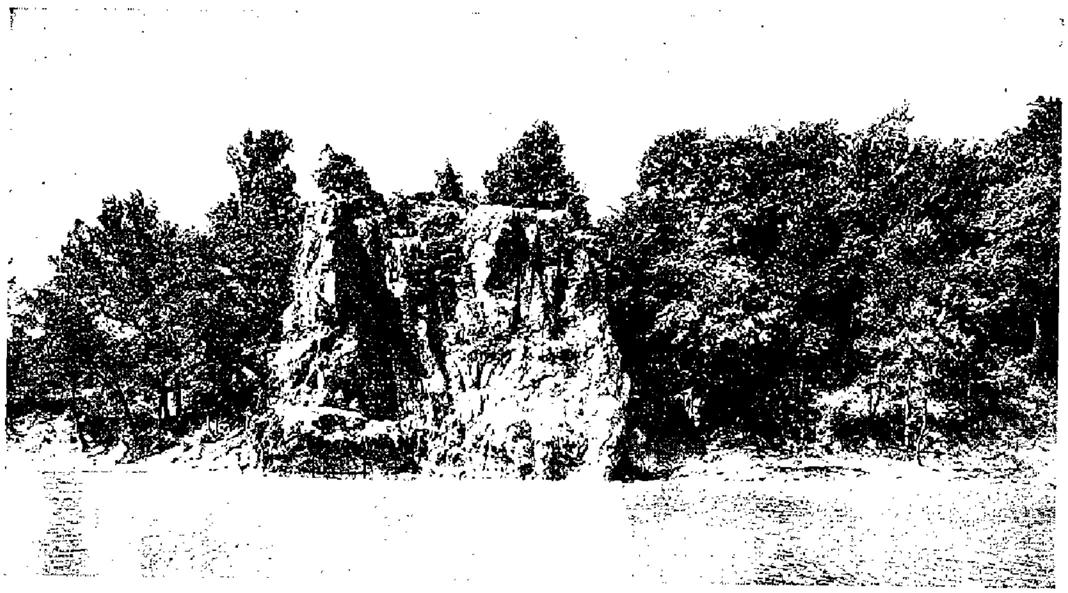
The Seneca Fault

The Seneca fault or syncline is a well known feature and is generally shown on all geologic maps of the region. How it extends across the southeast part of Ottawa County is shown on the map, Plate 1. The fault has been described[25] as double and in places multiple, letting down a long narrow block of Boone and overlying rocks below the level of the Boone. The amount of displacement along the fault has been described as varying from ninety to one hundred forty feet in places. In addition to the down-thrown block the strata on either side of the fault show a strong dip toward it in many places. The trend of the fault in Ottawa County is about N. 40° E., and in Mayes County about N. 55° E.

It is the opinion of the writer that this structural feature is more of a syncline than a double fault, although faulting to a variable extent is associated with it as shown in Plate V. B.

A short distance south of Seneca, Missouri in sec. 16, T. 27 N. R. 25 E. the drill records and mining shafts combined with surface outcrops of the Boone chert indicate that the Mayes limestone occurs between the Boone and the Cherokee shale as in the limb of a synclinal fold. There is a drill hole penetrating about one hundred feet of Cherokee shale in section 16, the position of which indicates a synclinal fold rather than a fault of large displacement. The structure near Seneca is therefore mapped as a synclinal fold.

PLATE V



A. Fault zone on west branch of Spring River at Devil's Promenade, present site of bridge. Photo by C. E. Siebenthal, U. S. Geological Survey.

B. Seneca faulted syncline, west bank of Grand River opposite mouth of Elk (Cowskin) River. Photo by C. E. Siebenthal, U. S. Geological Survey.

Where the structure crosses the west bank of the Grand River opposite the mouth of the Elk (Cowskin) River, shown in Plate V. B, there is a shallow synclinal folding of the Boone formation, the strata dipping from 5° to 10° toward the center, combined with distributive faults of five to ten feet of displacement. A short distance southwest of the above locality, in sec. 12, T. 25, R. 23 E. the Boone is seen to be overlaid by the Mayes, Fayetteville and the basal part of the Cherokee as in a typical synclinal fold. Farther south along the highway on the east side of sec. 28, T. 25 N., R. 23 E. the structure is that of a synclinal fold, the Little Cabin sandstone member of the Cherokee being in the middle of the trough.

The Seneca structure in Ottawa County between the well-defined synclinal fold near Seneca and that at Grand River, near the mouth of Elk River, is not well defined. Its location, shown on the map, is indicated only by some fracturing and a slight dip in the Boone strata.

FAULTING

There is faulting along the Seneca syncline as already described. Faulting is also common in the Miami syncline, as shown in the crosscut of the Angora mine, figure 3. There is much faulting also in the sharply folded section of the Miami syncline west of Afton where there are apparent displacements of fifty to one hundred feet.

Outside of the major structural features of the Miami and Seneca synclines faulting is probably not very pronounced.

A small fault of a few feet displacement, with much brecciation along the fault, occurs along Spring River a short distance below Devils Promenade shown in Plate V. A. Similar faults of a few feet displacement are fairly common in the mines of the district. Most of the displacement, however, along any one fracture observed in the mines was measurable only in fractions of an inch, although the cumulative result of the displacement, in a zone of fractures or in a fractured monocline may reach five or ten feet. Slickensided surfaces on walls of the rocks are quite common, affecting both the ore formation and the associated rocks, but such surfaces may be developed by very slight movement along fractures.

FRACTURING

Fractures and fracture zones consisting of several parallel fractures are common and may be readily observed in the roofs and along the side walls of the mine stopes. The presence of fractures in the ore-bearing Boone formation has undoubtedly influenced the distribution of the ore-bearing rock, and in both exploration and mining operations the trend of the fractures should be followed.

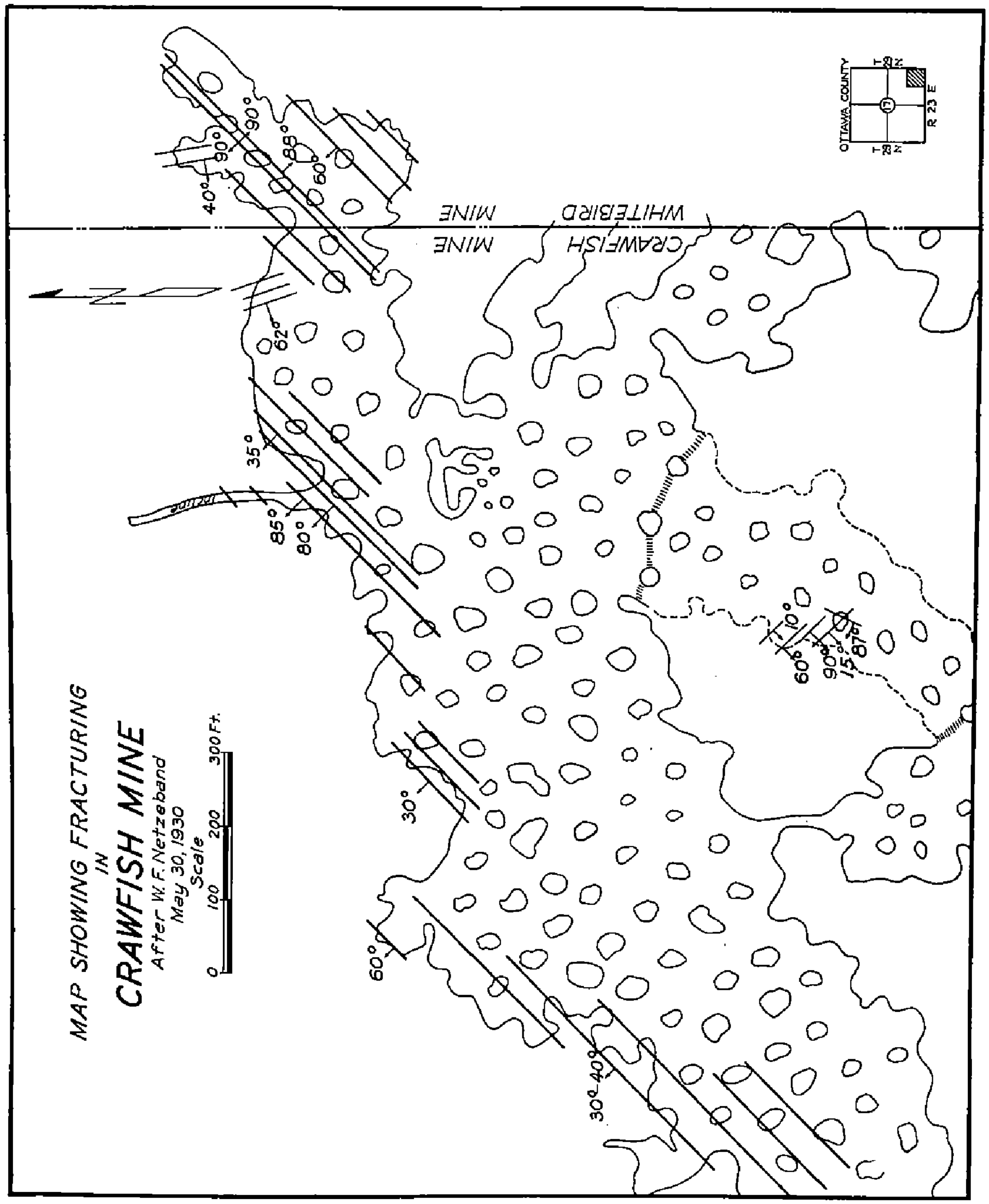


Figure 4. Map of Crawfish mine showing major fractures

The trend of fractures in the Crawfish mine is shown in figure 4, compiled from a map furnished by W. F. Netzeband, Eagle Picher Lead Company. A fracture map of the Brewster mine, furnished by P. W. George, Federal Mining and Smelting Company, is shown in Plate III, and a fracture map of the Woodchuck mine by G. M. Fowler in Plate IV.

Each of these maps indicates a close relation between fracturing and occurrence of the ore. The ore bodies apparently follow not only the bedding, but also follow the major fractures.

A study of the fracturing of the rocks in which the ore occurs is important and well worthy of much further investigation. It may be pointed out that the fracturing and jointing of the Boone formation, in which most of the ore occurs, was developed in more than one period of deformation. There were probably three periods of fracturing; the first during the post-Boone uplift, the second during the post-Mayes uplift, and the third during the post-Cherokee uplift. That fracturing and probably other forms of deformation were developed during each of these periods of uplift is shown in outcrops exposing two or more of these formations. The Boone, as exposed in outcrops along the Neosho River, is much more fractured than the Mayes formation immediately overlying. Likewise, the Mayes formation is more fractured and broken than the overlying Cherokee shale. However, it is believed that the most important fracturing of the ore-bearing rocks was developed in connection with the folding of the Miami syncline which was obviously formed during the post-Cherokee uplift of the region, since this folding affects the Cherokee.

The major fracturing immediately associated with the folding of the Miami syncline has a strong tendency to trend diagonally across the axis of this fold. The close relationship in the trend of the axes of folds and that of fractures or faults may be observed in many regions. This is due to the fact that the axes of the folds trend nearly at right angles to the direction of the maximum compression, while the fracturing, developed at the same time as the folding or a little later trends diagonally, in the general direction of the maximum shear about 45° to the maximum compressive stress.

As already stated, the axis of the synclinal fold extends in the general direction N. 25° E. varying between N. 20° E. and N. 30° E. The fracturing associated with this fold trends diagonally across the axis, as shown on the S. S. & G. mine map figure 5. As described by Siebenthal[26] the east ore run in the Scammon Hill mine has a trend N. 20° W., and of the middle run N. 15° W., and the west run of the old Pius Quapaw mine, N. 15° W. Each of these runs follows major fractures in the trough. The fractures in the S. S. & G. mine, Fig. 5, in the NE¼ NE¼ sec. 36, T. 29 N., R. 22 E., located on the eastern side of the trough have a trend of N. 10° W. and of N. 48° E. at the 320-foot (below surface) level. The ore runs in the Blue Bird mine also show a similar tendency to follow fractures which trend diagonally across the axis of the trough.

In the northeast part of the Crawfish mine, figure 4, Netzeband shows one set of major fractures trending N. 45° E. and a set of minor fractures trending N. 20° W. In the south part of this mine fractures are shown trending N. 25° E. and N. 45° W.

The fractures in the Brewster mine, shown in Plate III and in the Woodchuck mine, Plate IV, curve rather than trend in straight lines for any considerable distance. The fracture planes dip at various angles ranging from 40° to 90°. Most of them however, dip at 60° to 80° with slickensides developed on many of the fractures of steep inclination.

The map of the mining district, Plate II, showing the ground plan of mines illustrates the strong, tendency for the ore runs to trend in a northeast and northwest direction which is in general conformity with the trend of the fracturing.

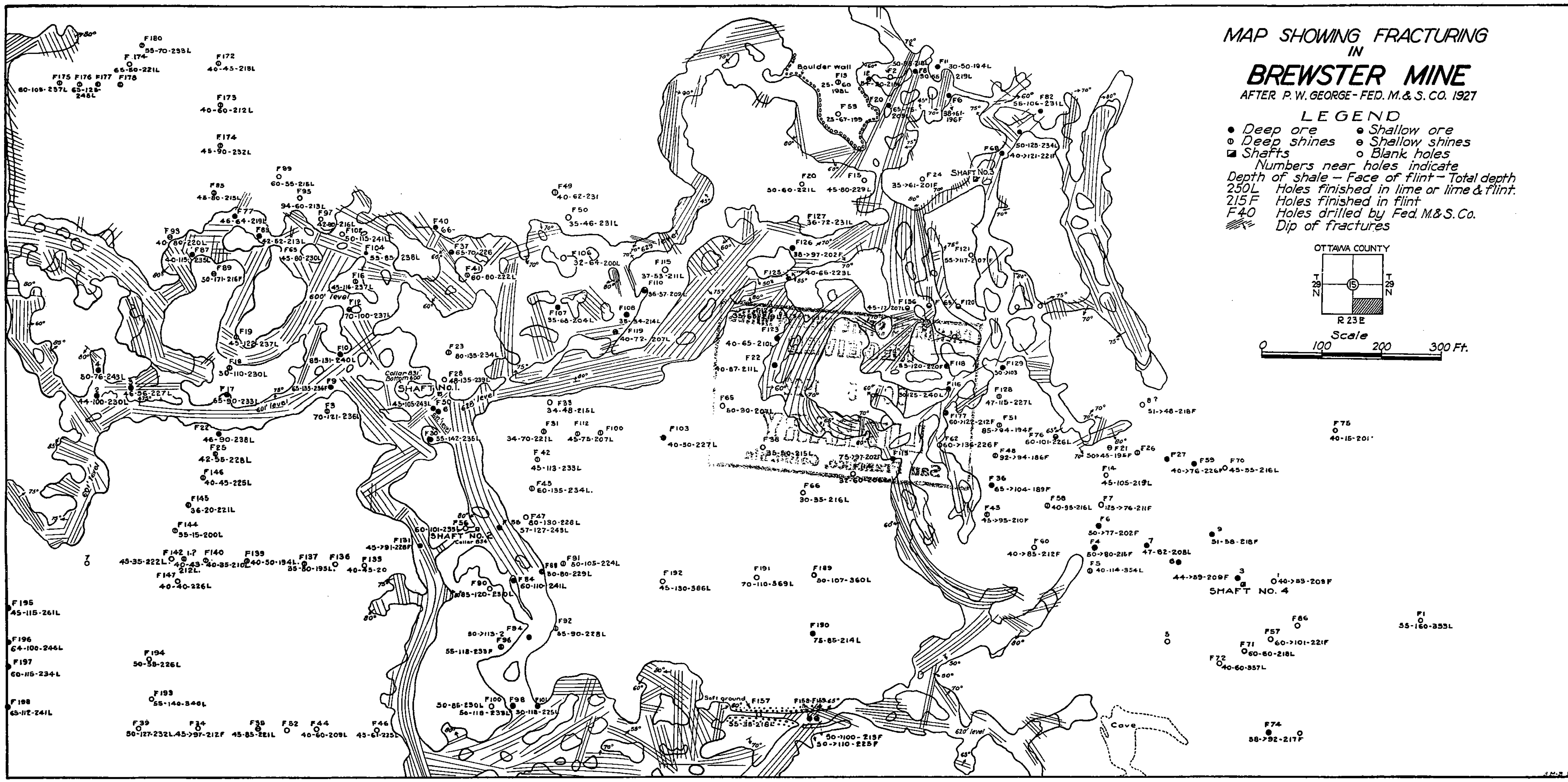
The fractures followed by the ore bodies are very probably related in their origin to the Miami syncline. The fractures in and near the syncline may have a more systematic arrangement than those outside. Further investigation may show, as in the Scammon Hill mine that within the syncline where compressive stresses have developed folding, the major fracturing follows shear zones diagonal to the stress and to the axis of the fold. Outside the syncline, however, where there is only warping and doming the fractures apparently form a curved pattern.

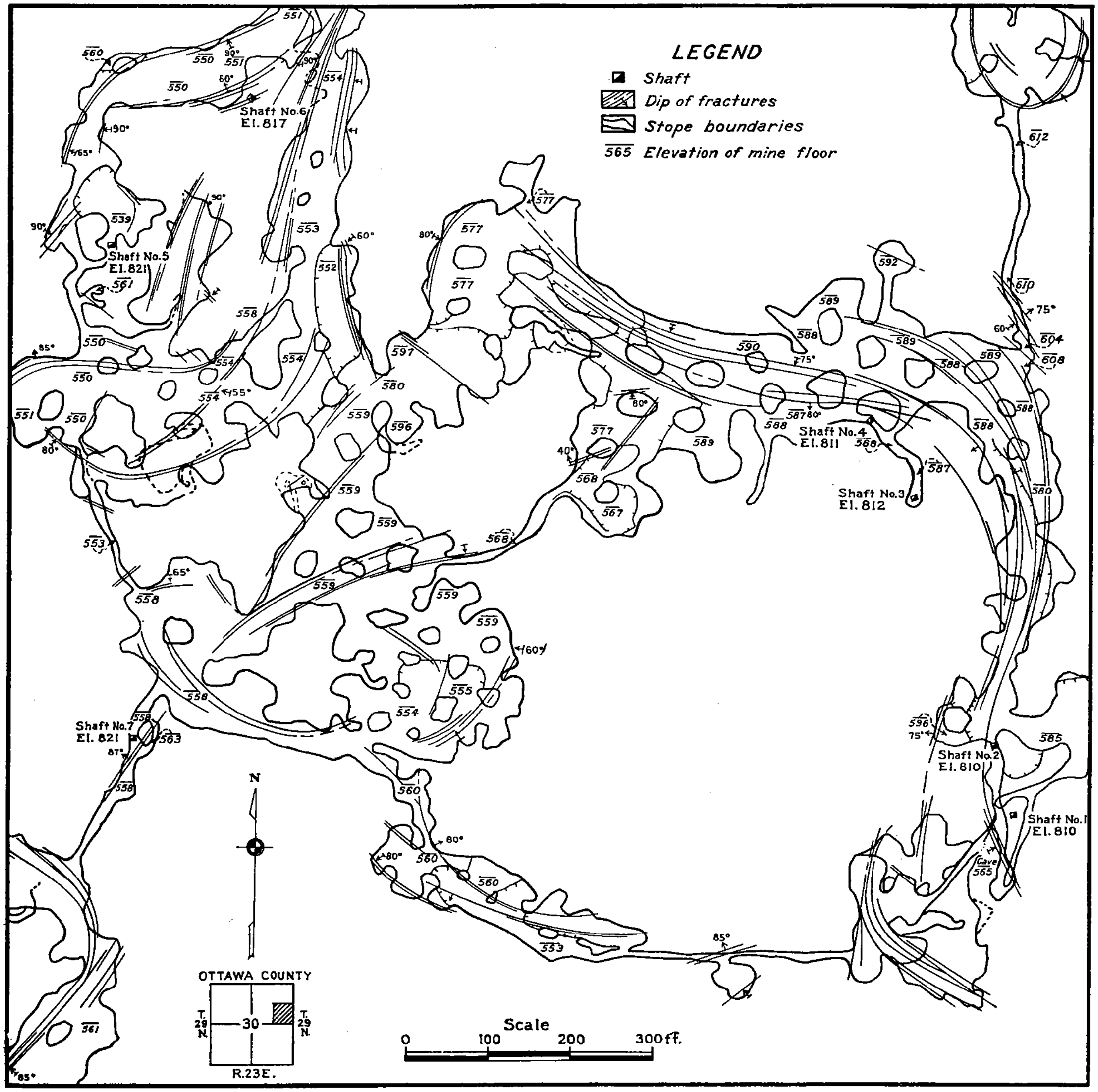
The curved fracture pattern shown in Plates III and IV may have an adequate explanation in the upthrust of igneous intrusives that appear to have affected the underlying rocks of the district.

BRECCIATION

Much of the ore-bearing rock of the mining district is a breccia composed mainly of angular light-colored chert fragments, cemented together by a later generation of chert, either light or dark-colored, called jasperoid. The cementing material may in part be of dolomite, calcite, or ore mineral, or more usually a variable mixture of these with the jasperoid.

The breccia originated in a combination of several processes and involves the mechanical breaking and shattering of the rock, mainly the brittle chert of the Boone formation, followed by and associated with chemical processes of mineralization including solution, deposition, and replacement.


MAP SHOWING FRACTURING
IN
BREWSTER MINE
AFTER P. W. GEORGE - FED. M.& S. CO. 1927
LEGEND
Deep ore
Shallow ore
Deep shines
Shallow shines
Shafts
Blank holes
Numbers near holes indicate
Depth of shale - Face of flint - Total depth
250L Holes finished in lime or lime & flint.
215F Holes finished in flint
F40 Holes drilled by Fed. M.& S. Co.
Dip of fractures
OTTAWA COUNTY
T 29 N
15
R 23 E
Scale
0
100
200
300 Ft.
SHAFT NO. 1
SHAFT NO. 2
SHAFT NO. 3
SHAFT NO. 4
Boulder wall
Soft ground
Cave
600' level
620' level



MAP SHOWING FRACTURING
IN
WOODCHUCK MINE
After G. M. Fowler
1930

The breccia occurs in irregular bodies of variable dimensions and like the ore runs which they contain have horizontal and vertical extensions, usually having greater width than height. The size of angular chert fragments in the breccias varies greatly ranging from a fraction of an inch in diameter up to boulders a foot or several feet across. The coarse breccias are often called "boulder-breccias" and the latter appear to grade into areas of shattered rock often filled with veins of ore and gangue mineral. The chert fragments in the breccias show by their shape and position that they

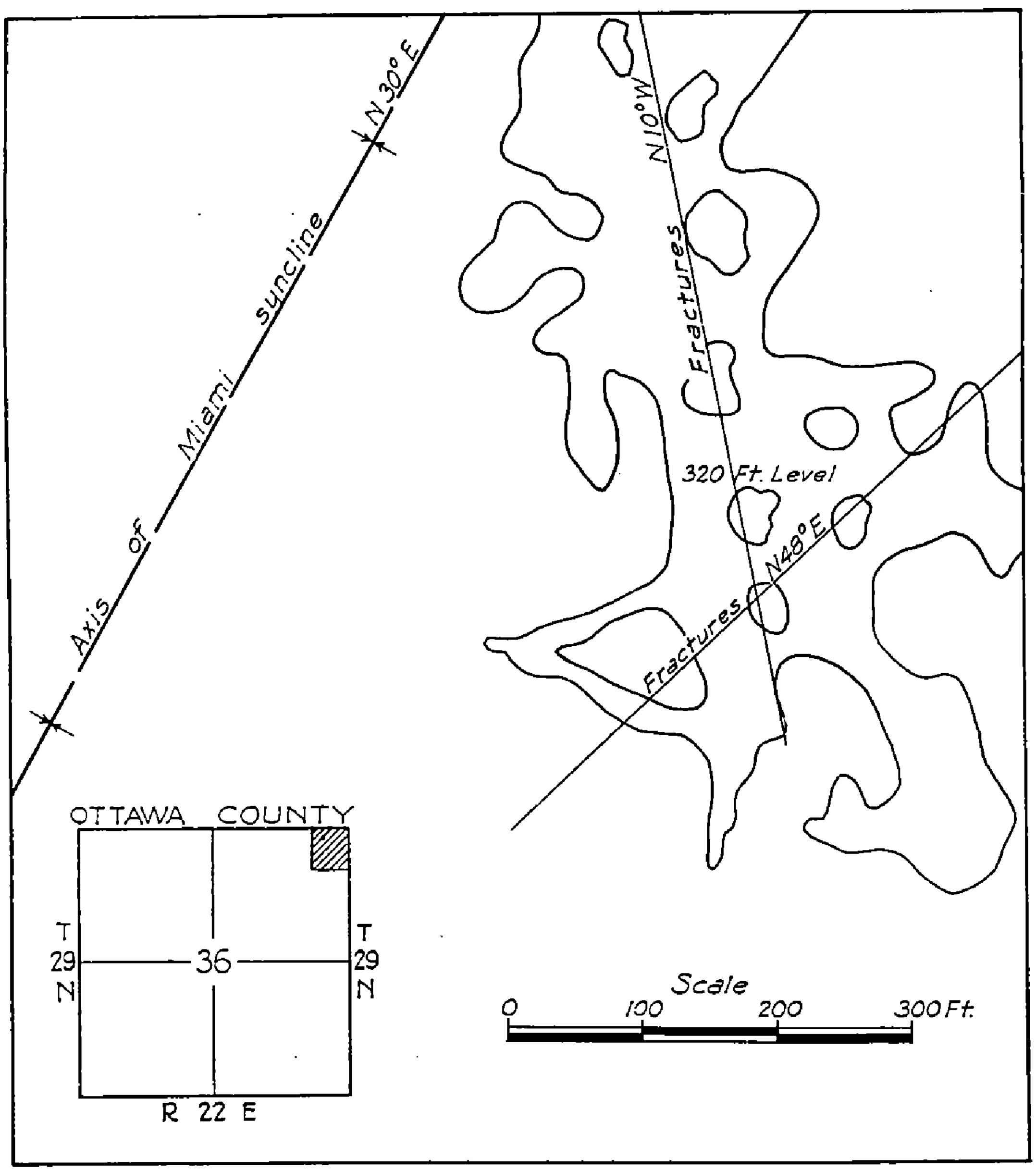


FIGURE 5. Map of S. S. and G. Mine showing relation of fractures to axis of Miami syncline.

were originally parts of larger pieces, that were broken and moved apart, and the intervening spaces filled with the jasperoid and associated ore minerals, as shown in Plate VIII.

The spaces between the chert fragments are not everywhere completely filled by cementation, and the resulting rock then is a breccia filled with many cavities. The cavities lined with ore and associated mineral are of variable size, ranging from microscopic to several inches or several feet across. The larger cavities have the appearance of small caves, and very strongly suggest the probability that the large caves encountered in the mines are the result of the same processes that developed the small cavities. Both large and small cavities may have originated as the result of the mechanical deformation that produced the folding, fracturing, and shattering of the Boone formation.

Two types of breccia. In other districts of the mining region, especially in Missouri and Arkansas, two types of breccia have been described which differ considerably in appearance and very materially in origin. One type is like that described above, due to shattering of chert followed by cementation of the shattered fragments with jasperoid, ore and gangue mineral formed by brecciation and cementation some distance below the surface.

The other kind of breccia is described as "basal breccia"[27] a conglomerate of ordinary or special sedimentary origin, the cementing material or matrix between the fragments of chert and limestone being an ore-bearing mud. The writer has not seen or recognized the latter type of breccia in the mines of the Miami-Picher district.

Caves. The caves in the mining district are in the cherty Boone formation the chert being relatively insoluble in character. They occur beneath the shale far below ground water level. They contain no stalactites and stalagmites and their floors are free from red clay. However, the walls are generally coated with well crystallized calcite, in the form of "dog tooth spar" and with other crystals of both gangue and ore. The shape of the caves, such as their domed roofs, and their great lateral extension of 25 to 150 feet, as compared with their small height of one to ten feet strongly suggests that they are not due to ground water solution but to deformation as already stated, being caused by the arching of competent strata followed by subsequent settling underneath when the stresses were relieved. Some of the larger caves are referred to in the description of the Beck, East Midas, Foch, Grace Walker, Netta, Pioneer, and Tri-State mines.

ORIGIN OF FOLDING AND FRACTURING

The origin of the stresses that developed the folding and fracturing of the rocks of the mining district is not fully understood and only suggestions are offered at this time. The stresses may have originated in some distant source, such as the Ozarkian region on the east or the Rockies on the west, or they may have had merely a local origin.

In May, 1930 in drilling a deep water well at the Bird Dog mine, less than a mile west of the Miami syncline, granite was struck at a depth of 1,245 feet. The occurrence of granite so near the surface in the district is unusual. The prevailing depth of the pre-Cambrian granite indicated in deep wells at Miami, and at Carthage, Missouri and Columbus, Kansas, is 1,750 to 1,850 feet below the surface.

The granite in the Bird Dog well may represent an ancient ridge in the floor of the pre-Cambrian, or it may represent a much younger intrusion like the granite intrusion of Rose Dome[28], Woodson County, Kansas, or the Spavinaw granite dike at Spavinaw, Oklahoma. Based on a comparative study of the drill cuttings of the granite and of rock overlying the granite in the Bird Dog well with the granite and metamorphosed contact rocks associated with the Rose Dome intrusive, and the Spavinaw granite dike, it is the writer's interpretation that they are all essentially alike and that the granite in the Bird Dog well is intrusive.

It is believed that the granite is a pegmatite granite dike, intrusive in the surrounding rock. Its location near the west side of the Miami syncline suggests the probability that it is genetically related to the syncline, and the granite in the form of a dike may be found later to extend along nearly the whole length of the syncline. The granite probably represents the central axis of an anticlinal fold, being complementary to the Miami syncline located on its southeastern side and both anticlinal and synclinal structures probably will be found accentuated with increasing depth. See Figure 7.

The cause of folding of the Miami syncline and associated fracturing and brecciation of the rocks is therefore believed to have originated in compressive stresses mainly due to igneous intrusion and is of local rather than of distant origin.

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HISTORY AND PRODUCTION

THE Peoria district, opened in 1891, is about six miles east of Spring River. The two districts on the west side of the river, referred to in *Mineral Resources of the United States* as the Miami district and the Quapaw and Sunnyside district (formerly Quapaw district) were formerly distinct but they have subsequently grown together, and the line now separating them is purely arbitrary. There is considerable value, however, from the statistical and historical viewpoint, to consider the two districts separately up to the close of the year 1914 when the rich mining field in the Picher, Cardin, and Century camps began their remarkable development. The Quapaw and the Miami districts are discussed separately to the close of 1914, and for the period 1915 to the present the continuous mining area west of the Spring River and south of the Oklahoma-Kansas State line is described as the Miami-Picher district.

TABLE XI.* *Production of lead and zinc concentrates in the Peoria district,* 1891-1928 (*In short tons*)

Lead Concentrates (Galena)		*Zinc Concentrates*			
		Sphalerite		*Zinc silicate & carbonate*	
QUANTITY	VALUE	QUANTITY	VALUE	QUANTITY	VALUE
2,206	$109,163	240	$8,609	2,924[a]	$76,467

[a]Concentrates mainly zinc silicate containing about 29 per cent zinc.

*The statistics of production in Tables XI to XVI have been compiled from annual *Mine Reports on lead and zinc in the Central States,* by J. P. Dunlop and others: Mineral Resources of United States, United States Geological Survey, 1891—1923; United States Bureau of Mines, 1924-1930.

Peoria District

The first discovery and earliest mining operations carried on in Ottawa County were in the vicinity of Peoria, in sec. 12, T. 28 N., R. 24 E. The first[29] mining was done by the Peoria Mining Company in May, 1891. This locality has never had railroad facilities, and the ore produced has been hauled by wagon and auto-trucks to Galena, Kansas, and to Joplin, Missouri. The area has been mined at relatively shallow depth in the Boone formation and the ore consists not only of galena and sphalerite, but also of such oxidized ores as calamine and smithsonite. The total production of the Peoria district, compiled by the United States Geological Survey, from 1891 to 1928, has been of small amount as shown in Table XI.

Quapaw District

The mines of the Quapaw district extend three to four miles southeast, east, and northeast of Quapaw. From 1904 to 1914, the principal mines were located at the old mining camp of Lincolnville, east of Quapaw. More recently the principal production has come from mines located northeast of Quapaw in the Sunnyside area which is continuous with and considered a part of the Miami-Picher district.

TABLE XII. *Production* of lead and zinc concentrates in the Quapaw district,* 1904-1914. *(In short tons)*

	Lead Concentrates (Galena)		*Zinc Concentrates (Sphalerite)*		*Zinc Concentrates (Carbonates) Silicates*	
	QUANTITY	VALUE	QUANTITY	VALUE	QUANTITY	VALUE
1904	150	$ 8,250	633	$ 18,990		
1905	566	34,450	2,670	103,480		
1906	669	51,299	3,242	124,528		
1907	647	43,644	3,062	118,440	97	$1,631
1908	504	26,076	3,539	109,779	19	300
1909	244	12,545	5,015	207,585	38	586
1910	270	13,727	3,921	152,166		
1911	329	18,202	2,245	82,571	6	85
1912	1	50	1,621	78,404	2	50
1913	97	5,000	1,097	41,037		
1914	1	50	146	5,091	2	40
	3,478	$213,293	27,191	1,042,071	164	$2,692

*The production of the Quapaw district from 1915 to 1930, mainly from mines operated north of the old Lincolnville camp, is included in Table XIV.

The first shaft[30] in the Quapaw district was sunk in 1904 on the Abrams land. Some shallow zinc silicate and galena were mined but the chief production was sphalerite and galena from depths varying from eighty to 150 feet. The most important mines in Lincolnville were the Katy mine and the Mission mine. In 1911[31] only four concentrating mills were in operation in the Lincolnville camp, at the Mission, Katy, Big Jack, and Good Luck mines. In addition, the White Eagle and the Sweeney or Mc-Alester mines were being operated.

The production of the Quapaw district from 1904 to 1914 is shown in Table XII.

Miami-Picher District

The Miami-Commerce district (or Miami district) extends from a few miles north of Miami to the mining town of Commerce.

The first[32] mines discovered and worked in what has been referred to as the Miami-Commerce district were in the vicinity of Commerce, then called Hattonville, about four miles north of Miami.

The first drilling was done by J. F. Robinson and G. L. Coleman (now Commerce Mining and Royalty Co.) in 1905. The first shaft was sunk in 1907 and a concentrating plant of one hundred tons capacity was built. The mill was completed in August, 1907 but was not operated steadily until 1908. The production of this mine for 1907 was included in that of the Quapaw district, hence the earliest reported production for the Miami district begins with the year 1908. Other mines, opened in the vicinity of Commerce in 1907, were the Old Chief mine and the Emma Gordon mine. Shafts were sunk in 1907 or 1908 at the Buckeye, King Jack, Turkey Fat,

TABLE XIII. *Production of lead and zinc concentrates in the Miami district,* 1908-1914
(*In short tons*)

	Lead concentrates (Galena)		*Zinc concentrates (Sphalerite)*		*Total value*
	QUANTITY	VALUE	QUANTITY	VALUE	
1908	1,730	$ 92,177	6,475	$139,595	$ 231,772
1909	4,056	210,586	11,509	361,029	571,615
1910	3,364	174,134	10,055	294,877	469,011
1911	2,847	152,527	8,391	247,530	400,057
1912	4,256	231,628	10,258	405,975	637,603
1913	7,710	397,927	23,018	725,163	1,123,090
1914	9,401	443,493	28,219	921,647	1,365,140
	33,365	$1,702,472	97,925	$3,095,816	$4,798,286

Lucky Strike, Index, Tom Lawson, and other mines. These mines were equipped with mills.

In 1911, L. C. Snider[33] reported the following mines in operation: Swastika, Morning Star (Commonwealth), King Jack, New State, Turkey Fat, Sullivan, Old Chief, Emma Gordon, Oklahoma Lead and Zinc, Carson-Dodson, Joplin-Miami, Queen City-Joplin, Okmulgee, Little Maxine, Golden Hen, Midas, Miami Yankee, Donna, and Consolidated. Most of these mines were located on either ten or twenty acre leases. The Emma Gordon and Turkey Fat continued in operation, at intervals, to 1925.

At Commerce the ore was discovered under shale in brecciated limestone and sandstone of Chester-Mayes age, in the same horizon of the important deposits worked in the older Lincolnville district east of Quapaw. In the Commerce area, however, the ores are galena and sphalerite, no oxidized ores being found beneath the shale.

At the discovery mine in Commerce, the Mayes "sand spar" ore-bearing rock was encountered at a depth of ninety feet below the surface under the shale. Below the Mayes was found the deeper-lying ore in the underlying chert breccias of the Boone formation. The ore in the Mayes was found at depths usually varying from seventy-five to 150 feet below the surface the depth depending on the thickness of the overlying shale. The lower ore bodies in the Boone chert were found at depths of 150 to 320 feet, having essentially the same distribution in the Boone as in the present producing area in the northern part of the district.

The production of the Miami district, mainly the Commerce area from 1908 to 1914 is given in Table XIII on page 47.

TABLE XIV. *Production of lead and zinc concentrates in the Miami-Picher district,* 1915-1930. (*In short tons*)

	Lead Concentrates (Galena)		*Zinc concentrates (Sphalerite)*		*Total value of concentrates*
	QUANTITY	VALUE	QUANTITY	VALUE	
1915	9,058	$ 494,524	28,280	$ 1,901,480	$ 2,396,004
1916	15,306	1,275,761	54,935	4,109,565	5,385,326
1917	32,765	3,300,634	159,656	10,762,324	14,062,958
1918	69,862	6,186,131	300,702	15,182,135	21,368,266
1919	67,768	4,598,760	336,948	14,489,402	19,088,162
1920	81,454	7,651,252	406,569	18,320,875	25,972,127
1921[a]	52,236	2,741,110	225,569	5,150,154	7,891,264
1922	79,705	5,987,561	389,144	13,375,413	19,362,974
1923	85,473	8,115,798	463,090	18,731,104	26,846,902
1924	91,882	9,801,526	516,228	21,127,090	30,929,435
1925	103,359	12,106,094	549,211	27,809,581	39,915,675
1926	90,597	9,690,059	531,613	24,404,099	34,094,158
1927	67,444	5,852,023	404,228	15,475,966	21,327,989
1928	56,839	4,851,076	354,071	12,852,797	17,443,872
1929	51,041	4,267,538	386,077	14,890,987	19,158,527
1930	39,000	2,526,611	268.171	8,162.479	10,689,090
	993,789	89,446,457	5,554,490	226,746,270	315,932,729
Table XI[b]	2,206	109,163	240	8,609	117,772
Table XII[c]	3,478	213,293	27,191	1,042,071	1,255,364
Table XIII[d]	33,365	1,702,472	97.925	3,095,816	4,798,286
	1,032,838	91,471,385	5,679,846	230.892,766	322,104,151

a. Includes a small amount from the Peoria district.
b. Peoria district 1891-1928.
c. Quapaw district 1904-1914.
d. Miami district 1908-1914.

In Table XIV the combined production of the Miami-Picher (Quapaw) districts from 1915 to 1930 is given to which is added the production stated in Tables XI, XII, and XIII. The maximum annual production was reached in 1926. However, the amount of production depends much on the prevailing market price of the ore. It seems probable that the production of 1926 may not be exceeded in subsequent years unless additional ore reserves are discovered.

The total value to 1930 of lead concentrates produced in Ottawa Coun-

icher district

	1908	1909	1910	1911	1912	1913	1914	1915	1916	1917	1918	1919	1920	1921	1922	1923	1924	1925	1926	1927	1928	1929	1930
per cent	2.2	2.4	2.9	2.0	2.1	1.5	1.24	1.10	1.15	0.94	1.22	1.13	1.18	1.76	1.29	1.08	1.04	1.01	0.86	0.68	0.61	0.55	5.54
" "	8.4	6.8	8.9	5.6	5.1	4.4	3.84	3.28	4.03	4.56	5.23	5.47	5.87	7.60	6.32	5.61	5.76	5.13	4.95	4.07	4.30	4.14	3.72
" "	10.3	9.2	11.8	7.6	7.2	5.9	5.08	4.38	5.18	5.50	6.45	6.60	7.05	9.36	7.61	6.69	6.80	6.14	5.81	4.75	4.91	4.69	4.26
" "	1.8	1.9	2.4	1.5	2.1	1.2	1.00	.86	.91	.76	.98	.87	.92	1.43	1.04	.86	.83	.80	.65	0.53	0.48	0.42	0.42
" "	4.1	3.4	4.3	2.8	5.1	2.4	2.03	1.82	2.33	2.72	3.13	3.21	3.52	4.54	3.78	3.34	3.41	3.01	2.83	2.36	2.49	2.42	2.19
" "	5.9	5.3	6.7	4.3	7.2	3.6	3.03	2.66	3.24	3.48	4.11	4.08	4.44	5.97	4.82	4.20	4.24	3.81	3.48	2.89	2.97	2.84	2.61
" "	79.8	79.6	79.5	78.3	79.6	79.8	80.00	78.9	79.0	80.4	80.2	79.4	80.2	81.0	80.4	79.9	79.2	78.9	78.5	78.2	78.4	77.8	76.80
dollars	$53.28	51.92	51.76	53.55	54.42	52.91	47.19	54.60	83.94	100.77	88.54	67.87	93.93	52.48	75.12	94.95	106.68	117.13	106.95	86.77	80.79	83.61	64.68
per cent	48.9	50.3	48.7	50.4	51.8	53.6	54.8	55.7	57.77	59.6	59.6	58.8	59.9	59.8	59.9	59.5	59.2	58.6	58.1	58.1	57.8	58.3	58.80
dollars	$31.21	31.21	29.32	29.50	39.80	31.50	32.66	66.48	74.80	67.44	50.55	43.00	44.96	22.83	34.37	40.45	40.93	50.64	45.91	38.29	36.30	38.57	30.09
short tons	225,184	317,574	223,212	224,450	293,500	581,100	763,920	891,800	1,406,900	3,523,200	5,754,700	6,168,200	6,943,100	2,969,500	6,159,500	7,937,200	8,804.000	10,605,200	10,934,000	9,932,400[3]	8,028,000[4]	9,324,600[5]	7,213,600[6]
per cent	.3	.2	.3	.4		0.2		0.12	.07	.51	.36	.57	.13										
" "	2.5	3.5	3.7	3.0	1.9	1.9	3.82	2.14	2.42	2.30	4.15	3.15	5.49										
" "	2.8	3.7	4.0	3.4		2.1		2.26	2.49	2.81	4.51	3.72	5.62										
" "	.3	.2	.2	.3		0.13		.09	.06	.41	.28	.43	.10										
" "	1.4	2.0	2.2	1.7	1.1	1.1	2.14	1.23	1.31	1.32	2.30	1.76	3.23										
" "	1.7	2.2	2.4	2.0		1.23		1.32	1.37	1.73	2.58	2.19	3.33										
" "	79.0	79.3	78.2	79.3	79.5	78.4	79.00	76.8	77.0	78.8	78.7	77.0	75.6										
dollars	$51.74	51.41	50.84	55.32	50.00	51.55	50.00	53.74	71.79	95.10	92.27	60.10	93.95										
per cent	56.8	57.9	57.9	57.0	57.8	55.8	56.2	57.5	54.2	56.9	55.5	55.8	58.8										
dollars	$31.02	41.39	38.81	36.78	48.36	38.03	34.87	80.97	73.30	61.41	41.19	44.30	42.14										

(3) Includes 7,199,100 tons crude ore containing 0.93 per cent lead conc., 4.95 zinc conc., and 2,733,300 tons tailings containing 0.01 per cent lead conc., 1.75 per cent zinc conc.

(4) Includes 5,527,700 tons crude ore containing 0.87 per cent lead conc., 5.55 zinc conc., and 2,500,300 tons tailings containing 0.01 per cent lead conc., 1.53 per cent zinc conc.

(5) Includes 6,408,400 tons crude ore containing 0.79 per cent lead conc., and 5.31 per cent zinc conc., and 2,916,200 tons tailings containing 0.01 per cent lead conc., and 1.50 per cent zinc conc.

(6) Includes 4,118,600 tons crude ore containing 0.92 per cent lead conc., and 5.23 per cent zinc conc., and 3,095,000 tons old tailings containing 0.03 per cent lead conc., and 0.99 per cent zinc conc.

TABLE XV. *Tenor of lead and zinc concentrates produced in Miami-Picher district Oklahoma* 1908-1930.

		1908	1909	1910	1911	1912	1913	1914	1915	1916	1917	1918	1919	1920	1921	1922	1923
MIAMI DISTRICT[1] (Includes Picher area after 1915.)																	
Lead concentrates	per cent	2.2	2.4	2.9	2.0	2.1	1.5	1.24	1.10	1.15	0.94	1.22	1.13	1.18	1.76	1.29	1.08
Zinc concentrates	" "	8.4	6.8	8.9	5.6	5.1	4.4	3.84	3.28	4.03	4.56	5.23	5.47	5.87	7.60	6.32	5.61
Total concentrates in crude ore	" "	10.3	9.2	11.8	7.6	7.2	5.9	5.08	4.38	5.18	5.50	6.45	6.60	7.05	9.36	7.61	6.69
Lead metal	" "	1.8	1.9	2.4	1.5	2.1	1.2	1.00	.86	.91	.76	.98	.87	.92	1.43	1.04	.86
Zinc metal	" "	4.1	3.4	4.3	2.8	5.1	2.4	2.03	1.82	2.33	2.72	3.13	3.21	3.52	4.54	3.78	3.34
Metal content of crude ore	" "	5.9	5.3	6.7	4.3	7.2	3.6	3.03	2.66	3.24	3.48	4.11	4.08	4.44	5.97	4.82	4.20
Average lead content of galena concentrates	" "	79.8	79.6	79.5	78.3	79.6	79.8	80.00	78.9	79.0	80.4	80.2	79.4	80.2	81.0	80.4	79.9
Average value per ton of galena concentrates	dollars	$53.28	51.92	51.76	53.55	54.42	52.91	47.19	54.60	83.94	100.77	88.54	67.87	93.93	52.48	75.12	94.95
Average zinc content of sphalerite concentrates	per cent	48.9	50.3	48.7	50.4	51.8	53.6	54.8	55.7	57.77	59.6	59.6	58.8	59.9	59.8	59.9	59.5
Average value per ton of sphalerite concentrates	dollars	$31.21	31.21	29.32	29.50	39.80	31.50	32.66	66.48	74.80	67.44	50.55	43.00	44.96	22.83	34.37	40.45
Total crude ore[2] of both districts	short tons	225,184	317,574	223,212	224,450	293,500	581,100	763,920	891,800	1,406,900	3,523,200	5,754,700	6,168,200	6,943,100	2,969,500	6,159,500	7,937,200
QUAPAW DISTRICT:																	
Lead concentrates	per cent	.3	.2	.3	.4		0.2		0.12	.07	.51	.36	.57	.13			
Zinc concentrates	" "	2.5	3.5	3.7	3.0	1.9	1.9	3.82	2.14	2.42	2.30	4.15	3.15	5.49			
Total concentrates in crude ore	" "	2.8	3.7	4.0	3.4		2.1		2.26	2.49	2.81	4.51	3.72	5.62			
Lead metal	" "	.3	.2	.2	.3		0.13		.09	.06	.41	.28	.43	.10			
Zinc metal	" "	1.4	2.0	2.2	1.7	1.1	1.1	2.14	1.23	1.31	1.32	2.30	1.76	3.23			
Metal content of crude ore	" "	1.7	2.2	2.4	2.0		1.23		1.32	1.37	1.73	2.58	2.19	3.33			
Average lead content of galena concentrates	" "	79.0	79.3	78.2	79.3	79.5	78.4	79.00	76.8	77.0	78.8	78.7	77.0	75.6			
Average value per ton of galena concentrates	dollars	$51.74	51.41	50.84	55.32	50.00	51.55	50.00	53.74	71.79	95.10	92.27	60.10	93.95			
Average zinc content of sphalerite concentrates	per cent	56.8	57.9	57.9	57.0	57.8	55.8	56.2	57.5	54.2	56.9	55.5	55.8	58.8			
Average value per ton of sphalerite concentrates	dollars	$31.02	41.39	38.81	36.78	48.36	38.03	34.87	80.97	73.30	61.41	41.19	44.30	42.14			

(1) Includes Quapaw district after 1921.
(2) Includes some re-milled old tailings, only small amount up to 1923, but reaching nearly 10 per cent of total milled in 1926.

(3) Includes 7,199,100 tons crude ore containing 0.93 per cent lead conc., 4.95 zinc conc., and 2,733,300 tons tailings containing 0.01 per cent lead conc., 1.75 per cent zinc conc.
(4) Includes 5,527,700 tons crude ore containing 0.87 per cent lead conc., 5.55 zinc conc., and 2,500,300 tons tailings containing 0.01 per cent lead conc., 1.53 per cent zinc conc.

(5) Includes 6,408,400 tons crude ore containing 0.79 per cent lead conc., and 5.31 per cent zinc conc., and 2,916,200 tons tailings containing 0.01 per cent lead conc., and 1.50 per cent zinc conc.
(6) Includes 4,118,600 tons crude ore containing 0.92 per cent lead conc., and 5.23 per cent zinc conc., and 3,095,000 tons old tailings containing 0.03 per cent lead conc., and 0.99 per cent zinc conc.

ty was over eighty-eight million dollars, and of zinc concentrates over 222 million dollars, the combined value being $311,415,061.

The tenor of the crude ore and of the concentrates in Oklahoma from 1908 to 1930 is shown in Table XV. The table is compiled from *Mineral Resources of the United States* and shows for each year the total tonnage of the crude ore (before being crushed and passed through the separating mills), the percentage of lead and zinc per ton in the concentrates, and the average value of concentrates per ton. Separate statistics for the Quapaw district are given to the year 1920, after which the data for the two districts are combined. Table XV shows several features of interest for the twenty-two-year period. From 1908 to 1912 the production in the Miami district (in the Commerce field) and in the Quapaw district (in the Lincolnville field) was relatively small and fluctuating with relatively low content (below fifty per cent) of zinc in the zinc concentrates. From 1913 to 1926 there was a steady increase of crude ore mined and milled, excepting for the year 1921, when many of the mines were shut down on account of the low price of ore. The zinc content of the sphalerite concentrates in the Miami district increased from 51.8 per cent in 1912 to 59.6 percent in 1917, mainly due to improved milling practice. Since 1917 the average zinc content of the concentrates from crude ore has been maintained at about 59.5 per cent. However, the lower content of zinc yielded by the concentrates from reworked old tailings and slimes has lowered the average for the entire district in the last few years. The crude ore in the Quapaw district, at least up to 1920, shows a lower content of lead as compared with zinc than that in the mines of the Miami district.

In 1924[34] about 140 mills in the Oklahoma part of the field were in operation. The quantity of crude ore mined and milled increased from 7,937,200 tons in 1923 to 8,804,000 tons in 1924. Since 1924 there has been a rapid increase in the amount of old tailings milled in the district. The 8,804,000 tons of crude ore contained 1.04 per cent of lead concentrates and 5.76 per cent of zinc. The average lead content of galena concentrates was 79.2 per cent, and the average zinc content of zinc concentrates was 59.2 per cent. An assay of a composite sample of 7,414 samples of ore shipped in 1924 from the Miami-Blue Mound area, made by Bruce Williams of Joplin, Missouri, showed an average content of 59.9 per cent of zinc, 1.42 per cent of iron, 0.78 per cent of lead, and 0.46 per cent of cadmium.

In 1925[35] about 135 mills were in operation in Oklahoma. The quantity of crude ore mined and milled was 10,605,200 short tons, containing 6.14 per cent of concentrates of which 1.01 per cent were lead and 5.13 per cent zinc. The average lead content of the galena concentrates was 78.9 per cent, and the average zinc content of the zinc concentrates was 58.6 per cent.

In 1926[36] about 143 mills were in operation in the district. The quantity of crude ore and tailings milled was 10,934,000 tons, containing 5.81 per cent of concentrates of which 0.86 per cent were lead and 4.95 per cent were zinc. The average lead content of the galena concentrates decreased from 78.9 per cent in 1925 to 78.5 per cent in 1926. The average zinc content of the sphalerite concentrates decreased from 58.6 per cent in 1925 to 58.1 per cent in 1926. Included in the ore milled in 1926 are 960,600 tons of old tailings, which yielded twenty-nine tons of galena concentrates, and 17,421 tons of zinc concentrates, the latter averaging 55.2 per cent zinc. The greatly increased quantity of concentrates made from tailings, resulting from the general use of

TABLE XVI. *Mine production of lead and zinc (metal content) in Oklahoma,* 1908 to 1930

	LEAD		ZINC		TOTAL VALUE
	Short tons	*Value*	*Short tons*	*Value*	
1908	1,781	$ 149,604	4,529	$ 425,726	$ 575,330
1909	3,427	294,722	7,806	843,048	1,137,770
1910	2,888	254,144	6,394	690,552	944,696
1911	2,501	225,090	5,150	587,100	812,190
1912	3,388	304,920	5,769	796,122	1,101,042
1913	6,228	548,064	11,664	1,306,368	1,854,432
1914	7,556	589,368	13,992	1,427,184	2,106,552
1915	7,306	686,764	14,314	3,549,872	4,236,636
1916	12,115	1,671,870	28,754	7,706,272	9,378,142
1917	26,358	4,533,376	85,835	17,510,340	22,043,916
1918	56,097	7,965,774	161,401	29,374,982	37,340,756
1919	53,872	5,710,432	178,410	26,047,860	31,758,292
1920	65,394	10,463,040	219,727	35,595,774	46,058,814
1921	41,552	3,739,680	121,372	12,137,200	15,876,880
1922	62,856	6,914,160	209,682	23,903,748	30,817,908
1923	66,904	9,366,560	242,421	32,969,256	42,335,815
1924	71,358	11,417,280	269,137	34,987,810	46,405,090
1925	79,946	13,910,604	283,371	43,072,392	56,982,996
1926	69,704	11,152,640	272,567	40,885,050	52,037,690
1927	51,680	6,511,680	206,611	26,446,208	32,957,888
1928	43,687	5,067,692	180,252	21,990,744	27,058,436
1929	46,513	5,860,638	192,042	25,349,544	31,210,182
1930	23,052	2,305,200	136,153	13,070,688	15,375,888
	806,163	109,643,302	2,860,355	400,493,840	510,357,341

The metal content of the ores has been calculated from assays, allowance being made for smelting losses of both lead and zinc. In smelting only about 80 to 85 per cent of the lead and about 85 to 90 per cent of the zinc in the concentrates is recovered.

In comparing the values of ores, shown in Tables XII, XIII, and XIV with that of metal shown in Table XVI it should be borne in mind that the value given for the ore is that received by the producer for concentrates at the mines, whereas the value of the lead and zinc is calculated from the average price for all grades.

Much of the ore mined in Oklahoma is smelted in the natural gas fields of the immediately surrounding region in Oklahoma and Kansas. Zinc smelters operated in Oklahoma are located at Bartlesville, Blackwell, Sand Springs, Henryetta, Kusa, Quinton, and Quapaw. Lead smelters near the district are located at Galena, Kansas and Joplin, Missouri. Much of the zinc ore is smelted in Illinois and Pennsylvania and most of the lead ore in Missouri.

flotation in treating slimes, accounts for the slight decrease in the average grade of the concentrates from 1924 to 1926.

In 1927[37] about 135 mills were in operation. The quantity of crude ore mined and milled was 7,199,100 tons, containing 0.93 per cent of lead concentrates. In addition 2,733,300 tons of old tailings and slimes were reworked by flotation plants yielding 0.01 per cent lead concentrates, and 1.75 per cent zinc concentrates. The total quantity of lead and zinc concentrates shipped was twenty-four per cent less than in 1926, the smaller production being mainly due to the lower price of concentrates.

In 1928[38] about 111 mills were in operation in the district. The quantity of crude ore mined and milled was 5,527,700 tons containing 0.87 per cent lead concentrates and 5.55 per cent zinc concentrates. In addition 2,500,-300 tons of tailings were reworked containing 0.01 per cent of lead concentrates and 1.53 per cent of zinc concentrates. There was a total production of 56,839 tons of lead concentrates and 354,071 tons of zinc concentrates, being 13 per cent less than in 1927, the lower production being largely due to the continued lower price of concentrates.

In 1929[39] about 120 mills were in operation. The crude ore mined and milled was 6,408,400 tons containing 0.78 per cent lead concentrates and 5.31 per cent zinc concentrates. In addition 2,916,200 tons of tailings were reworked, containing 0.01 per cent lead concentrates and 1.52 per cent zinc concentrates. The total production of lead concentrates was 51,041 tons, and of zinc concentrates 386,077 tons. There was a slight decrease in lead concentrates, but an increase in zinc concentrates as compared with the production of 1928. The price of both lead and zinc concentrates was above that of 1928. About 63 per cent of the production of the Tri-State region was mined from the Miami-Picher district.

In 1930[40] about eighty-three mills were operated. The quantity of crude ore mined and milled was 4,118,600 tons containing 0.92 per cent lead concentrates and 5.23 per cent zinc concentrates. In addition, 3,095,000 tons of old tailings and slimes were reworked, yielding .03 per cent lead concentrates and 1.70 per cent zinc concentrates. The total production of lead concentrates was 39,000 tons and of zinc concentrates 268,171 tons, about 32 per cent less than in 1929. The market value of both lead and zinc concentrates was below that of 1929. The Miami-Picher district, in 1930, produced about 63 per cent of the total output of the Thri-State region.

Table XVI shows the metal content and value of the lead and zinc mined in Oklahoma almost entirely from the Miami-Picher district from

1908 to 1930. During the period the total value of the metallic lead was over 109 million dollars, and of metallic zinc over 400 million dollars, the combined value of both metals produced being $510,357,341.

CHAPTER NOTES

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ORE DEPOSITS

MINERALS OF THE ORE DEPOSITS

THE minerals of the district may be grouped as the ore minerals of commercial value utilized for the extraction of lead and zinc and the minerals associated with the ores which have no value or are not economically important.

The first group includes the lead ore, galena, and the zinc ore, sphalerite. In addition to sphalerite there is also some smithsonite and calamine which are zinc ores developed by weathering of sphalerite above the level of ground water in the upper levels of the mines along the eastern margin of the district. The second group includes marcasite, pyrite, chalcopyrite, calcite, aragonite, dolomite, quartz, barite, anglesite and gypsum.

The foregoing list by no means includes all the minerals that occur in the district, but only those either of most abundance or of relatively rare occurrence which have attracted attention. Some of the latter, while fairly common associates of lead and zinc minerals in other regions, rarely or never have been observed in the district.

One of the most complete lists of minerals of the Galena-Joplin district is that described by A. F. Rogers[41] which includes thirty-nine minerals, either found by him within the district or reported by earlier investigators.

Sphalerite

Zinc sulphide (ZnS), or zinc blende, is the principal zinc ore mineral of the district. It consists, when pure, of sixty-seven per cent zinc and thirty-three per cent sulphur. The color of sphalerite varies from yellowish-brown to black. It is known to the miners as "jack," "black jack," or "rosin jack" dependent upon the variation in color due to the small amount of iron which it contains.

It crystallizes in distorted isometric-tethrahedral forms, and is characterized by distinct cleavage parallel to the dodecahedral faces. It occurs either as individual crystals or crystal aggregates filling cavities or in crystals and grains disseminated throughout the ore-bearing rock. The crystals vary in size from minute grains, microscopic in size, to very large crystals over a foot in diameter. About a ton of unusually large sphalerite crystals, many of them a foot in diameter, from the upper levels of the Blue Ribbon mine, were shipped to Wards Mineral Establishment by the writer in June, 1922.

The milled sphalerite of the district from 1916 to 1930 as reported by the smelters has varied from about fifty to sixty per cent zinc, with less than one per cent iron. The zinc content of the concentrates varies slightly from different mines partly because of the associated deleterious minerals but mainly on account of imperfect milling processes. In addition to the small amount of iron in the sphalerite there is present usually from 0.035 to 0.05 per cent of cadmium.

Galena

Galena (PbS), or lead sulphide, is the principal lead ore mineral of the district. It consists when pure of 86.6 per cent lead and 13.4 per cent sulphur. It has a bright lead-gray color and metallic luster. Galena is generally called "mineral" or "lead" by the miners.

It crystallizes in the isometric system, and occurs usually in the form of cubes, and of cubes with corners truncated by octahedron faces. It has perfect cubic cleavage.

Galena occurs either as individual crystals, as crystal aggregates filling veins and cavities, or as minute grains disseminated through the rock. They vary in size from very small to large crystals nearly a foot in diameter. Some unusually large crystals were mined from the upper levels of the Blue Ribbon mine. In order of crystallization galena followed sphalerite as shown in B, Plate VI.

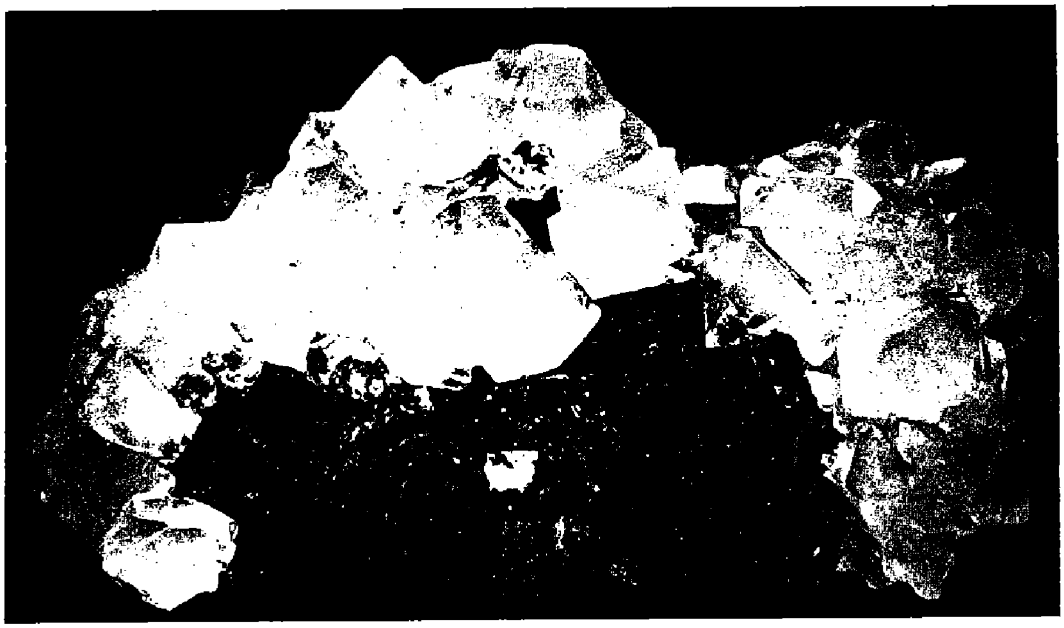
The milled galena of the district from 1916 to 1930, as reported by the smelters, has varied from seventy-nine to eighty-one per cent lead, the concentrates being sold on the basis of eighty per cent lead. The impurities in the concentrates usually consist of a very small amount of gangue mineral and associated sphalerite and pyrite. The galena of the western mines usually contains an important amount of silver but that of this district contains only about one to two ounces per ton, or a value of about ten cents of silver per ton of lead.

Calamine

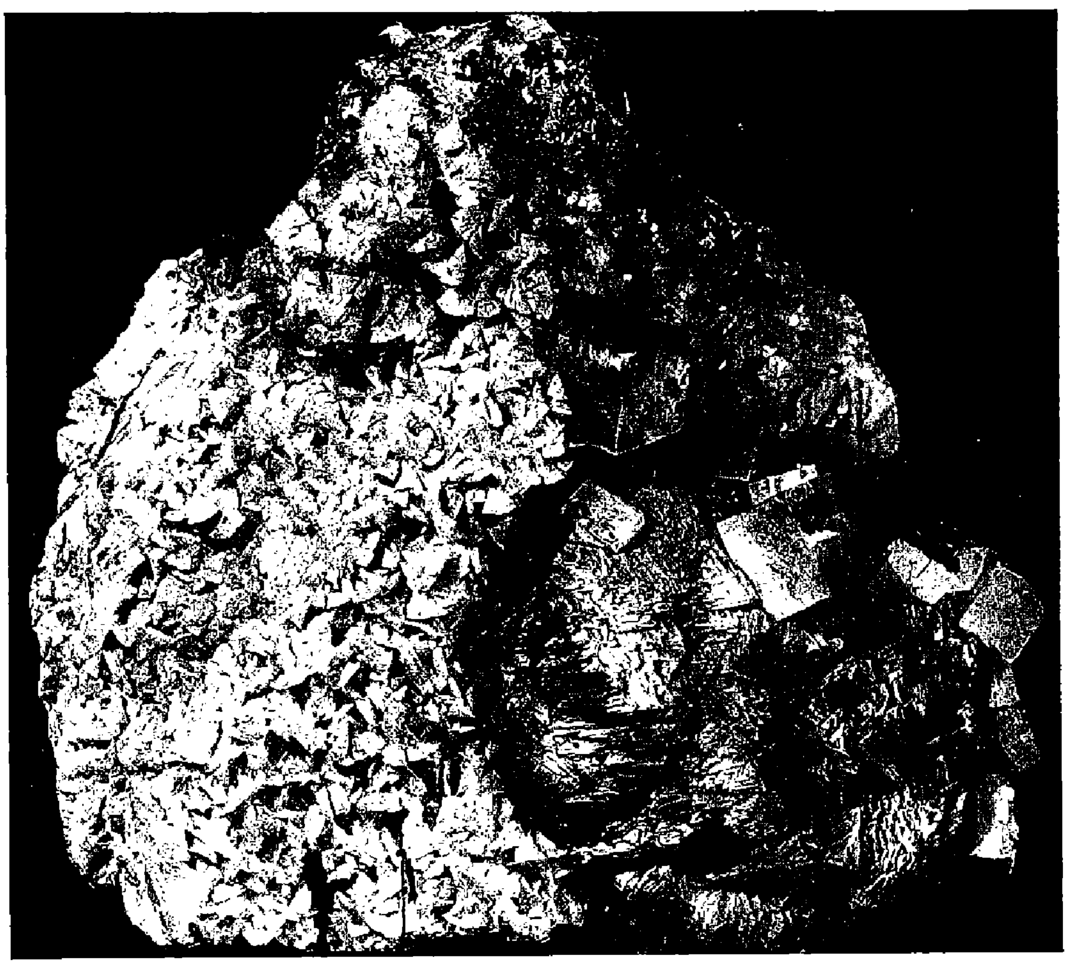
Zinc silicate ($[ZnOH]_2\ SiO_3$) contains 54.2 per cent zinc. It is usually colorless to pale green, or blue, and is transparent to opaque, with vitreous to dull luster. The crystal aggregates are arranged in fibrous, globular, and granular forms and in porous and earthy masses often mixed with clay.

Calamine is a secondary mineral formed by the action of silica-bearing water upon sphalerite and is found only in the mines of the eastern margin of the district, where, because of the removal of the overlying shale by erosion the underlying ore-bearing formation has been subjected to much

PLATE VI



A. Quartz on sphalerite, five-fourths natural size.



B. Galena on sphalerite with dolomite on chert, one-half natural size.

weathering. At present it is unimportant as an ore mineral but in the earlier history of the district considerable calamine was mined in the Peoria and Lincolnville areas.

Greenockite

Greenockite (CdS), cadmium sulphide, has been described by L. C. Snyder[42] as a yellow coating on the surface and in cracks of the sphalerite in the Quapaw camp.

Smithsonite

Zinc carbonate ($ZnCO_3$), contains when pure 52.03 per cent zinc. It occurs rarely in crystals, more commonly in botryoidal, granular and earthy form, in nodular and cavernous masses and is grayish-white to dark gray or brown in color. Where well crystallized it is in rhombohedral crystals with good cleavage. In the botryoidal and granular form it closely resembles calamine with which, as a secondary mineral after sphalerite, it is usually closely associated. It occurs only in oxidized ores in the mines of the eastern margin of the district, where the ore-bearing formation has been subjected to deep weathering.

Anglesite

Anglesite, ($Pb\ SO_4$) contains 68.3 per cent lead. It occurs in small whitish yellow crystals and as small nodular white coatings on galena. Although it is the result of the decomposition of galena, it is not found in the zone of weathering, but far below the surface. It occurs under thick shale at a depth of 290 feet in the Blue Goose and Angora mines, and also in the lower levels of the Howe and the Gardon mines. The common oxidized zinc and lead ore minerals, such as, smithsonite, calamine, and cerrusite found in the zone of weathering in the eastern part of the district were not found in association with the anglesite.

Pyrite

Both pyrite and marcasite (FeS_2), the two iron sulphide minerals, are common in the district. Pyrite crystallizes in the isometric system, commonly in cubes, and in pyritohedrons with the crystal faces usually striated. The color is pale brass-yellow. Pyrite usually occurs as small crystals, and is found much more commonly on the galena than on sphalerite. It occurs as small grains finely disseminated in the ore-bearing rock.

Marcasite

This mineral has the same composition as pyrite (FeS_2) but crystallizes in the orthorhombic system, commonly in tabular shapes of the "cockscomb" variety. The color is yellowish, much the same as that of pyrite. Both pyrite and marcasite are often called "sulphur" by the miners. The marcasite forms much larger crystals than pyrite, and the tabular plates range in size to one inch wide. It occurs abundantly as small crystals on both sphalerite and galena. It is also found as relatively thick coatings on the walls of small cavities and as grains disseminated through the rocks. Both pyrite and marcasite are found in small amounts throughout the Cherokee shale.

Pyrite and marcasite are both relatively resistant to alteration below ground water-level but in the mine workings where subjected to oxidization they tend, especially the marcasite, to decompose and form such secondary products as melanterite, limonite and gypsum. In a few of the mines oxidation of the marcasite by aërated mine water develops so much heat that special ventilating equipment is required.

Melanterite

The oxidation of marcasite when exposed to the moist air of the mines is very common and results in the production of sulphuric acid and a white efflorescence of ferrous sulphate, melanterite ($FeSO_4+7H_2O$) which may collect on various objects or on the walls of mine stopes or open mine pits. Melanterite is also called "copperas." It is readily soluble and has a sweetish, astringent taste. It occurs in considerable amount in the form of so-called "icicles" which develop from the dripping or seepage of mine water containing the iron sulphate in solution. On evaporation of the water the melanterite is precipitated in stalactitic and stalagmitic forms, on the roofs and floors of the mine stopes, as described in the Gordon mine.

Chalcopyrite

The sulphide of copper and iron, chalcopyrite, ($CuFeS_2$) is a common copper-bearing mineral of the district. The crystals are tetrahedral with one pair of faces, the larger being dull, somewhat oxidized and striated, and the smaller face more brilliant, not oxidized or striated. The crystals are usually small and about ¼-inch across, and have a brass-yellow color. It is usually not dintinguished by the miners from pyrite or marcasite and is generally called "sulphur." It occurs as small crystals on sphalerite and dolomite but has not been observed on galena.

Calcite

Calcium carbonate ($CaCO_3$) in the form of calcite crystals, known as "tiff," is one of the most abundant minerals associated with the ores. It crystallizes in the hexagonal system is various forms of rhombohedrons and scalenohedrons, with various types of pyramid and prism faces. The color is usually white or colorless, grading into various shades of yellow, pink, blue, or brown. Amber-colored calcite is quite common in the district. The mineral has remarkably good cleavage, permitting the crystals to break into small rhomb-shaped fragments.

Besides occurring as well defined crystals, calcite forms granular massive aggregates as the essential constituent of the common limestone of the district. The calcite in coarsely crystallized aggregates is closely associated with ore minerals and is found in veins, in irregular areas cementing breccia, in the filling of small cavities, and as a lining of variable, but often of considerable thickness to the walls of caves. The size of the calcite crystals varies from small to very large crystals, sometimes three or four feet in length in some of the large caves.

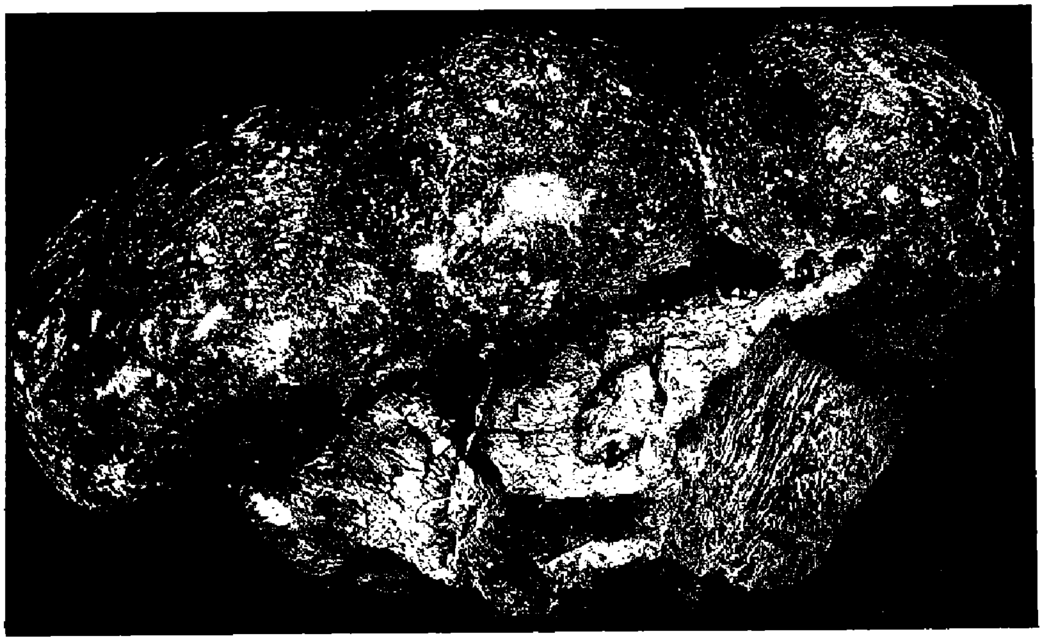
Much of the mine water is highly charged with calcium carbonate in solution which, on partial evaporation, leaves a soft slimy deposit of amorphous calcite on the walls of abandoned mine stopes. On further evaporation this finely granular or amorphous calcite may develop hard white coatings on the walls of the mines, and also minute stalactites and stalagmites on the roofs and floors of the stopes. This finely granular or amorphous form of calcite is very unlike the well-defined crystalline calcite above described which is closely associated with the ore, forms veins, fills small cavities and occurs as large "dog-tooth spar" projecting out in all directions from the walls of the fracture caves. This coarsely crystallized calcite is a very different type and was apparently developed under quite different conditions from the fine granular calcite now forming in the mines.

Aragonite

Aragonite is a form of calcium carbonate ($CaCO_3$) having the same composition as calcite, but crystallizing in the orthorhombic system. As observed in the mines of the district aragonite occurs most abundantly in aggregates or globular, mammillary, and reniform shape with internal radiating and divergent fibrous structure. The color is usually white to grayish-green, with a luster more vitreous and resinous than that of calcite. The outer portions of the globular masses are distinctly white, and the interior of some of the larger crystals grade to a greenish shade. The size of the aragonite crystals of hemispheric form varies from one-half inch to six or eight inches in diameter. (See B, Plate VII.)

As far as observed, the aragonite appears to be most commonly developed upon calcite, but it also occurs on sphalerite as shown in Plate VII, figure B. Marcasite occurs to some extent on the aragonite, and in the

PLATE VII



A. Aragonite on sphalerite, four-fifths natural size.

B. Aragonite on calcite, one-half natural size. The aragonite in A and B illustrates paramorphism—a molecular change to calcite.

Golden Rod mine No. 6 marcasite crusts, cup-shaped forms, "mundic cups," one to three inches across, were observed. The cup-shape is probably due to the solution of aragonite upon which the marcasite was originally encrusted. The aragonite appears to be mainly developed as a filling of cavities and openings. While it seems to be one of the later minerals to be formed, it occurs in more than one generation, as it alternates in deposition, not only with calcite, but also with the ore-minerals. It was observed in small crystals also in thin sections of the ore breccia.

The aragonite, although formed as the original calcium carbonate mineral in the various forms as above described, it was subsequently changed by paramorphism to calcite, as shown by the application of Meigen's test. This change to calcite, forming pseudomorphs of calcite after aragonite, is a common process and is due to the fact that the aragonite is not as stable as calcite.

Aragonite is usually formed from hot solutions while calcite may be formed from either hot or cold solutions. At about 470° C. aragonite changes to calcite. Aragonite may also be formed at ordinary temperatures through the action of organic agencies, or by precipitation from saline waters containing sulphates. The conditions influencing the development of the aragonite in this district is not known but may indicate moderate temperatures and its widespread occurrence in the mines of the Miami district may throw some light on the origin of the lead and zinc ores with which it is closely associated.

Aragonite was apparently of very rare occurrence in the ore deposits of the Joplin district as it was not observed by A. F. Rogers[43] in his very complete list of the minerals described in 1904. However, Rogers refers to an earlier list of minerals from the Joplin district, described by A. V. Leonard[44] in 1882, in which aragonite is listed. Aragonite is described by E. R. Buckley[45] and H. A. Buehler from an outcrop of Pennsylvanian shale breccia in the Granby area, where it forms a coating on limestone boulders. Dana's[46] list of minerals of Missouri refers to the occurrence of aragonite as a common mineral in the lead district at the Mine La Motte, Madison County, Missouri.

Aragonite appears to be a fairly abundant mineral in the Miami district. It is fairly common in the Grace Walker, Beaver, Woodchuck, and Netta mines. In the Woodchuck mine it occurs in all the mine stopes, from the lowest to the highest, through a vertical range of over one hundred feet of the ore deposits.

Dolomite

This mineral is a carbonate of calcium and magnesium ([CaMg]CO_3) much resembling calcite, but less common in its occurrence. Its color is gray to buff and is often called "tiff" by the miners. It occurs in massive granular form and as crystals lining cavities, usually small and fairly uniform in size, with rhomhedron faces usually curved to form saddle-shaped crystals about one-fourth inch in diameter. Dolomite also occurs as a cementing material in the breccias and is usually very closely associated with the ore minerals.

Dolomitization. An investigation of the well samples of the Ottawa County well, shows that the Mayes and Boone formations contained very little or no dolomite outside the mining district. On the other hand cuttings from these formations from the well of the Bird Dog mine and that of the Commerce Mining and Royalty Co. power station, within the mining district, contained very much dolomite. There is much more dolomite also in the limestone formations underlying the Boone within than outside of the mining district as shown in Table III. The Boone was apparently originally a nearly pure limestone formation and the dolomite in cavities and closely associated with the ore deposits is of secondary origin. Much of the dolomite, however, in formations below the Boone where occurring in well defined stratigraphic horizons, both within and without the mining district is evidently of syngenetic origin.

Although this investigation is not completed it appears that dolomitization and metalliferous mineralization are closely associated and have a common origin in the mining district. The secondary dolomite, however, extends to much greater depth than the ore deposits. This subject is referred to again in discussing silicification and the origin of the ore.

Barite

Barium sulphate ($BaSO_4$), is not very common, but it has been noted in several mines of the district. It forms tabular and prismatic crystals in the orthorhombic system. It is colorless to grayish and bluish-green, with vitreous to pearly luster. It is commonly known to miners as "heavy spar." It has good cleavage and tends to break into rectangular fragments. Very small crystals were noted on galena in the Brewster and Grace Walker mines. It was found lining small cavities in the Dobson mine in such quantity as to require its separation from the ore in mining. Some of the tabular crystals in the Dobson mine are one to three inches across. The common variety with bluish tinge occurs in large crystals and in massive crystal aggregates in the Blue Jay mine near Thom's Station, Missouri. Barite in small crystals with drusy quartz has been observed by the writer as a contact mineral in the intrusive granite area of Rose Dome, Kansas.

Although the mineral fluorite, CaF_2, has not been observed fluorine* occurs in the concentrates of the district in sufficient quantity to cause trouble in the acid plant of the National Zinc Company in Bartlesville.

Gypsum

The hydrous calcium sulphate ($CaSO_4+2\ H_2O$) occurs in small amounts in the district. The color is usually white to gray with a pearly to vitreous luster. It is found in small crystals which are tabular, prismatic, or acicular. It occurs as separate individuals mixed with particles of clay, or as radiating aggregates in minute cavities.

It is formed apparently by the oxidation of the metallic sulphides, mainly marcasite, which produces sulphuric acid. This acid then reacts upon calcite to form gypsum. As a result, radiating bundles of gypsum are found often in the solution cavities of calcite. Gypsum is also found associated with anglesite and quartz in small masses of white clay. It is also found as coatings of white mineral on various rock surfaces in the mines and along the parting planes of the Cherokee shale overlying the ore-bearing formation.

Quartz

Quartz (SiO_2) occurs in two varieties, in the crypto-crystalline form as flint or chert, and as well defined but usually small crystals and crystal aggregates.

Quartz other than chert, in the form of well defined crystals, is known to occur in many places in the district. Quartz crystallizes in the hexagonal system and usually forms somewhat elongated crystals with prism faces terminated with pyramids. Very small quartz crystals are fairly common as a coating in drusy cavities and upon siliceous surfaces of chert and jasperoid.

Quartz crystals one-fourth to one and one-fourth inches in diameter occur quite abundantly in certain parts of the Interstate-Hartley mine near Baxter Springs. It occurs on the walls of small cavities, as a coating upon chert, and is abundant on sphalerite, as shown in A. Plate VI. It also occurs as coarsely crystallized quartz in veins parallel to and inclined to the bedding. The quartz occurs as a gangue mineral with the ore in the same manner as the dolomite and calcite on the 290-foot (below surface) mine level. The quartz is colorless with shades of lavender, rose and yellow. In certain parts of the Hartley mine veins of coarse quartz predominate with little or no calcite, and in other parts veins of calcite are abundant with-

*Personal communication.

out quartz. Coarse crystalline quartz occurs in the Swalley, Paxson, Ballard and Keith mines near Baxter Springs.

In the vicinity of Peoria, in old lead and zinc diggings along Warrens Branch, about one mile northeast of Cave Spring, are veins filled with crystallized quartz one-fourth to one inch in diameter, which the writer did not see in place, but was shown angular blocks from the locality at the home of J. P. McNaughton. Crystals of quartz one inch in diameter have been reported from a twenty-five to forty foot drift in ore found in the old workings of the Mont. B. mine at Webb City, Missouri.

Chert

Fine-grained quartz in the form of chert or flint generally forms more than one-half of the rock in which the ore occurs in the mining district. Most of the chert in the Boone formation is white to gray but that found in close association with the ore deposits is usually dark-colored. The dark-colored flint is usually referred to as jasperoid by geologists, but is usually known as "bull flint" by the miners.

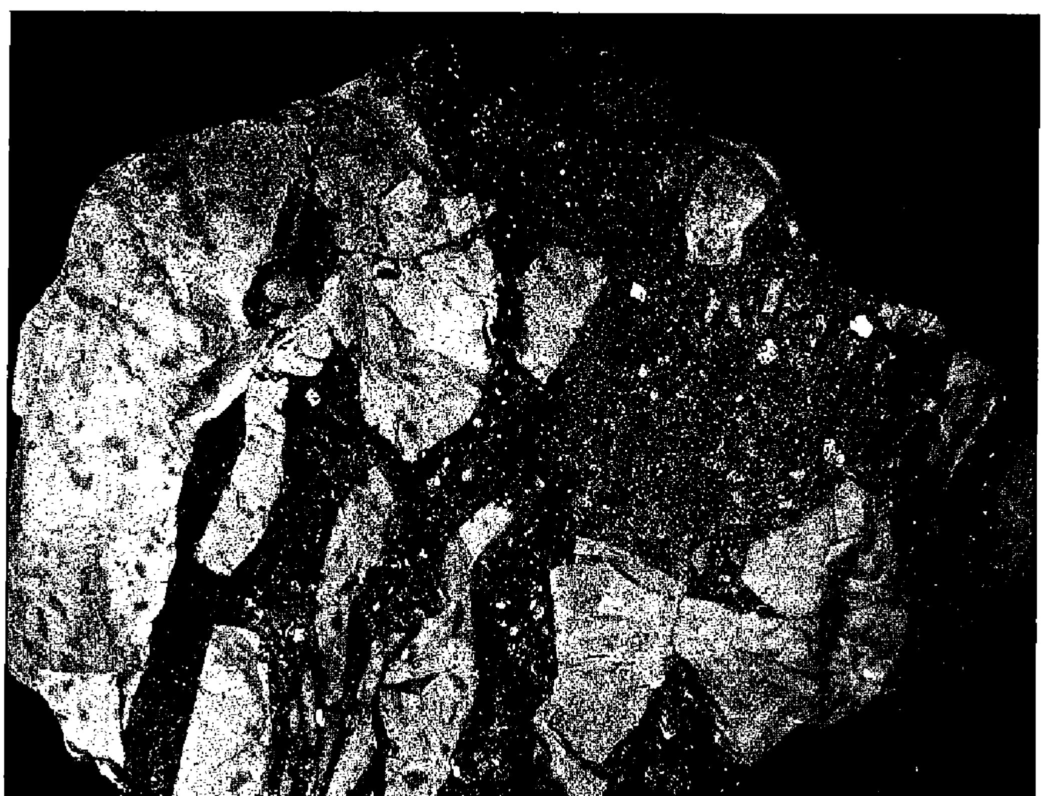
The two types of chert have long been recognized as representing two periods, or generations, of chert formation, the white to gray chert the earlier, and the dark colored chert or jasperoid the later. The later chert has been recognized generally as of secondary origin but the earlier chert has been considered by many as of primary origin,[47] deposited with the limestone strata of the Boone.

It is the writer's opinion that although there is a small amount of primary chert of organic origin in the Boone, there are in addition two types of secondary chert formed in two separate and distinct periods of silicification. The writer's view concerning the occurrence of three types or generations of chert is essentially the same as that of E. R. Buckley and H. A. Buehler,[48] and of F. B. Laney.[49] However, we do not agree as to the original source and the age of the secondary chert.

First period of silicification. The relative age of the two types of secondary chert is shown in the ore breccia, the older chert being represented in the angular fragments of white chert, and the younger by the dark-colored jasperoid chert forming the cement of the breccia as shown in A and B, Plate VIII.

The chert forming the fragments in the breccia is very fine-grained, the grains ranging from .0005 to .03 mm. in diameter. It consists mainly of micro-granular with much micro-fibrous quartz. The latter occurs in the various forms of chalcedony such as lutecite and quartzine. The micro-fibrous quartz so characteristic of the earlier chert was not observed in the coarser variety of

A. Jasperoid ore breccia, three-fourths natural size. Grace Walker mine.



B. Jasperoid ore breccia, natural size. Golden Rod mine no. 8. The dark-colored jasperoid ore solution apparently moved apart the shattered fragments of white chert.

later chert of the jasperoid type. So far as investigation extends also the earlier chert consists of much purer quartz than the later. It forms nodular and concretionary masses, and lens-like layers, very irregularly distributed throughout the Boone formation, especially in that portion above the St. Joe shaly member.

This type of chert replaces the fossils in the limestone, the calcareous fossils being partly or wholly replaced by fine quartz, the various stages in the process of silicification being readily observed. In the concretionary nodules of the chert, the concentric bands of the concretions cut directly across the stratification of the limestone. It is, therefore, interpreted as a metasomatic replacement of the limestone. The chert of this period is associated with the formation of stylolites in the quarries at Carthage and south of Joplin.

The fine-grained chert is represented not only in the angular fragments of the ore breccia as shown in Plate VIII but this type also occurs as abundant chert gravel in the basal beds of the Mayes formation, indicating its age as older than the Mayes. The age of the chert appears, therefore, to have been earlier than the Mayes, but later than the Boone, and thus was formed in a relatively short period in middle Mississippian time. The silicification apparently took place when the Boone was at or near the surface, and it may have occurred either under sub-marine or sub-aërial conditions.

Second period of silicification. The chert of the second period of silicification, represented in part by the jasperoid forming the ore-bearing cement of the breccia, is usually dark-colored and is quite uniformly coarser grained than the older white chert. The jasperoid phase consists of quartz grains ranging from .0005 to .30 mm. in diameter, about one-half being .15 to .30 mm. in diameter. The quartz tends to develop prismatic forms with pyramid terminations. The jasperoid, as shown by chemical analyses,[50] consists usually of ninety-five to ninety-seven per cent silica with small amounts of other constituents including iron and some carbonaceous material.

Much of the quartz and chert of the second period is light-colored. The well crystallized quartz, occurring on sphalerite, shown in A Plate VI and as small crystals lining cavities and in coarse quartz veins is light-colored and is a product of the second period of silicification.

The jasperoid is distinctly a vein-filling product of mineralization. It forms the principal gangue enclosing the ore mineral in the breccia, and it occurs as a metasomatic replacement of the walls of the fractures and fissures in the Boone limestone.

While the jasperoid does not form nodular masses with concentric banding like the earlier fine-grained chert, a common phase is characterized by a banded texture. The banding resembles stratification and it has been referred to as indicating a sedimentary origin, as a form of mud, in a conglomerate or basal breccia. However, thin sections of the banded jasperoid, examined by the writer, show no minerals of clastic origin, but only alternating layers of coarse and fine interlocking quartz crystals alternating with small ore minerals and fine dolomite and calcite.

The writer interprets the banding or crustification as due to crystallization from solution, a texture quite characteristic of veins of hydrothermal (epithermal) origin. The banded texture is best developed where the jasperiod is especially abundant and makes up a large part of the ore-bearing rock. It is found to a variable extent throughout the vertical range of the ore deposits of the Picher mines.

The jasperoid chert and ore are found in the overlying Mayes as well as within the Boone. The sandstone of the Mayes is invariably silicified to light-colored quartzite in the proximity of the ore deposits. The age of the second silicification is obviously that of the ore as more fully discussed under origin of the ore deposits. As later described the jasperoid and ore are apparently closely related in time of origin with the period of deformation during which the Miami syncline and associated fracturing and brecciation were developed. Since the folding of the syncline affects the overlying Pennsylvanian strata and similar structural features affect the Permian farther west, the age is probably Mesozoic.

It is of interest to point out that the second period of silicification, developing the coarser type of jasperoil chert, evidently took place when the Boone and Mayes were deeply buried by overlying strata, and under much deeper seated conditions than that of the finer grained chalcedonic chert of the first period.

Comparative amounts of the two kinds of chert. Although this investigation is not complete it appears to show there was much more chert deposited in the first period of silicification than in the second.

In Table XVII is shown the insoluble residue, mainly chert, found in drill samples of the Ottawa County well, located outside the mining district, as compared with that of samples of the Bird Dog well and the Power Station well, located within the district. The siliceous residue in both the Mayes and Boone is shown. The relative distribution of the chert is shown to be quite variable, ranging at various horizons from sixteen to eighty per cent in the well outside the district, to sixteen to ninety-seven per cent in the two wells within the district. The writer has grouped together in the table the five-foot beds in each well having about the same amount of chert rather than attempting to show the chert content of each five-foot bed at corresponding horizons in the three wells.

In drilling the Bird Dog well a new cable rope was used which was stretched sixty-one feet, the well being drilled 1,267 feet instead of 1,206 feet as logged. The thickness of the Boone is therefore estimated at 335 feet instead of 315 feet as logged.

TABLE XVII. *Insoluble residue, mainly chert, in Boone and Mayes formations*

1. *Ottawa County Well* (Outside mining district)			2. *Power Station Well* (Within mining district)			3. *Bird Dog Mine Well* (Within mining district)		
DEPTH *Feet*	THICKNESS *Feet*	RESIDUE *Per Cent*	DEPTH *Feet*	THICKNESS *Feet*	RESIDUE *Per Cent*	DEPTH *Feet*	THICKNESS *Feet*	RESIDUE *Per Cent*
Cherokee								
0-60	60		0-110	110		0-100	100	
Mayes								
60-120	60		110-135	25		100-135	35	
60-95	35	a	110-120	10	20	100-115	15	39
95-120	25	18	120-135	15	30	115,135	20	a
Boone								
120-497	377	56	135-500	365	63	135-450	315[b]	67
120-145	25	41	135-140	5	55	135-155	20	46
145-170	25	53	140-150	10	80	155-170	15	19
170-200	30	63	150-170	20	70	170-185	15	23
			170-185	15	80	185-200	15	47
			185-210	25	75	200-220	20	64
200-225	25	47	210-225	15	60	220-225	5	57
225-240	15	62				225-235	10	74
			225-250	25	30	235-250	15	88
240-255	15	32						
255-260	5	16	250-260	10	16	250-260	10	82
260-280	20	32	260-270	10	30	260-270	10	77
280-285	5	23	270-295	25	80	270-280	10	73
285-300	15	33	295-300	5	97	280-290	10	61
300-310	10	56	300-325	25	85	290-310	20	42
310-335	25	76						
335-355	20	50	325-360	35	62	310-350	40	96
355-405	50	80	360-390	30	40			
405-415	10	72	390-400	10	70	350-380	30	93
415-450	35	61	400 420	20	50	380-395	15	65
450-460	10	50	450-460	10	40	395-410	15	74
St. Joe								
460-497	37	30	460-500	40	31	410-450	40	30
Chattanooga								
497-512	15		500-505	5		450-455	5	

1. Location; SW SW sec. 12, T. 27N., R. 22 E. Elevation: 850 feet: depth 1055 feet. drilled 1927.
2. Location; NE NE sec. 25, T. 29N., R. 22 E. Elevation: 837 feet: depth 1229 feet: drilled 1929.
3. Location; SE SE sec. 13, T. 29N., R. 22 E. Elevation 822 feet: depth 1267 feet: drilled 1930.

a. No sample. Probably shale.
b. The cable rope was stretched 61 feet in drilling, and depth of well is 1267 feet rather than 1206 as logged. The thickness of the Boone is about 335 instead of 315 feet.

The amount of residue, mainly chert, is fifty-six per cent of the Boone formation in the well outside the mining district as compared with sixty-three and sixty-seven per cent in the two wells within the district. As no jasperoid was found in the well outside the district and it was abundant in the two wells within, the larger amount in the latter may be attributed directly to the additional jasperoid chert of the second silicification.

A certain amount, probably five to fifteen per cent of the Boone formation consists of quartz of clastic and organic origin deposited with the limestone strata. For our purpose an average of ten per cent may be considered as of primary sedimentary origin.

It may be assumed that the amount of chert and clastic quartz of primary origin in the Boone formation be of the order of ten per cent, that of the fine-grained chert of the first silicification forty-five per cent, and that of the coarser grained jasperoid chert of the second silicification of the order of ten per cent. This estimate is applicable only to the mining district where the jasperoid is present and especially near the ore deposits. That the content of chert is greatest in the vicinity of the ore deposits is recognized in exploration work as indicated by the preparation of silicification maps such as that of the Federal Mining and Smelting Company, shown in figure 10, used as a general guide in mining development.

The chert of the first period is much more abundant than that of the second period, and has a more widespread distribution throughout the Boone formation of the region. That of the second period, however, is apparently mainly localized in the areas of the ore deposits, although to some extent it is known to occur in fracture veins and as replacement of limestone in the outlying region.

The chert of the first period, as already described, is associated with little or no dolomite, while that of the second period, in the mining district at least, occurs with abundant dolomite. In addition to dolomite the younger jasperoid chert is associated with abundant calcite, and some aragonite, and with the ores and other metal-bearing minerals of the mining district. The origin of the chert of the two periods of silicification is briefly discussed under the origin of the ore.

Hydrocarbon compounds

Bitumen, known as "tar" by the miners, occurs in appreciable quantity in some of the mines. The source of the tar is very probably in the coal seams and in the oil-bearing phases of the Cherokee shale that overlies the ore-bearing rock of the district. It formerly occurred in abundance in the tar spring in Cardin. Tar Creek is so named because of the tar seeps along the stream. It occurs in some mines in sufficient quantity to interfere with milling the ores. Where abundant it drips down from the roofs of the upper stopes of the mines indicating its source from the overlying Cherokee rather than from any underlying formation. Tar from the Gordon mine is utilized by the Picher Roofing Company for roofing purposes.

SIZE AND SHAPE OF ORE DEPOSITS

The ore deposits of the Miami district occur mainly in the upper half of the Boone formation, and also to some extent in the overlying Mayes formation. The ore is closely associated with the highly silicified and dolomitized phases of these formations and the workable deposits assume various forms, more or less irregular in shape. The shapes of the ore bodies are best illustrated in their main outlines, at least, by the shapes of the mined-out chambers of the mines, or mine stopes. These may be classed roughly in two main groups, one in which the ore forms broad tabular bodies or "flat runs;" the other in which the ore forms relatively narrow vertical bodies or "vertical runs." In addition small bodies of the ore may be described as "pockets."

Flat runs

The dimensions of the flat ore runs are quite variable, ranging from ten or twenty feet to 500 or even 1,000 feet in width, and usually ranging from ten to thirty feet in height. The top and bottom of these flat runs are roughly parallel and follow the bedding planes of the formation. The flat ore runs may be developed at a single mine level or they may occur at two and occasionally three levels.

Vertical runs

The dimensions of the vertical runs range from ten to fifteen feet in width and often attain one hundred to 150 feet in height. The vertical runs have steeply inclined walls and generally follow the nearly vertical fracture and fissure zones in the rocks.

Pockets

The ore pockets are merely small occurrences of ore-bearing formation. These are usually somewhat circular in shape, like a pocket, and appear to be separated from the larger ore bodies by a very slightly mineralized or barren formation.

The ore in these roughly shaped bodies is in much broken and brecciated formation, often described as "boulder formation," being composed of angular silicified or dolomitized blocks of fractured rock cemented by ore and gangue mineral. The "boulder formation" grades into more or less massive silicified formation filled with veins and irregular ramifying seams of ore. The ore is thus found in ground more or less broken by brecciation, fissuring and jointing. The original rock is obviously much changed by processes of deformation, accompanied by vein filling in the open fractures and by replacement of the wall rocks by ore and gangue mineral carried in and deposited by the mineral-bearing solutions.

In the older mining district about Joplin a common form of ore body was the "blanket-vein" or "sheet-ground" deposit, the ore occurring in thin sheets intercalated between nearly horizontal beds of chert. The "sheet-ground" ore body, in its typical form at least is not present in the Miami district, its nearest correlative being the broad, tabular ore body. In the earlier mines of the Quapaw-Lincolnville area on the eastern margin of the Miami district, the ore is described[51] as occurring in a "blanket breccia" which has a blanket form similar in some ways to the "sheet ground" but differing from "sheet ground" in other respects.

The size and shape of the ore deposits in various mines are further discussed in the description of mines at the end of this volume. Figures 11A and 11B show ground plan and cross sections of the ore in the Beaver mine and figures 12A and 12B in the Scammon Hill mine.

DISTRIBUTION OF ORE DEPOSITS

Locally the ore tends to occur along the planes of bedding and fracturing of the strata as already described. The ore apparently owes its distribution mainly to conditions favorable for the easy passage of ore-bearing solutions along the structural features of the rocks.

The ore is not found throughout the Boone chert formation in which it mainly occurs but it is confined to a general zone fifty to 150 feet thick, located usually in the lower part of the upper half of the formation. The position of the ore-zone is somewhat variable but it is usually from one hundred to 150 feet below the shale. The well-known oolite horizon of the Boone is at 110 to 125 feet below the top of the formation and most of the ore-bodies are found near this horizon.

However, in certain localities, namely in the Miami syncline, the ore-bodies are found not only in the upper part of the Boone formation but also in the Mayes limestone, overlying the Boone. (See Figure 6). The occurrence of ore in the Mayes formation is best illustrated in the Scammon Hill mine near Commerce, shown in figure 12B. Ore-bodies in the Mayes formation are described in the Central, Crystal, Howe, Harrisburg and the Roanoke mines, and are said to occur in other mines in the syncline not visited by the writer.

A characteristic ore-bearing rock of the Mayes formation is "sand spar" which apparently represents silicified and mineralized sandy phases of the Mayes limestone formation. The "sand spar" being in the Mayes formation is found at the top of the ore-zone close to overlying shale. The commonly observed association of galena above sphalerite is well illustrated by the fact that the "sand spar" usually carries a relatively high content of galena and hence the Mayes is generally higher in lead ore than the underlying Boone. In the Scammon Hill mine the ore mined to date (1930) is mainly lead ore from the Mayes formation, the ore in the underlying Boone, mainly zinc, having been mined only to a slight extent.

In the Central and the Crystal mines, ore-bodies have been mined at three levels the ore extending through a vertical height of over one hun-

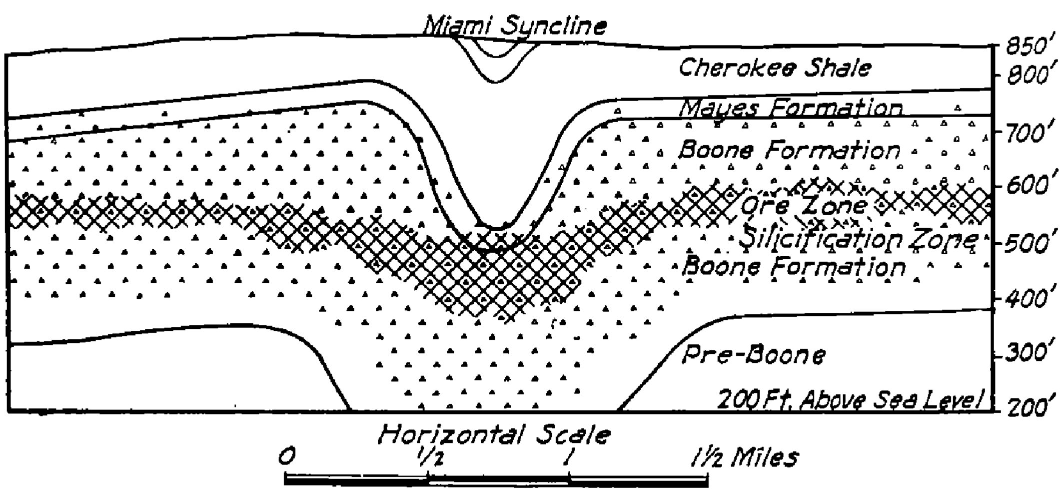


FIGURE 6. Generalized section showing position of the ore zone in and adjacent to the Miami syncline

dred feet, the stopes in the uppermost levels in the Mayes formation being roofed with shale much of which has now caved in.

The zone in which the ore bodies adjacent to the Miami syncline is found is usually the lower part of the upper half of the Boone, but where the strata are depressed in the syncline, the ore extends into the overlying Mayes formation, as illustrated in the diagram, figure 6.

The diagram is intended to show only general relations, the vertical scale being greatly exaggerated, ten times that of the horizontal. The ore-zone is not a continuous body of ore but only a general zone in which the ore-bodies occur. The lateral or horizontal distribution of the ore may be seen on the map showing the ground plan of mines, Plate II. The vertical range in distribution of the ore may range from ten feet to one hundred feet, the ore occupying only a minor part of the zone, being mined on one to three levels with more or less barren rock between.

The diagram is especially intended to show that while the ore-zone maintains its position at about 125 to 150 feet below the Cherokee shale formation on either side of the Miami syncline, the zone continues to maintain the same elevation through the depressed strata of the syncline, and thus in the bottom of the syncline the ore is found to extend up through the upper beds of the Boone formation and into the limestone and sandy limestone beds of the Mayes overlying it.

RELATIVE RICHNESS OF MINES IN THE TRI-STATE REGION

It is the general opinion of mining men of the region that the mines in the newer district about Picher are much richer than those in the older district about Joplin and Galena. So far as known to the writer, however, no one has collected statistics of production showing the relative richness of orebodies in the two districts.

At present it is difficult to secure any records or reliable information concerning production of the abandoned mines in the old district. Only estimated production based on best information now available can be given for the old mines. In the new district about Picher, however, essentially complete records of production are still available from the companies now operating.

Joplin District

The American mine, a 280-acre lease in the Carterville area, in sections 16 and 21 of T. 28, R. 32 (Missouri), mined from four shafts, from 1902 to 1919 yielded a production of 126,681.94 tons of zinc concentrates and 53,352.96 tons of lead concentrates. The ore was mainly sheet ground and about 140 acres underground was mined out.

The old Lincoln mine[52] later known as the Athletic mine, located on 160 acres, the NW¼ of sec. 3, T. 27, R. 32 (Missouri) developed an average face or height of stope of about nine feet, over a mined-out area of about forty acres, yielding an average of about three per cent zinc concentrates, and very little lead. This mine yielded a total production of about 35,280 tons of zinc concentrates and a small amount of lead concentrates.

The Wilson mine[53] was located on an eighty-acre lease near Duenweg about one-half mile south of the Athletic mine. There was some sheet ground but the ore-bearing rock was mainly mined from two stopes having a height of fifteen to forty-five feet, with an average height of thirty feet, the area of ground mined amounting to six or seven acres. The ore averaged about two per cent zinc and lead concentrates, about eighty-five to ninety per cent of the ore being zinc concentrates and ten to fifteen per cent lead concentrates. The production of this mine approximates 12,250 tons of zinc concentrates, and 1,350 tons of lead concentrates.

Galena district

The South Side mine, an eighty-acre lease, located in Galena, Kansas, the NE¼ SE¼ of sec. 14, and NW¼ SW¼ of sec. 13 of T. 34 S., R. 25 E. (Kansas) is apparently the oldest producing mine of the Tri-State district. This mine began operation in 1877 and is still active though only on a small scale since 1917. It has a record of continuous production (in 1930) of 54 years. The annual production from 1877 to 1901, as compiled by Irene G. Stone, is given in *Geol. Survey of Kansas,* Vol. VIII, p. 106. No complete records of production since 1901 are now available, but based on records of ten per cent royalties from 1911 to 1928 furnished by Mr. Cole of the Galena National Bank the approximate production since 1901 has been estimated. This estimate is based on the assumption that the relative proportions of lead concentrates 27.5 per cent and zinc concentrates 72.5 per cent from 1877 to 1901 has been maintained from 1902 to 1928. Given the ten per cent royalty paid each year from 1911 to 1928 and the annual value of lead and zinc concentrates for Kansas (from *United States Mineral Resources*), an approximation of the production from 1911 to 1928 was calculated. No records of production from 1902 to 1910 inclusive, could be found and the estimate for each of these nine years is based on the average annual production for the five years previous to 1902 and the five years subsequent to 1910.

It is estimated[54] that four acres were mined out below the seventy-five foot (below surface) level and about three-fourths of the area mined above the seventy-five foot level. Much of the upper ground is honeycombed with small "diggings," worked from the surface down to ground water-level.

The recorded production of the South Side mine from 1877 to 1901 and the estimated production from 1902 to 1928 is shown in Table XVIII.

TABLE XVIII. *Production of South Side mine, Galena, Kansas,* 1877-1928

YEAR	LEAD CONCENTRATES	ZINC CONCENTRATES
1877-1901[1]	31,630.75 tons	83,276.18 tons
1902-1910[2]	7,326.00 tons	37,485.00 tons
1911-1928[3]	6,115.00 tons	16,136.00 tons
Total	45,071.75 tons	136,897.18 tons

1. Production recorded, see Kan. Geol. Survey, Vol. 8, p. 106.
2. Production estimated on averages.
3. Production estimated on 10 per cent royalties.

Picher District

The mines of the Picher district selected for comparison with those of the Joplin and Galena districts are the Beaver, Beck, Brewster, Goodwin, Woodchuck, and Velie-Lion in Oklahoma, and the Barr and Webber in Kansas, the locations of which are shown in Plate II. Their production is known but their acreage of underground workings is only estimated. The list does not include all the richest mines of the district but represents only a fair average of the richest.

The estimated production of the four important mines described in the Joplin and the Galena districts, and the recorded production of eight important mines in the Miami-Picher district, with estimated area mined out and the production per acre leased and mined is shown in Table XIX.

TABLE XIX. *Production of important mines, per acre leased and mined, in the Joplin, Galena and Picher districts*

MINE	ACRES IN LEASE	ESTIMATED ACRES MINED	PERIOD OPERATING	LEAD CONCENTRATES (*tons*)	ZINC CONCENTRATES (*tons*)	CONCENTRATES PER ACRE LEASED (*tons*)	CONCENTRATES PER ACRE MINED (*tons*)
Joplin district:							
American	280	140	1902-19	53,352	126,681	643	1,286
Lincoln	160	40		some	35,280	220	880
Wilson	80	7		1,350	12,250	170	1,800
Galena district:							
South Side	80	60	1877-1928	45,071	136,897	2,274	3,032
Picher district:							
Beaver	40	9	1916-28	19,768	51,890	1,791	7,963
Beck	80	16	1919-28	4,549	88,840	1,167	5,836
Brewster	80	16	1919-28	14,957	112,098	1,588	7,941
Goodwin	50	18	1917-28	5,536	71,016	1,531	4,253
Oklahoma Woodchuck	40	10	1917-28	20,052	79,610	2,441	9,966
Velie-Lion	80	16	1917-28	18,153	70,299	1,106	5,529
Barr (Kansas)	60	14	1917-28	26,021	100,504	2,108	9,037
Webber(Kan.)	60	14	1919-28	21,962	100,228	2,036	8,733

A comparison of the production of the mines in the three districts as shown in Table XIX indicates the production of ore per acre leased and per acre mined to be much greater in the new district about Picher than in the two older districts with the possible exception of the South Side mine in Galena. The South Side mine, however, because of its location outside the Cherokee shale-covered area, where not only the shale but also the upper thirty or forty feet of the Boone has been removed by erosion, affords unusually favorable conditions for developing small "diggings" along ore crevices above ground water-level, above the main ore-bearing zone. Probably at least one-fourth of the South Side production was developed from small deposits above the main ore-bearing zone, a type of mining also quite common throughout the Joplin district, but not practical in mining the deeper-lying ore deposits, beneath the shale, in the Picher district.

The important production from shallow depth in the South Side mine seems to indicate that considerable ore in small deposits above the main ore-zone is probably left in the ground when the deeper mines of the Picher-Miami district are abandoned.

The mines listed in the Miami-Picher district, were active producers in 1928 and will probably yield from ten to fifty per cent more than reported

TABLE XIXA. *The Ratio of Zinc Ore to Lead Ore in* 34 *mines of the Miami-Picher District*

MINE	ZINC ORE TO LEAD ORE	MINE	ZINC ORE TO LEAD ORE	MINE	ZINC ORE TO LEAD ORE
Anna Beaver	3 to 1	Golden Rod 5	16 to 1	New Chicago	6 to 1
Beaver	2.5 to 1	Goodwin	13 to 1	New York	6 to 1
Bingham	2.5 to 1	Gordon	2.2 to 1	Woodchuck	4 to 1
Beck	19 to 1	Grace Walker	7 to 1	Otis White	4 to 1
Birthday	4 to 1	Harrisburg	2 to 1	Pioneer	1.9 to 1
Blue Goose 1	4 to 1	Howe	1.7 to 1	Ritz	4 to 1
Blue Goose 2	5 to 1	Jay Bird	7 to 1	Royal	24 to 1
Brewster	7.5 to 1	Lucky		Scammon Hill	1 to 1.6
Central	1.1 to 1	Syndicate	1.6 to 1	Tri-State	14 to 1
Crystal	1.3 to 1	Malsbury	4 to 1	Velie Lion	4 to 1
Discard	4 to 1	Mudd	4 to 1	Whitebird	4 to 1
Foch	10 to 1	Netta	4 to 1		

at that time. Apparently the South Side mine in Galena has about as great a production as some of the best mines in the Miami-Picher district, but farther east about Joplin the production per acre has been less than one-fourth of that already developed in the new district about Picher.

RELATIVE DISTRIBUTION OF ZINC ORE AND LEAD ORE

The total amount of zinc concentrates produced in the district (see Table XIV) is 5,679, 846 tons tons, and of lead concentrates 1,032,838 tons. Of the total produced 84.6 per cent is zinc ore and 15.4 per cent lead ore, the ratio of zinc ore to lead ore being approximately 5.5 to 1. While this ratio indicates the average composition of the ore of the entire district it will be seen that when the production of individual mines is considered the ratio varies greatly.

In Table XIXA is shown the ratio of zinc ore to lead ore of thirty-four mines described at the end of this volume. The ratio of zinc ore to lead ore of some of the important mines is as follows: Royal, 24 to 1; Beck, 19 to 1; Goodwin 13 to 1; Brewster, 7 to 1; Netta, 4 to 1; Anna Beaver, 3 to 1; Beaver, 2.5 to 1; Harrisburg, 2 to 1; Central, 1.1 to 1.

The relatively high content of lead ore is especially characteristic of the mines located in the Miami syncline. If the ratio of zinc ore to lead ore for the entire district be taken as 5.5 to 1 the ratio for individual mines in the syncline is generally between 4.5 to 1 and 1 to 1 and that outside the syncline is generally between 4.5 to 1 and 24 to 1.

The high content of lead ore in the syncline is well illustrated by the combined production of the Central and Crystal mines located on adjoining twenty-acre leases. The combined production of the two mines from a typical cross section of the ore zone in the syncline is 23,159 tons of zinc concentrates and 18,956 tons of lead concentrates indicating a ratio of zinc ore to lead ore of 1.2 to 1.

The Scammon Hill mine, located in the syncline, has produced to date much more lead ore than zinc ore. However, only the upper part of the ore zone, within the Mayes formation has been mined, and when the ore in the lower part of the zone, in the Boone, is mined out the ratio will probably be about the same as that of the Central and Crystal mines. Other mines in the syncline producing a high content of lead ore are the Harrisburg, Howe and Lucky Syndicate.

The production of the Joplin district, according to the *Twenty-second Annual Report of the U. S. Geological Survey,* Part 2, page 65, from 1894 to 1900 was 1,338,484 tons of zinc concentrates and 188,541 tons of lead concentrates, indicating 87.6 per cent zinc ore and 12.4 per cent lead ore. The production of the Galena district, 1886 to 1903, according to the *Kansas Geological Survey,* vol. 8, p. 65, was 691,529 tons of zinc concentrates and 112,444 tons of lead concentrates indicating 86 per cent of zinc ore and 14 per cent of lead ore. Of the total production of the Miami-Picher district, as already stated, 84.6 per cent was zinc ore and 15.4 per cent lead ore.

The percentage of lead ore in the Miami-Picher district is appreciably higher than that in the Galena and Joplin districts, and the highest content of lead ore in the entire region is reached in the mines of the Miami syncline. Two significant facts appear to be brought out by a study of the relative distribution of the zinc and the lead ores:

1. There is a pronounced lack of uniformity in the composition of ore bodies as indicated by the marked variation in the ratio of zinc ore to lead ore in individual mines of the district.

2. In addition to the recognized tendency for the galena to form above sphalerite as observed in cavities and in large mined out ore bodies indicating

a vertical zonal distribution there is also a distinct lateral zonal distribution of the galena and the sphalerite, the ore bodies with highest proportion of galena being developed in the Miami syncline.

ORIGIN OF THE ORE

The origin of the lead and zinc ores of the Mississippi Valley region has always been a moot question. Three theories have been advanced, all of which are in essential agreement that the ores are of secondary origin. The theories, however, differ from one another as to the source of the ores and the manner of their deposition.

According to two of the theories, the original source of the ore is held to have been sparsely distributed throughout the surrounding sedimentary rocks and their concentration, into rich ore deposits was effected by cold meteoric waters, either (1) by descending ground waters, or (2) by ascending artesian waters. The third theory (3) holds that the ores were deposited by ascending thermal waters of magmatic origin.

Any acceptable theory should reasonably explain not only the origin of the ore, but also the very extensive metasomatic replacement by silicification and dolomitization of the limestone in which the ore is found, and likewise the occurrence of such coarsely crystallized associated minerals in cavities and veins as calcite, aragonite, dolomite, quartz and barite. In addition any acceptable theory of origin should reasonably explain the localized distribution of the ore both within the district and in the outlying region and also the limited interval, or period in which the ore was formed.

The author believes the theories ascribing the origin of the ore and associated mineralization to the work of ordinary ground water to be unsatisfactory and inadequate, and considers the magmatic theory as the best explanation of their origin for reasons given in the following discussion.

Although similar lead and zinc ores and gangue minerals are known elsewhere to be associated with igneous rocks the principal objection to the magmatic theory of origin of the ore in the Tri-State district has been the absence of known intrusives in the proximity of the ore. However, in recent years, intrusives in Pennsylvanian rocks have been described in various localities in the surrounding region, such as that of the Rose Dome[55] intrusive in Woodson County, Kansas, and the periodotite dike in the Pennsylvanian and Permian strata in Riley County[56] Kansas. Knight and Landes[57] have recently described the intrusives at Rose Dome and Silver City as laccoliths.

Intrusives occur also in southern Camden County, Missouri as described by Winslow.[58] At Spavinaw,[59] Oklahoma, granite pegmatite projects up through the adjacent strata and arches up the overlying Boone formation.

There is, therefore, gradually increasing evidence of Post-Carboniferous intrusive rocks in the surrounding region, corresponding in age to that of the ore deposits.

In May, 1930, granite was struck within the mining district at relatively shallow depth in drilling a water well at the Bird Dog mine near Picher. The true depth of the well (corrected for the sixty-one feet stretching of the drill rope) is 1,267 feet, the granite being encountered at 1,246 feet. The usual thickness of the paleozoic strata in the region of the mines is between 1,800 and 2,000 feet, hence the granite projects up into the lower Paleozoic rocks some 500 to 700 feet above the general level of the Pre-Cambrian floor.

The granite is medium grained, of porphyritic texture with relatively large crystals of feldspar phenocrysts enclosed in fine grained micropegmatitic groundmass of quartz and orthoclase. The larger crystals one to five millimeters in diameter consist of bluish gray albite-oligoclase cores surrounded by outgrowths or enlargements of red orthoclase in crystal continuity. The feldspar makes about 60 per cent and the quartz about 30 per cent of the rock, the remaining 10 per cent being pyrite, chlorite, hornblende, green pyroxene?, epidote, apatite, ilmenite, fluorite, kaolinite, hydrargillite, and calcite. Two distinct periods of crystallization are indicated, the earlier represented by the more basic plagioclase cores of the phenocrysts, and the later by intergrowth of quartz and orthoclase. The albite-oligoclase cores of the phenocrysts are much more altered than the outgrowths of orthoclase both at the subsurface of the granite and at the bottom of the drill hole about 20 feet below. Pyrite, chlorite, epidote, fluorite and apatite are relatively abundant among the accessory minerals. Fluorine, a common magmatic element, has ben observed, as already stated, in the zinc concentrates of the district in the acid plant of the National Zinc Company in Bartlesville.

It has been suggested that the granite may represent an old buried Pre-Cambrian ridge but the texture of the granite as well as the marked silicification of a sandstone bed at the contact, and the development of extensive folding and fracturing in the adjacent rocks, is believed to clearly indicate its intrusive origin.

1. The granite, a porphyritic type, has also the interlocking graphic texture of quartz and feldspar of a pegmatite, a characteristic of hypabyssal rocks and accepted generally as indicating an intrusive origin. Pegmatites are regarded as the latest products of igneous rock magmas, and represent watery residual magma, except that the greater part of the water and other volatile substances was expelled in the final crystallization. In its pegmatitic character the granite is essentially like that of the granite intrusive in the

Rose Dome area of Woodson County, Kansas, about seventy-five miles northwest of the mining district, and of the Spavinaw granite about thirty-five miles to the south.

2. As evidence of exomorphism the sandstone at the contact with the granite is silicified into a quartzitic phase, and the feldspar and hornblende of the granite are endometamorphosed to chlorite, hydrargillite and epidote, characteristic minerals of hydrothermal action.

3. The five-foot sample of well cutting at the contact consists of mixed fragments of the sandstone and the granite, having the character of a mechanical mixture due to drilling, and there is no evidence of arkosic sediment either in the contact sample or in the next overlying five-foot sample of quartzitic sandstone. There appears to be no evidence, therefore, that the granite is Pre-Cambrian and furnished sediment to the overlying clastic rock.

4. The granite encountered in the well of the Bird Dog mine is on the west side and within one mile of the center of the Miami trough which extends through the mining district. This trough, as already described, is a synclinal fold, the limbs of the fold carrying down the Cherokee shale and underlying strata one hundred to two hundred feet below their normal position. The rise in the sub-shale surface a short distance east of the Bird Dog mine, as shown on the sub-shale map by R. V. Ageton,[60] is some forty to sixty feet, indicating distinct arching of the strata overlying the granite, adjacent to the syncline.

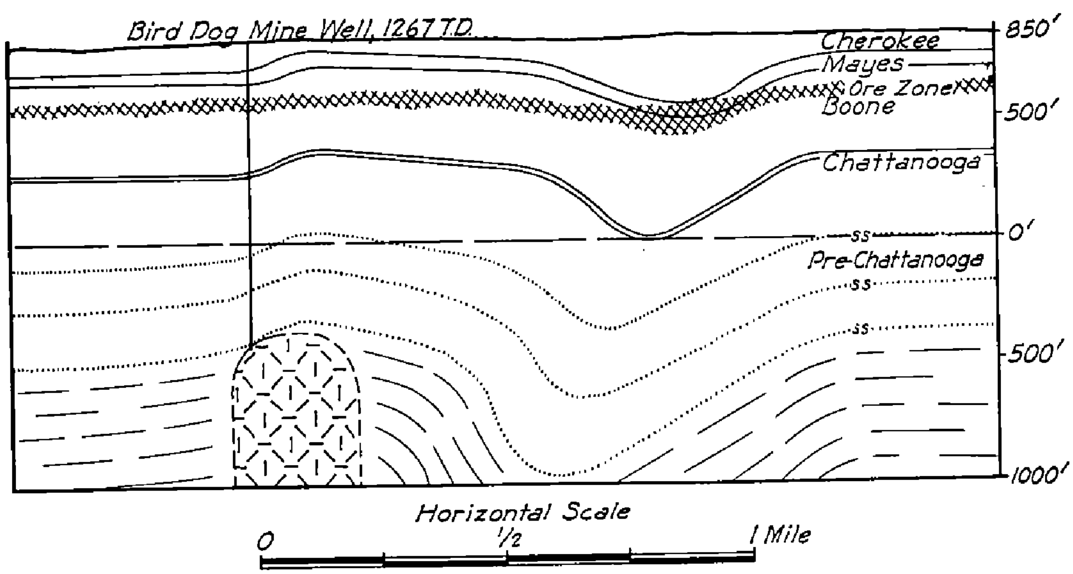


FIGURE 7. Section showing relative position of the pegmatic granite to the Miami syncline and to the ore-zone.

A cross-section drawn through the porphyritic granite and the syncline is shown in figure 7. The amount of folding at the general level of the "sub-shale" (base of the Cherokee shale) is based on drill records showing thickness of the shale. The extent of folding at the level of the granite is estimated and it is assumed that the folding is accentuated with depth, a characteristic of structures in the surrounding oil fields to the west, and likewise characteristic of folding caused by sub-surface intrusives. The granite body is assumed to be about the same size as that in the Rose Dome area and at Spavinaw. The position of the zone in which the ore deposits occur is also indicated in the figure.

The Miami syncline is only a slight fold between Commerce and Afton, but in the mining district and at Afton, it is a very pronounced structural feature being characterized by some local faulting with a probable maximum displacement in a few places of thirty to forty feet, by much fracturing diagonal to the axis of the fold, and by much brecciation shearing and shattering of the rock. The location of the syncline adjacent to the granite is believed to indicate a close genetic relationship between the two. The syncline with its associated fracturing and brecciation was apparently formed by the intrusion of the granite dike.

If the syncline is due to folding along a subsurface granite dike intrusion, the nearly straight trend of the syncline for twenty-five to fifty miles is readily explained for dikes characteristically follow nearly straight lines with only slight variations, and many are known to reach from twenty-five to over one hundred miles in length. The width of dikes is variable but many dikes are known to reach one hundred feet to over one-half mile in width.

The granite encountered along the syncline is probably not the only subsurface intrusive of the locality, but may be considered as only symptomatic of widespread but more or less localized magmatic activity affecting the underlying rocks of the mining district. In this respect, therefore, the district may resemble the Rose Dome area, seventy-five miles to the northwest, where in addition to pegmatite granite, there are also basic igneous rocks intrusive in the Pennsylvanian strata, encountered not only in deep wells but also appearing at the surface in the adjoining Silver City metamorphic area.

The deformation of the Boone formation and overlying Mayes is apparently greater within the mining districts than in the outlying non-mineralized region. The rocks of the Picher district appear to be more sharply folded and more fractured and brecciated than those of the Joplin district.

The principal type of ore-bearing rock in the Joplin district was the "sheet ground" which, although largely brecciated rock, formed mainly tabular bodies of wide lateral extension along bedding planes and of short vertical range. In the Picher district there is little or no typical sheet ground but most of the ore is in coarse or fine breccia, in nearly vertical fracture zones, and generally developing a greater vertical range in the distribution of the ore than in the Joplin district.

Although the ore is believed to be of magmatic origin it is not in direct contact with the igneous rock from which it is derived. At the Bird Dog mine (see Fig. 7) the ore is about 1,000 feet above the granite, and between the two is rock barren of ore.

Lead and zinc ores, however, in other parts of the world, are classed as a type of ore deposit formed from hydrothermal solutions that have cooled and condensed from hot mineralized vapors, driven out from near-by crystallizing magmas. Also the minerals associated with the ore, such as the abundant jasperoid of the silicified zone and the dolomite, calcite, aragonite, fluorite and barite are characteristic minerals of hydrothermal origin.

Between the ore deposits and the underlying intrusive magma (represented by the granite dike) is barren rock in which the vapors issuing from the crystallized magma were too high in temperature and pressure for condensation and crystallization. At a higher level, nearer the surface, under conditions of lower temperature and pressure the mineralized vapors condensed to hydrothermal solutions from which the ore and associated minerals crystallized. Being controlled by temperature and pressure the conditions favorable for crystallization would approximate a common level in the fractured and brecciated limestone strata and thus develop a widespread lateral zone of ore some distance above the crystallizing magma source.

It is the opinion of the author that the solution that deposited the ore of the breccia, shown in Plate VIII, possessed sufficient density, magmatic energy and pressure to hold not only the white chert fragments in suspension but also to move them apart. Essentially the same view concerning the magmatic nature of the ore solution has also been expressed by Spurr in his paper on the Picher district referred to at the end of this chapter.

At the Bird Dog mine the granite is about 1,000 feet below the ore, but in other places the ore-zone may be somewhat farther (several thousand feet) from its magma source. The Cherokee shale overlying the Boone and Mayes formations was probably an important factor in the location of the ore zone because the overlying impervious shale would prevent a further rise of the hydrothermal solutions, and thus contribute an additional cause of the lateral spread of the ore. That conditions of temperature and pressure within the hydrothermal solutions was the controlling factor, rather than the proximity of the shale, however, seems to be indicated by the fact that the ore-zone rises to higher stratigraphic horizons in the depressed Miami syncline than elsewhere, in some places even extending into the shale, in order to maintain approximately the same level through the district.

While the zone of metalliferous mineralization is confined to the upper part of the Boone extending up into the overlying Mayes limestone only in the synclinal structures the dolomitization and silicification, associated with the ore and of the same age reaches down to much greater depth, as shown by examination of samples of deep water wells of the mining district. That the amount of chert in the Boone is greater in the two wells investigated within the district as compared with one without is shown in Table XVII.

So far as my investigation has extended the silicification of formations below the Boone is not markedly different within the district from that outside. However there is a much greater amount of dolomitization below the Boone within the district than without as shown in Table III. This table shows several distinct limestone horizons at depth of 497 to 1055 feet in the well outside the mining district, namely at 497 to 535 feet, 700 to 815 feet, 820 to 885 feet, and 900 to 985 feet. On the other hand the drill samples from the Power Station well within the districts, although variable in content of dolomite and calcite, indicated a complete absence of nearly pure limestone horizons and was distinctly more dolomitic than calcareous throughout its entire depth below the Boone, from 505 to 1229 feet. My investigation of samples also from the Bird Dog mine well showed them to be essentially like those of the Power Station well.

It is my belief that while the zone of ore deposition is confined to the higher levels of limestone strata within the mining district, the secondary dolomite and the jasperoid type of chert (second period of silicification) may reach down to its source in an underlying magma. Evidence favorable to this view, in nearby areas, is indicated by the fact that similar chert and dolomite are abundant at the contact with the pegmatite granite at Spavinaw and chert and silicified sandstone (with drusy quartz and barite) are contact minerals in the Rose Dome and Silver City intrusive areas in southern Kansas.

The temperature associated with the ore deposition was evidently moderate or low. It seems not unreasonable to think of the temperature at the granite contact to have been 300° C. to 450° C. and at the zone of ore deposition as low as 150° C. to 300° C. The temperatures suggested are only approximations, for temperature conditions at intrusive contacts and of hydrothermal crystallizations are little understood and are generally inferred from the nature of the mineralization. Conditions of pressure, and composition of the ore-bearing solutions are additional factors of consideration. With reference to pressure the ore-zone was probably developed beneath 3,000 to 4,000 feet of strata with considerable additional pressure derived from gaseous emanations from the crystallizing intrusive, probably an underlying batholith. The relatively low temperature is indicated by the absence of high temperature exomorphic minerals, such as complex silicates, at the contact with the granite. Furthermore the ore minerals and also the associated gangue as already stated are characteristic of deposits elsewhere formed by hydrothermal action at moderate or low temperature.

Coarsely crystallized quartz amethystine and rose as well as white (see Plate V. Fig. A.) is usually formed at higher temperatures than fine quartz, and aragonite (Plate V. Fig. B.) is usually formed at higher temperatures than calcite, hence the occurrence of these minerals may indicate considerable variation in temperature in various localities. Aragonite was apparently unknown in the old Joplin district, and coarse quartz very rare, hence these minerals may indicate that temperatures were somewhat higher in the Picher district than in the Joplin district.

As already shown in Table XXI, the Picher-Miami district is much richer in ore, probably four or five times richer, than the older district about Joplin. The richest mines are obviously centered about the sharply folded section of the Miami syncline where deformation is greatest and where porphyritic granite is apparently intruded.

The zonal distribution of the ore, with reference to richness of ore bodies and relative content of lead, is generally characteristic of ores of hydrothermal origin.

The theory of magmatic hydrothermal origin of the ore as outlined, although independently reached after a study of the geology of the ore deposits, is in essential harmony with that of Spurr,[61] and of Emmons[62] who have recently discussed the origin of the Mississippi Valley lead and zinc ores. It is also in accord with that of Niggli,[63] Tarr[64] and Graton,[65] each of whom in their general classifications of ore deposits, consider most lead and zinc deposits, including those of the Mississippi Valley region, as of hydrothermal origin. Likewise Fowler and Lyden,[66] as a result of their recent special study of the Tri-State ore deposits consider them of magmatic origin.

The theory that the ore is derived from an underlying batholith a dike from which is encountered in the deep well at the Bird Dog mine, as already stated, not only offers an adequate explanation of the source of the ore and associated minerals, but also offers a satisfactory explanation for the local development of folding and fracturing of the rocks which largely controlled the local distribution of the ore deposits. The underlying magma not only brought in the ore but its intrusion also folded and fractured the rocks in which the ore was deposited and hence, the structural features and the ores are contemporaneous in origin.

The age of the local deformation (and ore deposition) is obviously post-Pennsylvanian as the folding involves the overlying Pennsylvanian shale. The age involved is probably Mesozoic, and most likely contemporaneous with the orogenic movements and magmatic activity characterizing the Jurassic or the Cretaceous period in outlying regions. At that time a much greater thickness of strata, probably 2,000 to 4,000 feet, or more, extended over the mining district.

Origin of the chert. Two periods of silicification have affected the Boone formation, but only one has affected the overlying Mayes formation. I interpret the chert of the first period as well as that of the second as derived from upward moving solutions of probable hydrothermal origin. The first silicification apparently took place soon after the Boone was deposited and before the Mayes was formed as chert pebbles from the Boone are abundant at the base of the Mayes. The earlier silicification (of mid-Mississippian age), occurring when the Boone was apparently very near or at the surface, was not associated with metalliferous mineralization and with little or no dolomitization.

Although the fine granular and chalcedonic chert of the first peroid of silicification is not genetically related to the ore deposits, and is generally accepted as earlier in age, its probable origin as hydrothermal, as above stated, is believed to be strongly supported by three important characteristics. These characteristics are its great abundance, its widespread roughly zonal distribution throughout the Boone and its relatively short period of origin. The writer has estimated the secondary chert of the first period (see Table XVII) as closely approximating forty-five per cent of the 300 feet of formation above the St. Joe member. Some geologists contend that the chert is only surficial in its distribution but its abundant occurrence throughout the Boone is not only shown by the investigation of the writer but is also generally understood by every well driller and miner of the district.

The silica of the first period, replacing fossils and forming nodular concretions is restricted to the Boone limestone and does not occur in the overlying Mayes except in the form of detrital chert gravel derived from the Boone. It was introduced into the Boone, as already described, in the interval between Boone and Mayes time, within the Meramec (post-Waverly) of the Mississippian. This epoch, during which the Boone was uplifted above and again lowered below sea level was a time of widespread diastrophism throughout America with marked igneous intrusions in the Northeast. Igneous activity, probably of this epoch, though correlation is not definite, affected the basal Stanley of the Ouachita Mountains of southeastern Oklahoma.

Establishing the age of the chert of the first silicification within definite limits, is of great importance in determining its probable origin. The chert, though secondary, is practically as old as the Boone and hence has been affected by essentially the same amount of subsequent deformation. The enormous amount of chert and its short period of origin, although probably formed very near or at normal groundwater temperature during uplifting of the Boone is believed to be better explained by the hydrothermal theory, a process relatively short in its duration, than by a theory involving only uniformitarian processes, such as the infiltration of silica by groundwater from overlying strata through weathering. Furthermore, in this region, there appears to be no evidence that any formation was deposited upon or subsequently eroded from the Boone from which the silica could have been derived within the interval of its origin between Boone and Mayes time.

According to my view, therefore, the silicification of both periods has a similar origin in underlying magma. The difference in the mineral composition of the two types of chert, the first mainly purely siliceous, the second siliceous, calcic, magnesic, and ore-bearing is considered as due to unlike magmatic derivation, a characteristic feature of hydrothermal solutions. The difference in texture, the first fine grained, chalcedonic and formed near the surface, the second coarser grained and formed far below the surface, may reasonably be attributed to the unlike physical conditions affecting precipitation and crystallization, under which they were formed, involving differences in temperature and pressure, depth below surface, proximity of the magma, combined with the unlike chemical composition of the solutions.

During and after the second period of silicification apparently developed under deeper seated condition than the first and associated with dolomitization and ore deposition, there was extensive erosion. This erosion period extended through the Mesozoic and the Tertiary to the present time, and finally resulted in the removal of much of the overlying strata. Along the eastern border of the district where erosion has completely removed the Cherokee, Mayes and part of the Boone, the ground water-level has been lowered to the ore deposits, the primary zinc sulphide ore has been subjected to weathering by surface ground waters, and such secondary minerals as silicate and carbonate of zinc have been formed.

PROSPECTING

In further developing known ore-bodies or in finding new ones drilling operations are confined to the generally recognized limits in distribution of the ore to the upper half of the Boone. The importance of the trend of fracturing has also become generally recognized in exploration and mining.

However, in many drilling operations the upper half of the Boone is not always thoroughly drilled out, the drilling being stopped before reaching the middle portion of the formation. This is largely due to the fact that the thickness of the Mayes limestone and Cherokee shale is not always fully considered in determining the limits in depth of drilling below the sub-shale surface. Especially is this true in the exploration of the Boone in the area of the deep "shale trough," the Miami syncline.

The sub-shale maps of Siebenthal and of Ageton, previously referred to, are valuable in showing the thickness of the formations down to the limestone and the uneven underlying surface of the latter. However, the uneven sub-shale surface is apparently largely due to such variable sub-surface conditions as warping of the strata combined with the variable thickness of the sandstone and shale of the Mayes formation. In interpreting the sub-shale maps these variable conditions should be taken into consideration.

The practice of shallow drilling below the shale in the bottom of the trough is apparently based, in large part at least, upon the prevalent view, believed to be erroneous by the writer, that the trough is due to underground solution and thus resulting in the removal of the upper part of the Boone formation.

If the trough is a synclinal fold, as described by the writer (p. 32) the same thickness of Boone underlies the deep shale in the trough as elsewhere under the shale, and, therefore, if the trough is to be explored at all its exploration should reach to much the same depth below the top of the Boone as elsewhere in the district. The chances for finding ore deposits in the upper part of the Boone including also the overlying Mayes in the synclinal trough are at least as good as anywhere else in the district.

For example, where the Cherokee shale in the trough has a thickness of 200 feet, there may be, in addition, twenty to fifty feet of Mayes formation underlying the shale, and if the middle portion of the Boone is to be reached, the total depth of drilling should reach 450 to 500 feet below the surface. This condition is known to be approximated on the Scammon Hill lease, in the syncline, where ore was encountered in drilling at 450 to 500 feet. Likewise where the shale is 300 feet thick the drilling should reach 550 to 600 feet in depth.

This suggestion as to the advisability of deeper drilling under the deep shale is based upon the synclinal nature of the trough, as already explained, and as illustrated in figure 6, showing the ore-bearing horizon in the upper half of the Boone to have been carried downward beneath the deep shale in the axis of the synclinal fold.

Since the ore and associated gangue minerals including the abundant chert, were precipitated from the same mineral-bearing solutions, areas of abundant silicification are usually associated with ore deposits. The distribution of abundant chert with ore has been recognized and used to a certain extent as a favorable guide in exploration. (See silicification map of Brewster mine, figure 8).

However, two periods of silicification affected the Boone formation and only one, the later, was associated with ore deposition. Even in the later period the amount of ore deposited is relatively small as compared with that of the jasperoid. The ore and jasperoid chert of the second period of silicification are more or less masked and confused with the abundant chert of the first silicification. Where there is relatively little silicification of the limestone, very little or no ore is likely to be found. Also where there is abundant silicification, especially of the first period, no ore is likely to be found. Areas of low silicification, therefore, should be avoided, but areas of high silicification may or may not contain ore, being dependent upon the age of the silicification involved.

The explanation offered for the sharply folded portion of the Miami syncline in the central part of the Picher area as due to a dike intrusion, carries the implication that other sharply folded sections of the syncline may have a similar origin and hence are worthy of exploration. The syncline in the vicinity west of Afton (see map Plate I) is sharply folded, and this locality may deserve some prospecting. However, the Seneca syncline, south of Seneca, has already been prospected to a considerable extent and apparently only small ore-bodies have been found. The sharp synclinal folding near Afton with respect to ore deposits may prove to be like that at Seneca rather than that at Picher. That some ore is found in the syncline at Seneca and much ore in the syncline at Picher is very significant, and this association of close folding and faulting with the ore may very well be utilized as a guide in exploration.

The magmatic theory, offered by the author as the most plausible explanation of the origin of the ore, may suggest to some that ore should be found at greater depth, say down to 1,000 feet or more in the district. Such a suggestion or belief, however, is fallacious, for the hydrothermal theory of origin, as described, implies that the ore would be confined to a zone some

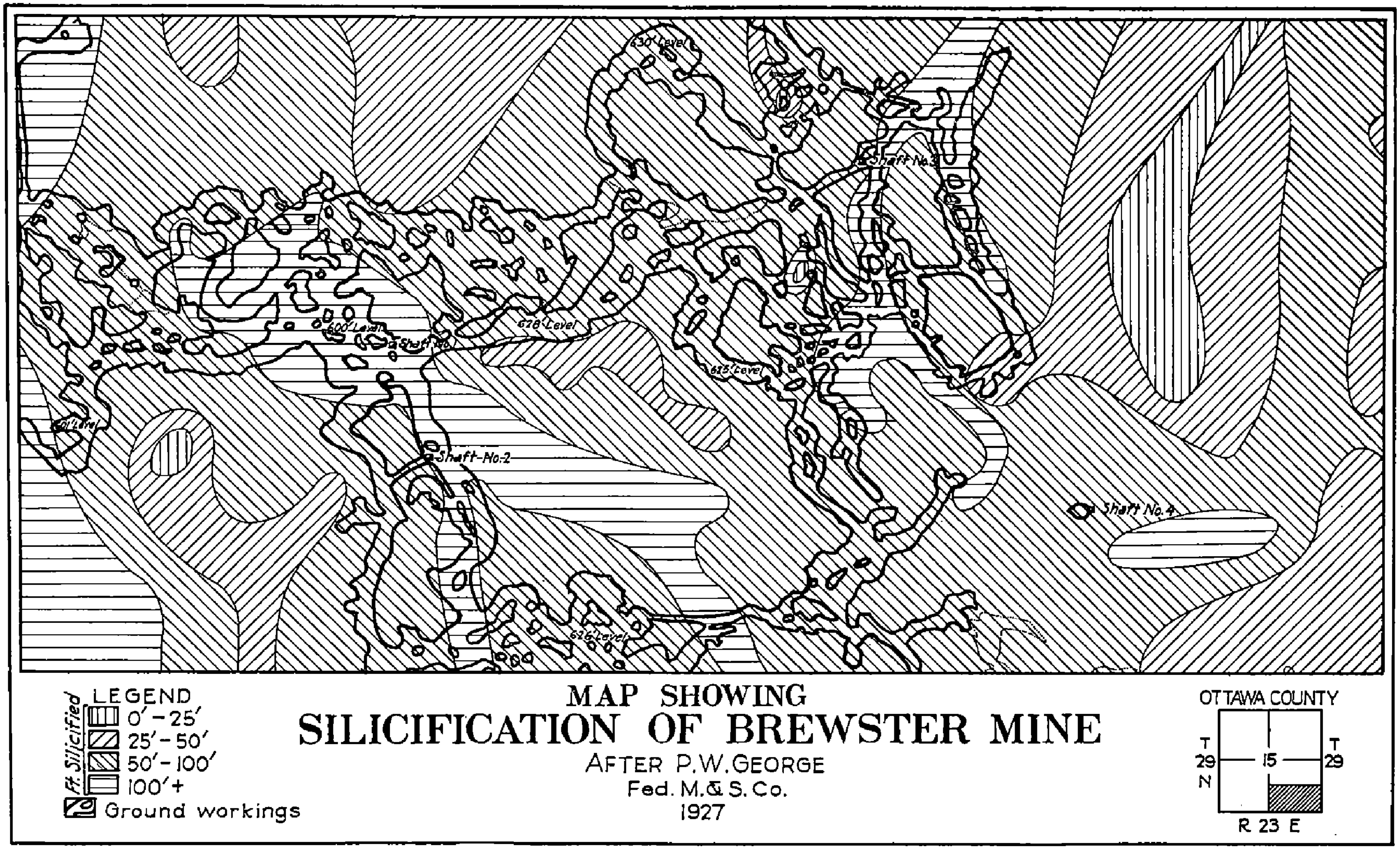


FIGURE 8. The map shows great variation in silicification (chert) and that the ore is in areas of much chert. The thickness of Boone formation drilled is 150 to 200 feet and "Ft. Silicified" is the amount of chert estimated in drill samples.

distance above the magma where pressure and temperature conditions were favorable for crystallization of the ore minerals. Below this zone, which has always been fairly well defined by exploration in the Tri-State mining district, conditions would not be favorable for ore deposition, hence no deeper drilling than through the upper part of the Boone, as generally practiced, is advisable.

If the very thick shales of the Cherokee and underlying Mayes formations have been a factor in determining the location of the underlying ore-bearing zone in the Miami-Picher district, by preventing the upward spread of mineralized solutions, a similar shale formation where of sufficient thickness may have played a similar rôle in some outlying regions. The Chattanooga shale in the mining district is usually either absent or only five or ten feet thick and is apparently an unimportant factor. In southern Ottawa County, however, and farther south, the Chattanooga is usually from 20 to 40 feet thick and where it is associated with other conditions favorable to ore deposition, such as an adequate source of ore-bearing solutions, it may be a factor in the distribution of possibly occurring underlying ore deposits. It may be suggested that if such sharply folded and faulted structural features as the Miami and the Seneca synclines are ever explored such exploration should extend into the formations below the Chattanooga shale where the latter is an important underlying formation.

In discussing the prospecting for ore, some reference should be made to the possible use of geophysical methods* in locating, not necessarily ore-bodies within the proven field, but certain underlying rocks, such as intrusives. The intrusive may have determined the occurrence of adjacent areas or belts of much deformation, such as folding, fracturing and faulting favorable for ore deposits as illustrated by the intrusive granite adjacent to the Miami syncline in the Picher district. The Miami-Picher district with its continuation into Kansas, as now limited by mining operations, may be the center of a larger field extending under the Pennsylvanian shale to the westward. Geophysical methods may serve as a useful method of exploring for igneous rocks under the deep shale.

*In the summer of 1931 a magnetometer survey was made of the Tri-State region by the Missouri Geological Survey through cooperation with the mining companies. See report of the Mo. Geol. Survey, Rolla, Mo. and the Tri-State Producers Association, Miami, Okla.

CHAPTER NOTES

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MINING METHODS*

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LEASING SYSTEM

LEAD and zinc concentrates are almost invariably produced and sold under the leasing and royalty system, and only a few producers have acquired fee title to mineralized tracts. Leases are usually taken for a period of ten years, though in recent years the clause "For ten years and as long thereafter as lead and zinc minerals are found (or produced) in paying quantities" has found favor.

The prevailing royalty rate is ten per cent of the sale price of both lead and zinc concentrates. Leases made before development may carry a rate as low as five per cent, and tracts known to contain ore may command royalties of 15 per cent or more. A sliding scale of royalty based on the market price is occasionally specified but is not generally favored.

The size of the leased tracts ranges from twenty to two hundred acres or more, but the forty-acre tract is the standard producing unit. The standard lease contract stipulates that a concentrating plant shall be operated on the leased tract and prohibits the removal of ores for concentrating elsewhere. There is now a marked tendency toward consolidation of leased tracts for centralized milling, and many such consolidations have been effected in the past two or three years, with the lessor's consent. Before the large mill with its lower costs and increased efficiency came into general use, the practice was for the first lessee to make subleases on part or all of his holdings at an increased rate of royalty. This resulted in the pyramiding of royalties to a point where profitable operation became impossible. Subleases are now made at a royalty increase of about 2.5 per cent, and many first leases place a limit on the total amount of royalty that may be exacted.

An interesting phase of mineral leasing in the Tri-State district has developed from the presence of 7,000 acres of mineralized restricted Indian land in the major producing area lying between Baxter Springs, Kansas, and Commerce, Oklahoma. This area of northeastern Oklahoma is part of the Quapaw Indian Reservation, from which is produced more than two-thirds of the Tri-State district's output of lead and zinc. Before the dis-

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covery of lead and zinc ores in this area the reservation was allotted to the Indians, each allottee receiving two hundred and forty acres. Lands belonging to incompetent allottees or heirs are administered by the Interior Department, and the Indian owners of such lands are wards of the Government. Their lands are leased under congressional authority in accordance with regulations promulgated by the Secretary of the Interior. The office of Indian Affairs and the United States Geological Survey, through a co-operative agreement, jointly supervise the leasing, prospecting, mining, and milling operations, the sale of concentrates, and the collection of Indian royalties. Most of the departmental leases carry a royalty rate of 10 per cent with the privilege of subleasing at not to exceed 12.5 per cent. They run for a term of ten years and for such additional period as lead and zinc minerals may be found in paying quantities, but in no event beyond March 2, 1946, the end of the present restricted period fixed by Congress.

With the co-operation of governmental agencies responsible for the administration of the departmental leases, operators of mines on restricted lands have pioneered several notable achievements in mining and milling which have been of benefit not only to the land owners but to the industry as well.

PROSPECTING

Surface prospecting. The northeastern Oklahoma zinc and lead ore producing area is rolling grass-covered prairie land, with some low hills and few surface exposures of the country rock. See Plate* IX, A. Churn drills are almost exclusively used in prospecting from the surface, as the presence of many openings and broken formations of limestone and flint preclude the use of diamond drills.

Churn-drill rigs are of the tractor type operated by gasoline motors. The bit is six and one-fourth inch and, with twenty-six foot stem and jars, weighs about one ton. Drilling may be divided into two classes—wildcat drilling in an unexplored area, and development drilling or drilling done to extend known reserves of ore. Common practice in prospecting an unexplored tract is to drill several lines of holes at intervals of about 300 feet and at right angles to the supposed trend of the ore bodies. Samples of the cuttings from each five-foot run below the Cherokee shale are collected and piled on the ground, where each sample is tagged for depth. The degree of silicification and other characteristics of the mineralized bed, as well as the most favorable area for further drilling, are determined from these samples. When ore is encountered, two and one-half foot runs are made and the cuttings sampled and assayed.

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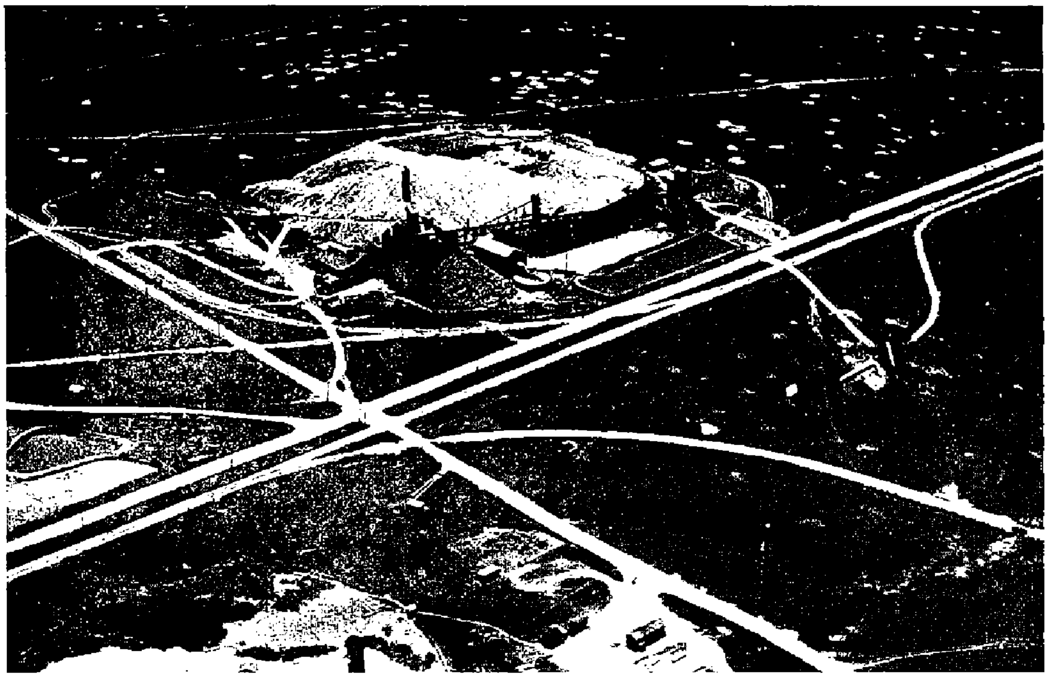
*The illustrations used in this chapter were kindly loaned by the Tri-State Ore Producers Association.

PLATE IX



A. Typical mining property near Picher

B. Shovelling crude ore into buckets

Logs of holes are kept by the drillers, and the drill superintendent or geologist makes his record from the sample piles. Drillers classify ore as "shines," "goodshines," "fair lead," "good jack" (sphalerite), etc. Depth of shale and marker formations, open ground, water flow, and other data of interest are noted on the driller's log.

More holes are required to delimit the ore bodies where the ore occurs in "runs" than where the ore covers a wide area and is of the "sheet ground" type. Under the first condition 100 or more test holes may be drilled on a forty-acre tract; under the second condition ten or fifteen holes may prove up a "mill site." When ore is found in a test hole, additional holes are drilled around it to determine the strike of the ore body.

The frequently observed occurrence of ore bodies lying adjacent to shale basins has led to what is locally termed "shale drilling." Drilling of this type locates the contact between the Cherokee shale (or the underlying Mayes shale) and the Boone formation (or the overlying Mayes limestone) by lines of holes drilled on 200-foot or 400-foot centers. A contour map showing the base of the shale is made from the data obtained, and the area adjacent to the deep shale is prospected by deep drilling. It is said that by this method a considerable area can be classified at relatively small cost.

Churn drilling is done under contract at a cost of seventy-five cents to $1.50 a foot, the cost depending upon the location and depth of holes and the nature of the formations penetrated. Shale drilling costs about fifty cents a foot. The holes are located with reference to land lines, and surface elevations are determined by survey. When the drill holes are mapped symbols are used to indicate the type and assay value of the ore encountered. Prospect holes, following the westerly dip of the mineralized beds, range in depth from 100 feet in the eastern part of the field to 450 feet in the western extension.

Underground prospecting. Underground prospecting is usually carried on in producing mines or mines that have depleted reserves. However, in some places where the ore bodies occur in narrow runs or small disconnected pockets, prospecting by sinking winzes and driving crosscuts, drifts, and raises is more economical than drilling from the surface. These methods are sometimes supplemented by drilling in the floor of open stopes with specially constructed churn drills operated by compressed air. These drills, which require only 18 feet of head room, are useful for deeper prospecting from mine openings where the surface above is covered with tailings or occupied by buildings. Drilling costs for the underground churn drill range from $2 to $2.50 a foot for holes as much as sixty feet deep.

For prospecting stope walls, a heavy hammer drill using jointed steel has been used to penetrate 150 feet or more. The holes are drilled with sufficient rise to permit the cuttings to be washed out for sampling. This method has been effective in developing parallel runs of ore. The cost is \$1.50 to \$2 a foot. The floor or back of stopes and drifts is sometimes prospected with vertical test holes drilled with Leyner type or jackhammer drills. The cuttings are sampled or the holes blasted when conditions justify such action.

In new developments, where churn-drilling results are not always conclusive, it is sometimes advisable to sink a shaft and drift out to areas where doubt exists as to the size and grade of ore bodies before mill construction is commenced. Shaft sinking, drifting, and raising methods are described under the heading "Development system."

ESTIMATION OF TONNAGE AND VALUE

The failure of a mining enterprise to return the capital invested in it can usually be attributed to such factors as market conditions as they affect the value of the product, excessive costs due to unfavorable mining conditions, incompetent management, and overvaluation based on insufficient prospecting and development. It is the last-named factor with which we are concerned in this chapter.

In the northeastern Oklahoma zinc and lead mining district it is usually possible to determine within a satisfactory limit the tonnage and grade of ore bodies by churn drilling. The value of a prospective mine is based upon the tonnage of ore blocked out by the drill and the assay content of the cuttings. The area of each ore body in square feet times the average height of ore face as shown by the drill-hole log gives the content in cubic feet, which is reduced to ore tons. A factor of 12.5 cubic feet to the ton being used for ore in place, the ore tons times the weighted average percentage of ZnS and PbS for the group of holes gives the gross tonnage of zinc and lead concentrates. Multiplying the concentrate tonnage by an assumed market value for the two concentrates, estimated for the productive life of the ore body, gives the gross value. From the gross value are deducted the mining and milling expenses and royalty to determine the net profit or value of the mine. Experience has shown that an ore body that is under water at the time of drilling mills out about 10 per cent better than the estimate based on the drilling, because a portion of the fine ore floats away while the hard gangue minerals are being broken up by the drill.

In calculating tonnage and value allowances are sometimes made for mill recovery, usually estimated at 85 per cent for zinc concentrates and 90 per cent for lead concentrates. If the ore body is sufficiently wide to require pillars, a deduction of about 10 per cent is made from the estimated ore tonnage.

DEVELOPMENT SYSTEM

Shafts. After the ore body is delimited by drilling, a shaft is sunk to the bottom of the ore or deeper. The depth of shafts ranges from about 100 feet in the eastern part of the Oklahoma field to about 400 feet in the western part. As the ore deposits lie at comparatively shallow depths, the ore bodies are developed from vertical shafts, usually having but one compartment, though two or three compartments with ore pockets and skip installations have been used where the ore reserves in the vicinity of the shaft appeared to justify the more costly equipment.

Early in the life of the enterprise an auxiliary shaft or field shaft is sunk about 300 feet from the first shaft, which is usually the mill shaft. The two shafts are then connected by a drift, which aids ventilation and overcomes the difficulties encountered in carrying on operations in a one-shaft mine.

Shafts five by seven feet or six by six feet in cross section are the standard sizes for the district. Most shafts are sunk five to twelve feet below the level of the ore bodies in order to provide a drainage sump. Over the sump a platform is constructed for handling the ore buckets. From the collar down to a point below the shale the shaft is close-cribbed with two by six inch pine timbers. Lagging and filling in behind the cribbing is essential, as the shale slacks and the cribbing gets out of line unless it is held securely in place. No cribbing is necessary below the first shale unless deeper shale or broken strata are encountered. In that event "jump" cribbing resting on six by six inch bearing timbers set in hitches cut in the solid rock is installed. Recent practice is to put in continuous cribbing to guard against the possibility of the bucket hanging up or overturning in the shaft, as no guides or crossheads are employed, and the bucket swings free in the shaft.

No ladders are used in the shafts. Men are raised and lowered in buckets, and machinery and supplies are handled either in buckets or with the cable. Air lines, water columns, and conduits are clamped to one corner of the shaft if a suitable drill hole is not available in the vicinity.

When strong flows of water are encountered, pump seats are cut as required. At the bottom of the ore level a station is cut, pillars being left to protect the shaft. As most shafts are sunk below the ore body, ore production can commence as soon as the shaft is completed. In areas not previously unwatered it is customary to sink through tight unbroken formations in the vicinity of the ore as disclosed by drilling and then to install at the ore level adequate pumping equipment to handle the flow of water that will be encountered in crosscutting to the ore body. To take care of excessive flows, the crosscut may be bulkheaded with a door and gate valves installed, by which the initial flow is kept within the capacity of the pumps until the head is sufficiently reduced to resume crosscutting.

Labor and dynamite for a five by seven foot shaft may be contracted for at $8 a foot in the shale and $14 a foot in the hard rock where no water is encountered. The company furnishes drilling equipment, air, and supplies other than dynamite. The cost of a 300-foot shaft will be about $5,000.

Pull drifts. Pull drifts or crosscuts are driven to connect the shaft with the ore body or to connect ore bodies with one another. A crosscut connecting two ore bodies may be inclined if the bottom of the ore lies above or below the main haulage level. Pull drifts are driven seven by nine feet in cross section, and the work is usually done on contract. The contractor furnishes the labor and the powder, and the company supplies the equipment, as in shaft sinking. The contract price is about $6 a foot, and the total cost ranges from $10 to $12 a foot.

Raises. Raises are driven only occasionally and are generally inclined at an angle of about 45° so that they can be used as ore chutes. They are cut six by six feet in cross section and connect isolated ore bodies found above the main level. When the upper ore body has been opened up, the raise is converted into an ore chute by the installation of a gate for loading. If no other means of entrance to the upper level is available, the raise is divided for a manway, or a second raise is driven. The latter plan is advantageous for ventilation. The cost of driving raises is practically the same as for pull drifts.

MINING

Stoping. Mining is done by the room and pillar method, which consists of the cutting of open stopes with irregularly spaced pillars. The ore body having been cut by shaft or crosscut, the problem presented is how to mine the better grade of ore and leave only the lowest grade for pillars to support the roof or "back." The structure and formations in the back of the stope and the width and height of the ore body control the size and spacing of the pillars. If the shaft has been completed in the ore body, stopes are opened up radially for the full height of the ore, with pillars twenty to fifty feet in diameter and properly spaced to support the back, usually thirty to one hundred feet apart. The minimum height of the working face is about six feet, the average about twenty-five feet, and the maximum well over 100 feet. About fifteen per cent of the ore body is left for pillars. Later, when the reserves are depleted, as much as fifty per cent of the tonnage left in pillars may be recovered by slabbing operations or by the complete removal of certain pillars where this can be accomplished without causing the back to cave. If the character of the rock permits, the back is arched between walls or pillars.

Where the ore body is over ten feet in height, a type of underhand stoping is employed as shown in figure 9. A machine drill is clamped to a

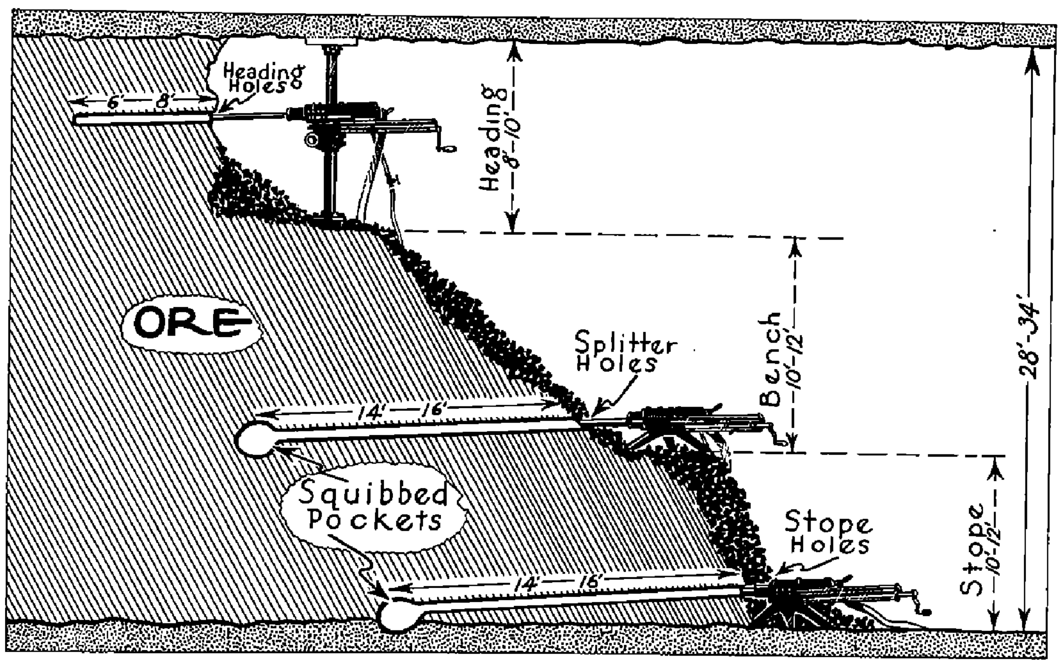


FIGURE 9. Sketch showing general arrangement of drill holes in ore-body.

eight to ten foot column set up near the "back" of the stope in order to advance the upper face or heading, a bench being left beneath it ten or twenty feet or more high above the floor of the stope. After the heading or breast has been advanced twenty or thirty feet, the bench is drilled and blasted, and the process is repeated on subsequent shifts. A row of stope holes is drilled with their collars at the level of the stope floor and pointed slightly downward. These holes are blasted, leaving a vertical face seven to ten feet high. The broken ore is only partly loaded out, sufficient broken material being left against the face to set up a tripod for drilling the splitter holes. One or more rows of splitter holes, the number depending on the height of the lower face, are drilled to a depth of about eighteen feet in the face below the floor of the heading and above the floor of the stope. These holes are pointed slightly upward. Where more than one row of splitter holes is required, the lower row is drilled and blasted first. Splitter and stope holes are squibbed or chambered three or four times before blasting.

Drilling. The drills used are operated by compressed air at a pressure of seventy to ninety pounds and are of the water Leyner type, using 1.25-inch hollow round steel. (See Plate X A.) A few one-man machines are used, but the heavier two-man type is generally favored. The starter steels are three feet long, and the steel lengths increase two feet for each succeeding change. Steels as long as eleven feet are used for heading rounds, and steels as long as twenty-one feet for stope holes. The bit is the standard cross bit with 18° taper. The starter gage is 2.75-inch and the gage on each succeeding change is dropped one-fourth inch to a depth of eleven feet. The next changes are dropped one-eighth inch, and the last steel bottoms the holes at 1.5-inch gage.

Jackhammer drills are used for drilling boulders and for trimming. They use one-inch hollow hexagon steel cut in one-foot lengths up to five feet. Starters have a two-inch gage and succeeding changes drop one-eighth inch; the last change bottoms the hole at 1.5-inch gage. The steel consumption is about 0.073 pound to the ton of the ore mined. Drilling is done by day labor and by the bonus and contract system.

Steel is usually sharpened by mechanical sharpeners located at the mine and sometimes placed underground. Where several mines are operated by one company, it has been found advantageous to employ a centrally located steel-sharpening plant to which all steel is hauled by truck. Air compressors are located at the mine unless several units are being operated by the same company, when a central compressor plant is sometimes employed.

Blasting. Blasting is done at the end of the shift, usually by the drill man, though occasionally a powder man is assigned to this duty. (See Plate X B.) The heading or breast holes are shot without squibbing, but split and stope holes are chambered before blasting. The heading rounds are loaded with three-fourths of a box of ammonia dynamite, twelve to fourteen sticks to the hole. A six-hole round is used in hard, tight formations. Holes are stemmed with clay cartridges, and an average heading round breaks about fifty tons of ore. After the split and stope holes have been squibbed three or four times with fifteen to forty-five sticks of dynamite and washed out, the breaking charge of two to four boxes of dynamite is loaded and stemmed. (See fig. B.) Primer shots are usually placed in a safety shot tube

PLATE X

A. Drilling ore in the mine stope.

B. Charging drill holes with sticks of dynamite made for the purpose. The average splitter hole will break about 250 tons of ore. Dynamite consumption is around a pound to the ton.

Dynamite of various grades is used in the district, but the preference is for the bulkier types. As most of it is manufactured locally, mines seldom stock more than one week's requirements. Small magazines are sometimes built at the mine, and only the day's requirements are taken into the mine.

A man known as the "roof trimmer" inspects all parts of the mine, particularly after blasting, and bars down all loose material from the back and walls. Where the back can not be reached with a bar, extension ladders are employed, sometimes with rope guys. Working faces are also examined before machine men and shovelers begin work.

Loading. Although mechanical loaders, shovels, and drags have been used in the district, it is generally believed that, except during periods of labor shortage and high wages, ore can be loaded at the lowest cost by hand shoveling into buckets (called cans) or cars, as shown in Plate IX B. Sheet iron or wood planks are laid before blasting, and in shoveling from this prepared surface No. 2 scoops are used. Most of the ore breaks into pieces small enough for shoveling, but there are many large boulders, which are either broken up with a sledge or blasted at the end of the shaft. Shoveling is done by contract, the rate paid being based upon the size of the bucket or car, which holds from 1,000 to 1,650 pounds of ore. In each car or bucket the shoveler sticks a wooden paddle carrying his number. When the container arrives at the hoisting station, the "tub hooker" or cager retrieves the paddle and credits the shoveler on a tally board. From this board the shift boss takes the totals for each shoveler, and the grand total is checked against the tally of the "hoistman" or hoist operator. When buckets are used, they are set on four-wheel trucks called cars which are equipped with rings and hooks for coupling into trains.

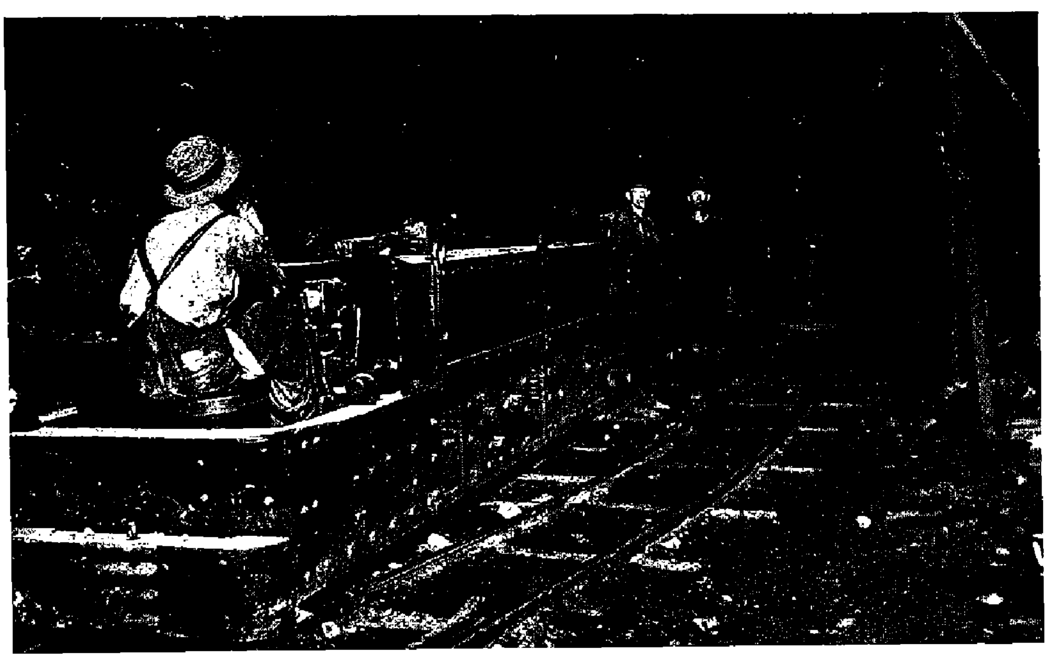
A good shoveler will load seventy-five to ninety buckets to the shift. He cleans up about five feet on each side of his bucket, and from three to six shovelers work in the average stope. The cost for each ton loaded ranges from about fifteen to twenty cents.

Haulage. After the buckets or cars are loaded they are trammed by the shovelers to a "lay-by" or siding, where they are made into trains and hauled to the shaft by mules as shown in plate XI A. The "lay-by" is kept as near the shovelers as conditions permit. On long hauls electric haulage motors of the trolley or storage battery type are used in some mines as shown in Plate XI B. A mule will pull five or six cars; the motor handles fifteen to twenty. Buckets are stopped within eight or ten feet of the hoisting station on the shaft "lay-by." Continuous rope haulageways operated by electric motors have been used successfully in some mines where conditions make installation of this type feasible. Current practice is to use twenty-five-pound to thirty-five-pound rail on motor lines with eighteen to twenty-four-inch gage. Other haulage uses eight to twelve pound rails with the gage ranging from twelve to twenty-four inches. Rolling stock equipped with roller bearings is coming into general use. On inclined haulageways cars are handled by small hoists driven by compressed air or electricity. If the incline is steep, only one car to the trip can be handled.

Hoisting. One of the most interesting phases of mining operations in the Oklahoma lead and zinc mining district is the hoisting practice. The use of skips or cars and cages for hoisting is exceptional, and practically all operating shafts are equipped with the unique bucket-hoisting plant developed in this district. The ore is hoisted with a single-drum hoisting engine mounted forty to sixty feet above the collar of the shaft on the platform of the "derrick" or head frame. This platform is so placed that the hoist operator can look down the well hole and watch the progress of the free-swinging bucket attached to the cable. The hoisting procedure is as follows: the loaded ore bucket, sitting on a truck, is pushed from the station siding to the "dog house," a small wooden platform which receives the returning empty bucket. This platform is so placed that when the truck with the loaded bucket touches its side, the bucket is in the exact center of the shaft. When the returning empty bucket comes down the shaft, the hoist brake is applied so as to slow its progress sufficiently for the "hooker" or cager to swing the bucket over the loaded can, where he guides the remainder of its descent to the platform. At the instant the cable has slacked the snap hook is released from the bale of the empty bucket and snapped on the raised bale of the loaded bucket. The operator now lets in the clutch and hoists at the full speed. When the bottom of the bucket reaches the level of the hoist operator's eyes, he stops it and closes a counterbalanced door immediately beneath the suspended bucket. This door serves as a chute and is inclined toward the "hopper" or ore bin. The bucket is dumped onto a grizzly above the bin, and the hoist operator tips it by slackening the hoisting cable after he has hooked the ring fastened to the bottom of the bucket to a suspended tail hook. After being dumped the bucket is returned to its normal position, the door raised, and the bucket lowered to the underground hoisting platform. No signals are used in hoisting ore, and the cycle of operations described takes place within thirty to forty seconds. A safety signal known as the "skidoo-bell" or light is operated by the hoistman in the event a rock is dislodged from the shaft wall or falls from the bucket. When this signal is given, men working near the loading platform

PLATE XI

A. Haulage of ore in the mine by mules.



B. Haulage of ore in the mine by electric motor.

leave the vicinity. A signal bell operated by a wire controls the handling of men and materials in the shaft. Some shafts are also equipped with speaking tubes.

About 95 per cent of the hoists in use are driven by electricity and generally powered with 112-horse-power twenty-five-cycle 220-volt motors. The rope speed ranges from 1,600 to 2,000 feet a minute. There are a few first-motion hoists in use, mostly on shaft-sinking jobs where compressed air or stem is used.

The hoisting operation described is known as the center-pull method. A variation of this system is to place the truck for the empty bucket in the center of the shaft and stop the truck with the loaded bucket to one side of it. It is necessary to stop and center the loaded bucket after it leaves the truck.

The hoisting cable is of five-eighths-inch, seven by eighteen non-spin type and will handle about 40,000 tons before scrapping. The shive wheels are usually thirty-six inches in diameter. Bin capacities range from 100 to 500 tons and average about 300 tons.

The efficiency of the bucket hoist may be judged by the capacity of the installation, which handles 800 to 900 buckets, or about 600 tons, to the eight-hour shift from a depth of about 300 feet.

Formerly head frames and ore bins were built exclusively of wood, but recently all-steel construction has been favored. The initial cost of the steel structure is higher, but maintenance costs are lower and the structure is fireproof. It has been found entirely feasible to skid both types to new locations when the ore reserves become depleted at the original site. The new type of steel head frame measures seventy-four feet from the collar of the shaft to the roof of the hoist house.

Surface tramways. Hoisting is usually being done at one or more field shafts, and the ore must be trammed to the mill over surface tramways. In the usual installation the ore is drawn from the field-shaft ore bins into three-ton end-dump tram cars. These cars, eight to twelve of which make up a train, are hauled by gasoline or steam locomotives to the mill. On arriving at the mill the cars are pulled upon an incline one at a time and dumped into the mill bin. An electrical hoist equipped with a twenty-five or thirty-five-horse power motor is used for this work. The pitch of the incline is about 25° from the horizontal.

In one of the latest tramway installations ten-ton steel cars equipped with automatic drop bottoms are used. These cars are loaded from cylindrical steel bins with center discharge, from which ten cars can be loaded in less than five minutes. A fourteen-ton gasoline locomotive furnishes the motive power, and the train dumps into an 800-ton subsurface bin. The cost of hauling does not exceed 1.7 cents a ton for the short hauls from the field shafts and the mill—all under one mile.

Pumping. Most of the mine workings are comparatively dry, and only the deepest mines have to pump to operate the lowest workings. This condition is due to the open character of the ore-bearing formations and to the fact that a large number of the mines are connected underground with neighboring properties. Where it is evident that the pumping by one company is partly draining the workings of other companies, it is not unusual for those benefited to share the pumping expense. A recent survey showed that forty-three stations in the Oklahoma-Kansas field were lifting an average of more than 9,000 gallons a minute over a twenty-four hour period.

The common practice is to drain the underground water to a sump, usually at the shaft, either by means of ditches along the drifts or by pumping. From this point the water is raised to the surface by electrically driven centrifugal or triplex pumps. In one mine (see description of Pioneer mine) a natural cave is utilized as a reservoir for temporary storage during the daily pumpage. In some mines strong acid water is encountered and special acid-resisting pumping equipment has been installed.

Ventilation. As most of the mines are equipped with two or more shafts and many of them are connected by drifts, natural air currents are developed which generally produce satisfactory ventilation. Where the air circulation is poor in working faces some distance from the mine openings, blowers are used. These may be installed near the shaft and connect with the working face by fabric or metal tubing, or they may be installed on the surface and supply fresh air through suitable drill holes.

Because of the relatively small quantity of timber used in these mines, the absorption of oxygen and the production of carbon dioxide by decaying timbers is an unimportant factor. However, the open ground in which much of the ore is found often contains considerable marcasite, and occasionally pockets of gas are found—mostly carbon dioxide and carbon monoxide developed as a by-product from the oxidation of the marcasite. Small amounts of methane have been detected in some caves when first opened.

Dust arising from underground operations because of the silicous character of the ore-bearing formations creates a considerable health hazard, which every effort is made to allay. Muck piles and haulageways are thoroughly wet down before shoveling and haulage operations are commenced, and wet drilling, even for collaring holes, is required.

Timbering—Many of the mines require no timber underground except in the shafts and for miscellaneous uses. The principal need for timber when used, is not to support the total weight of the overlying strata but to maintain the roof in place and prevent rock falls. The cracking or gradual breaking of posts gives warning that they are taking weight, and additional timbering is put in or the area is blocked off and the roof permitted to cave. In vital parts of the mine, such as near a shaft or main haulageway, rock-filled cribs are constructed when additional support appears necessary. In crosscutting, lenses of deep shale are occasionally encountered and tunnel sets with fore-poling are used to advantage. Where the opening is of greater height than the tunnel set, a square-set system is used, or the openings above the sets are blocked with short cribbing. Oak timbers are most commonly used, and they may be installed either milled or in the rough.

Supplies and labor. Most of the mining equipment and supplies used and all repairs are made in the district and are obtainable with minimum delay from nearby supply houses, shops, and foundries. Of the companies using electric power only one generates its own electricity. The others purchase power from a 150,000 horse power public-utility plant on the Spring River about fifteen miles northeast of Picher, Oklahoma.

The northeastern Oklahoma lead and zinc mining district is fortunate in having an exceptionally loyal and efficient class of labor. There are no unions, and the men are of American parentage and as a class are intelligent, resourceful, and ambitious.

Many companies maintain full-time safety engineers who make regular and systematic examinations of the mine workings and equipment. An excellent spirit of co-operation exists between the men and the safety engineers, and it is not unusual for a mine to work 10,000 or more man-shifts without an accident involving lost time. The general safety work is supervised by the safety director of the local operators' association, and through a co-operative agreement all applicants for work are given a thorough physical examination at a clinic operated by the United States Bureau of Mines.

COSTS*

Cost accounting in the Tri-State district is the result of custom and differs from the methods of other mining districts. Owing to the use of the leasing system, the method of selling zinc and lead concentrates fixes

*By Wade Kurtz, C. P. A., Joplin, and the Tri-State Zinc and Lead Ore Producers' Association.

TABLE XX. *Average Concentrate Ton Cost,* 1930

	ZINC AND LEAD OPERATING COST	PERCENTAGE OF TOTAL COST
Labor, all classes	$11.0130	33.01
Salaries	1.6655	4.99
Explosives	1.7688	5.30
Supplies and repairs	4.0028	12.00
Power and power fuel	3.0340	9.10
Liability insurance	.5922	1.78
Fire and tornado insurance	.4583	1.37
Taxes (exclusive of income tax)	.2960	.89
Exploration and development	.0835	.25
Miscellaneous	1.8972	5.69
Total mining and milling	24.8113	74.38

	ZINC	LEAD	ZINC AND LEAD	PERCENTAGE
Operating cost	$24.8113	$24.8113	$24.8113	74.38
Royalty	2.9774	6.0697	3.2394	9.71
Depreciation and depletion, or amortization of capital investment	5.3090	5.3090	5.3090	15.91
Total concentrate cost	33.0977	36.1900	33.3597	100.00

TABLE XXI. *Average Rock-Ton Cost,* 1930

	OPERATING COST	PERCENTAGE OF TOTAL COST
Labor, all classes	$0.6428	44.39
Salaries	.0972	6.71
Supplies and repairs	.2336	16.13
Explosives	.1032	7.13
Power and power fuel	.1771	12.23
Liability insurance	.0346	2.39
Fire and tornado insurance	.0267	1.84
Taxes (exclusive of income tax)	.0173	1.20
Exploration and development	.0049	0.34
Miscellaneous	.1107	7.64
Total mining and milling	1.4481	100.00

the concentrate ton as the producing unit and provides that royalties shall be paid on the basis of an agreed percentage of the selling price per ton.

When a mining company produces zinc and lead concentrates for its own smelter, there must be, to compute the royalty, a sale by the mine at the market price and a purchase by the smelter.

The district also uses the rock-ton cost, which is not a complete cost but merely the cost of mining and milling and is used for the purpose of measuring the mining and milling efficiency.

The concentrate-ton cost shown in Table XX is computed by dividing the total expenses by the total concentrates produced, and the rock-ton cost Table XXI is computed by dividing the mining and milling expenses by the total rock tons hoisted. Each cost is computed monthly and yearly. For the purpose of mine management an estimated rock-ton cost is computed daily or weekly.

These two costs are kept separately by the individual companies, and for several years the Tri-State Zinc and Lead Ore Producers' Association has been computing the consolidated average costs of the members of that

TABLE XXII. *Yearly average cost summaries*

	ROCK-TON	CONCENTRATE-TON		
		ZINC	LEAD	ZINC AND LEAD
1921	$1.6613	$25.7328	$31.0947	$26.9979
1922	1.7472	35.6013	39.7926	34.8767
1923	1.9225	40.1353	49.9611	41.4037
1924	1.9900	42.7355	52.5845	44.2186
1925	2.2065	46.4747	56.1310	47.7510
1926	2.0148	46.2871	54.9000	47.4302
1927	1.7306	41.4196	47.5365	42.3404
1928	1.6664	38.6556	43.6894	39.3988
1929	1.7120	42.8937	47.9693	43.7353
1930	1.4481	33.0977	36.1900	33.3597

TABLE XXIII. *Yearly Recoveries*
(Ratio of tonnage of concentrates to ore mined, in per cent)

YEAR	ZINC	LEAD	ZINC AND LEAD	YEAR	ZINC	LEAD	ZINC AND LEAD
1921	7.16	2.30	9.46	1926	4.96	0.83	5.79
1922	6.14	1.35	7.49	1927	4.75	.83	5.58
1923	5.76	.97	6.73	1928	4.95	.81	5.76
1924	5.28	.98	6.26	1929	4.37	.80	5.17
1925	5.67	.90	6.57	1930	4.99	.85	5.84

organization monthly and furnishing this information to them for comparison. Owing to the variations in accounting practices by the several companies, it is necessary to group these consolidated averages in a general classification of accounts.

The cost figures included herewith in Table XXII are consolidated averages representing about three-fourths of the production of the district. Some misunderstanding has occurred during recent years outside this district relative to these average costs. They are purely averages, not typical figures, and this means that many mines are either above or below these averages.

They can not, therefore, be used as a criterion as to what the Tri-State district can do in the way of production during periods of low prices, for often in such times only the higher-grade ores are mined in order to keep plants in operation.

The average recoveries shown in Table XXIII are computed by dividing the tonnage of zinc and lead concentrates produced by the rock tons hoisted. The recovery of a mine vitally affects the average cost of zinc and lead concentrates.

The cost figures of the individual mines are worked out more in detail than the average costs given herewith, but the Tri-State district has never gone into such refinements of cost accounting as are used by larger mines of longer life. The methods in use are practical for these short-lived mines.

Since the introduction, during recent years, of flotation and fine grinding, many old tailing piles have been re-treated. Costs under these operations necessarily exclude mining expense but may include royalty, depreciation, and depletion.

MILLING IN THE TRI-STATE DISTRICT

By CARL O. ANDERSON
Metallurgist, The Century Zinc Company

THE ores of the Tri-State District consist of fairly coarsely crystallized lead and zinc sulphides (galena and blende) in a flint gangue. Small amounts of pyrite, marcasite, calcite, dolomite and other minerals are usually present, but only occasionally do these constitute more than minor obstacles in milling.

INTRODUCTORY

In achieving the separation of the constituents of an ore into its component parts or into economically satisfactory products, use is made of some property of the associated minerals, a property in which they differ from one another in appreciable degree. Specific gravity is one of the principal properties on which separation is based, and, of course, is the one that underlies gravity concentration as exemplified by jigging and tabling. By gravity concentration, milling in the Tri-State District accomplishes the extraction of the great bulk of its economic minerals; flotation, although of much importance, is as yet purely a secondary process in the district.

Until the last decade jigging and tabling were practiced almost exclusively in the old Joplin district and in the newer Kansas-Oklahoma district (opened about 1915). The ores were regarded as free-milling; tests had indicated that usually the economic minerals were sufficiently liberated from the gangue at about thirty-five mesh, a size very suitable for tabling. However, not until 1925 did flotation really sweep the district, and since then much time and effort has been expended in weighing the feasibility of flotation replacing gravity concentration in part or in whole. The ores respond beautifully in most instances to treatment by flotation, but other factors have, and will continue to block the acceptance of flotation as a complete substitute for jigging and tabling. Flotation is an excellent auxiliary process and doubtless will grow in importance.

For at least two reasons gravity concentration will continue to be the principal tool of milling in this district; namely, hardness of the flint and the low value of the principal economic mineral, zinc blende. Flint is one of the hardest rocks to grind fine and of course this entails high costs. The total recoverable value from a ton of Tri-State crude ore as mined is never large, ranging from less than $1.50 per ton crude ore on a zinc concentrate market of $20.00 to $25.00 per ton (1931) to almost $3.00 per ton crude ore on a $40.00 market for zinc concentrates, the latter being generally accepted as a normal price. The market conditions cited represent an excellent example of how economic factors control ore dressing considerations.

PRODUCTION AND RECOVERY

To appreciate the magnitude of the amount of crude ore mined and of the proportionate tonnages of lead and zinc concentrates produced a close study of Table XXIV should be made. It presents a summary of the whole

TABLE XXIV. *Crude ore mined and concentrates produced in Tri-State mills, 1925 to July, 1931*

	1925	1926	1927	1928	1929	1930	1931[a]
Zinc conc. in tons	810,100	850,300	701,100	576,900	635,300	455,898	152,131
Zinc conc. in tailing in tons		No Rec.	54,700	57,000	62,200	71,017	24,020
Zinc conc. (in crude ore) in tons	810,100	850,300	646,400	519,900	573,100	384,881	128,111
Lead conc. (in crude ore) in tons	142,400	134,000	100,900	80,300	91,100	57,691	17,809
Total conc. in tons	952,500	985,300	747,300	600,200	664,200	442,572	145,920
Crude ore (in 1000 tons)	14,650	14,940	11,160	8,816	10,640	6,997	2,134
Concentration ratio	15.38:1	15.163:1	14.93.1	14.69:1	16.02:1	15.81:1	14.62:1
Zinc conc. recovery, per cent	5.53	5.70	5.80	5.90	5.39	5.50	6.00
Lead conc. recovery, per cent	0.97	0.90	0.90	0.91	0.85	0.83	0.83
Total conc. recovery, per cent	6.50	6.60	6.70	6.81	6.24	6.33	6.83

a. First six months.

district's operations for the last six and a half years. The data are completed from statistics prepared by the Tri-State Producers Association.

Zinc concentrate is usually sold on a 60 per cent zinc content basis but the tonnage above reported would have a tenor of 58 to 59 per cent zinc. Lead concentrate is usually sold on an 80 per cent lead content basis, but the recorded tonnage has a slightly lower tenor.

Production reached its peak in 1926. After that it slowly decreased until a sharp decline started about May, 1929. The general business depression explains the tonnage figures for 1930 and 1931, but it is very doubtful if the district will ever return to its 1926 production unless additional large ore reserves are developed in areas at present unknown. Intensive drilling in 1927, 1928 and 1929 in adjacent areas and in areas miles distant failed to develop ore bodies to replace those being depleted. The high rate of depletion of ore bodies may be pictured better when it is noted that the 1926 rate of operations "worked out" a forty-acre tract of mineral bearing ground every two weeks with more than 150 milling plants in operation.

The concentration ratio represents the number of tons of crude ore required to produce one ton of concentrate (tonnage of lead and zinc concentrates combined); this means that about fifteen to sixteen tons of crude ore are required to produce one ton of concentrate. The term, extraction, is seldom used in this district. The term, recovery, the reciprocal of the ratio of concentrates, is the commonly accepted expression. The zinc concentrate recovery has varied in the six and a half years tabulated from about 5.4 per cent to 6 per cent (meaning that 5.4 to 6 tons of zinc concentrates have been recovered per 100 tons of crude ore mined). The lead concentrate recovery has been somewhat under 1 per cent. For this period of six and a half years, 69,337,900 tons of crude ore have been mined and milled with a production of 3,912,792 tons of zinc concentrate (average recovery, 5.64 per cent) and 624,000 tons of lead concentrates (average recovery 0.90 per cent). It is evident that this is primarily a zinc district.

GENERAL MILLING PRACTICE

For economic operation cheap milling has always had to be done and must continue to be practiced. The ores mined years ago immediately surrounding the city of Joplin, Missouri were generally free milling. The mills were very simple and the Harz type of jig was the principal concentrating device. Occasionally one to three or four tables with or without some classifying device were used. The practice in these mills has been well described in the writings of Bruce and of Wright (see Bibliography).

When operations began in 1915 about Picher, Oklahoma and Baxter Springs, Kansas, most of the experienced operators from the old Joplin field, either moved mills from the old district or built new mills of the same design. The Kansas-Oklahoma ores were much richer than those in the Joplin area and contained a considerable percentage of zinc mineral not freed by the amount of crushing required for the jigs. Thus the old Joplin mill with its usual two or four jigs and occasional tables was relied on to perform a more difficult service. The inadequacy of the Joplin mill was soon realized as the tailing and slime losses were excessively high. Johnson and Heinz in their handbook *Milling Details and Milling Practice* issued in 1919, set forth that as a result of much testing, the average local mill was only sixty-three per cent efficient. The writer obtained much data in 1921 and 1922 from which it was evident that a number of mills did not extract in excess of fifty per cent of the zinc mineral. Thruout this discussion, unless specifically stated, the milling details relate only to recovery of zinc, the lead mineral being usually readily extracted in excess of ninety per cent and rarely presenting a difficult milling problem.

This district always has been a stronghold for the Harz type of jig and the district continues to be one of the very few places in the world where jigging is practiced extensively. Every mill has from two to seven jigs. Many kinds of jigs have come and gone but the Harz type alone has survived. The Bendelari jig has a number of admirable features and has gained some popularity in recent years.

Since 1915 tables have been adopted in all plants, the use of them having increased until about 1922, some mills treating less than thirty tons of crude ore per hour on about two dozen tables. For some years operators have made every effort to recover efficiently by tabling the mineral in the slime sizes, many contending that slime tables were so efficient that for the remaining slime values a flotation department was not justifiable economically. As interest in flotation began to grow (1924) the trend turned toward smaller table departments so that now no tables are employed in some plants.

A great variety of classifiers have been used but no one has dominated the field. However, much disagreement exists regarding the benefits of classification for tabling. At the present time much interest prevails concerning this question in some mills while at others none exists.

Flotation appeared in a crude way soon after the Picher district was developed but it received no impetus until about 1923 when the newer reagents, such as the Xanthates, the various sulfurized and thio compounds, etc., first came into use. Until this time flotation royalties to the Minerals Separation Co., Ltd., had been about $4.80 per ton of flotation zinc concentrate. The royalty had acted as a serious obstacle to adoption of flotation, but about this time it was reduced 50 per cent which with subsequent reductions has made the present cost a nominal charge. However, the first filter, the American disc type, for dewatering flotation concentrates was not installed until the latter part of 1924 and not until then did the flotation fever really seize the district. Previously the flotation size had been tabled not only to separate the lead and the zinc but also to produce marketable concentrates. Now it would be indeed difficult to find a milling plant making any appreciable zinc concentrate production without a flotation unit.

Ten years ago relatively small tonnages were treated in each plant. Twenty-five to thirty tons per hour was about the average. In 1922 tonnage per hour began to increase and by 1926 the average was close to forty tons per hour. The mills were not increased in size but the flowsheets were revamped. Coarser initial crushing accounted in most cases for the increased capacity. During the past three years the trend has been toward larger mills. Fifty tons capacity per hour is now common and a few mills have capacities of 100 tons or more per hour. The idea of central milling, that is milling the ores from a number of leases in one plant is growing in favor and is giving impetus to construction of larger concentrators. (In 1932 the Eagle-Picher Company began the construction of a large central milling plant north of Commerce.)

Regardless of changes during the past fifteen years the district now has jigging, tabling and flotation machines in its mills and probably will continue to have them for some time (except at plants where tables have been eliminated).

A flowsheet of the Bird Dog mill, Commerce Mining & Royalty Co., the largest mill in the district, as described by E. Isern[67] is shown in figure 10. This plant is modern and shows in its flowsheet, aside from a number of special features, much of the better practices in the district. This discussion, however, does not confine itself to the practice in any one plant but to the general practice. The Bird Dog flowsheet exemplifies the multitude of products and the numerous lines of flow, but in no greater degree than in plants handling only one-fourth of the tonnage; the Bird Dog plant treats up to 130 tons of crude ore per hour.

The operation of the Tri-State mills may be discussed from several standpoints. One basis of consideration is by the principal sections of the plant, namely, crushing and screening, jigging, tabling, and flotation; ball milling is an auxiliary feature and will be mentioned under the above headings. Another method of consideration concerns the extraction of the minerals, or the concentration of the ore constituents. Recovery of free coarse mineral either of lead or zinc, has been so well perfected that usually ore-dressing problems are regarded as revolving around chat, sand and slime together with their isolation and their treatment. The milling practice will be considered under the principal sections of the plant, including the ore dressing problems involved. (See figure 10 for mill practice.)

CRUSHING AND SCREENING

The crude ore is hoisted from the mine shaft in containers usually in "cans," buckets of about 1,200 pounds capacity, but at a few plants in skips of about 3,000 pounds capacity. From the hoisting container the crude ore is dumped into a hopper of wooden or steel construction of 150 to about

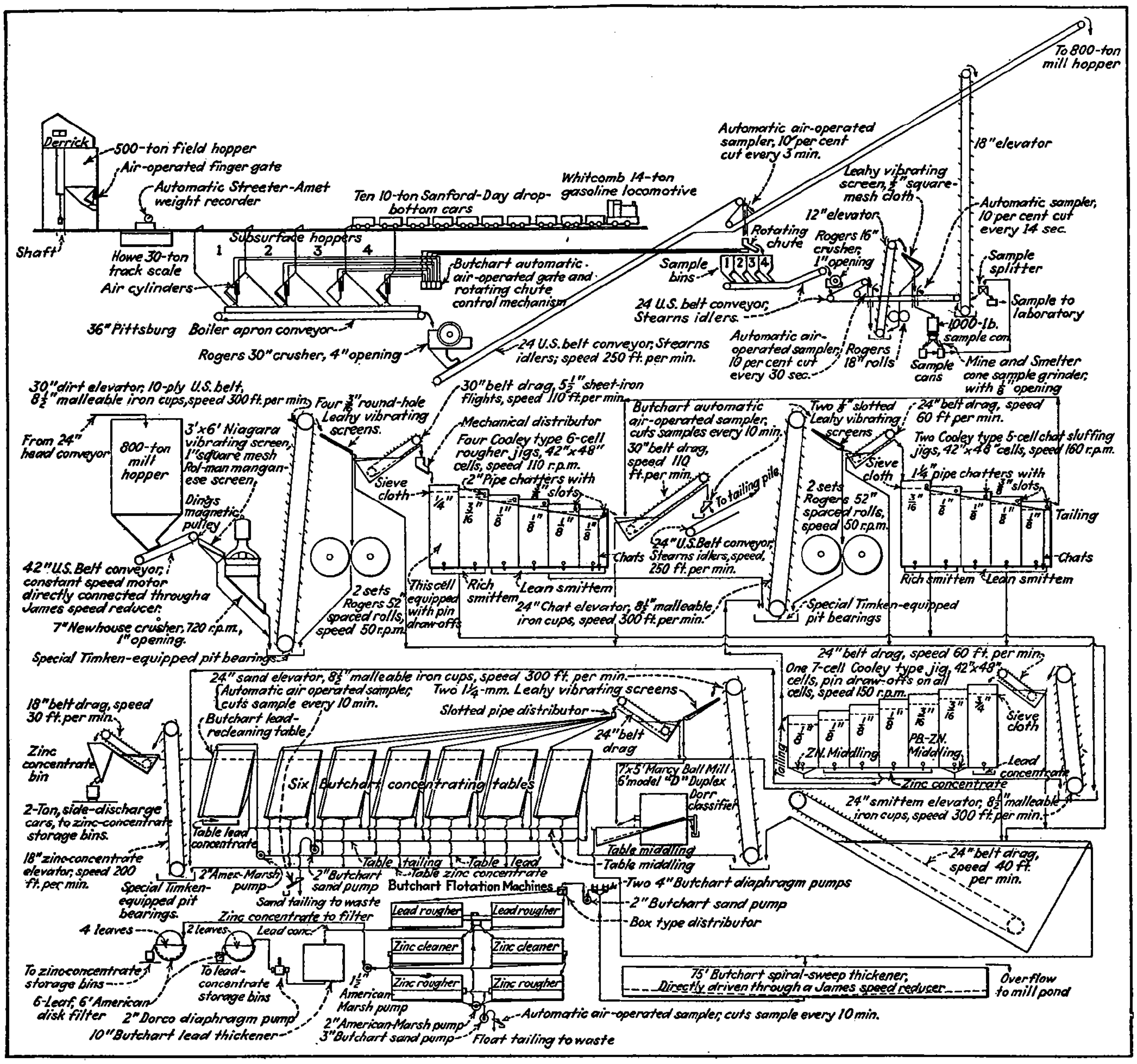


FIGURE 10. Flow sheet of Bird Dog mill

800 tons capacity. Usually the crude ore is fed directly from the hopper to the crushing equipment and then to the jigs. In recent years a few of the larger plants have installed separate crushing departments including storage hoppers from which a uniform quantity of crushed crude ore may be discharged to the concentractor. A separate crushing plant and an intermediate storage add greatly to the flexibility of operations by rendering mine and mill more independent of each other and aids the ore dressing efficiency by providing the mill with a regulated and uniform quantity of feed. Of course the intermediate hopper is an equalizer between the crushing department and the concentractor proper.

Dry crushing is practiced only in those mills where separate crushing departments operate. Dry crushing is used in only one mill to reduce the crude ore to sizes suitable for jigging. In all plants without separate crushing departments wet crushing alone is employed, the water being added first to the jaw crusher.

Primary breaking in every mill is done in the Blake type of jaw crusher, locally manufactured by a number of foundries. Rarely have other types of crushers been employed and their use has never spread. Usually the crude ore is fed directly without any feeder arrangement other than a gate in a spout from the hopper. Jaw crushers from 16 inches to thirty-six inches in width of jaw are in use. The jaws, cushion plates and side plates are generally of a good grade of "hard iron" and manufactured locally. These parts made of manganese steel or chrome steel are now used in many plants. The hard iron or cast iron for these crusher parts is so resistant to wear and is so cheap (less than three cents per pound) as compared to eleven to twelve cent steel, that the steel must show about four times the length of service. Breakage is the greatest disadvantage of using hard iron and although the actual economy of using steel parts is often questionable, many plants do so because of the less frequent changes and replacements causing less interruption.

Although the miners are instructed to load no piece of crude ore weighing more than fifty pounds, boulders, sometimes two feet or more in one dimension come to the crusher. The discharge of the crusher will pass through a two inch to four inch ring and it goes for secondary crushing to the "breaker" rolls ranging from thirty-six to sixty-six inches in diameter. Some years ago many sets of rolls of small diameter, twenty-four inches and thirty inches were used for various tasks, but a distinct trend toward the larger rolls has developed and now rolls of less than thirty-six inches diameter are seldom used, the popular sizes being about forty-two inches and larger in diameter. Some of the reasons for the larger sized rolls are the greater weight, and the larger angle of nip which facilitates crushing and permits treatment of larger tonnages. Nearly all of the rolls are geared and of the old Cornish type; they are manufactured locally as are the hard iron roll shells which are attached to the cores by white pine shingle wedges. The face of the rolls is from about sixteen inches to twenty-four inches and the speed is twenty-five to thirty r. p. m. Only one of the roll shells is driven and the two shells are held together by tension springs. Some rolls are not geared but are spaced and both shells are belt-driven and at speeds of about sixty r. p. m. Shells of manganese steel and of chrome steel are now in use but here again is a question of balancing the hardness, low cost and breakage of the cast iron against the resistance to wear, high cost and the non-breakage of the steel. When it is observed that the total cost for shells, crusher jaws, all replacements and repairs for all of the crushing equipment in plants equipped with hard iron (except labor and power) amounts to from 4.5 cents to 6 cents per ton of crude ore, it is realized that careful comparisons must be made to justify using steel parts to effect a saving.

Although Tri-State flint is very resistant to crushing and the economic minerals, zinc blende and galena produce slime very readily, screens of any kind are seldom employed before reaching the primary crusher or the breaker rolls. This is because of the necessary severe "shooting" or blasting of the crude ore, often causing 40 per cent and more of the blende to break into the minus seven-eighths inch mesh portion and 10 per cent in the minus 325-mesh portion before being hoisted from the mine. Simplicity and low first cost of mill equipment has usually militated against introduction of additional screening devices for the purpose of separating this fine product from the crude ore. Of course with the perfecting of flotation, less concern is felt about the amount of sliming of the economic minerals.

Various devices are used and others are being considered for the secondary crushing duty. Jaw crushers have been used but have not been regarded as satisfactory because of failure to achieve a sufficient degree of reduction in size. The Newhouse suspended jyratory reduction crusher is now receiving a thorough test in one plant as described by H. D. Keiser.[68] The Symons cone crusher, which has successfully replaced rolls for this duty in many mining districts of the world, has been installed and rejected in one plant, but is being favorably considered for installation on others. Rolls consume considerable power, the shells corrugate and as a result grinding capacity and efficiency decrease. The degree of reduction secured is not sufficient, and other considerations indicate that efforts will continue to be made to improve the secondary crushing. The low first cost and the relative ruggedness of the locally manufactured crushers and rolls constitute a barrier to the introduction of other kinds of crushing equipment from without the district.

The discharge of the breaker rolls, the largest piece of which is usually thru 1½ inches, is elevated and screened; the oversize is sent to the "return" rolls which operate in closed circuit with the screen having three-eighths inch to nine-sixteenths inch openings, square or round. The return rolls are of the same types as the "breaker" rolls. For this duty of completing the crushing, rolls are generally regarded as quite satisfactory; low maintenance cost and relatively little corrugating and grooving are observed. Rolls also are used for grinding all middlings down to sizes ranging from six millimeters to about two millimeters, the latter size being about the smallest to which rolls can reduce Tri-State ore material with any success. Speeds range from a little less than thirty r. p. m. for the geared type to as high as seventy-five r. p. m. for the double-belted spaced type.

The trommel screen has been the favorite, but in recent years many types of vibrating screens have been used. The cylindrical trommel, usually four feet diameter by eight feet length, has been used most frequently although occasionally the many-sided (six, seven or eight sides) trommel also has been used. Perforated steel plate with round holes has been used almost exclusively for trommel screen cloths; the more efficient wire, square-mesh screen cloth has been used but little because the rate of wear is high and replacements are frequent. The perforated plate is very durable and has been adopted also on many vibrating screens. Some of the vibrators introduced into the district have failed because of fragile construction; others operate very efficiently under moderate loads, but serve very poorly under overload. However, the more rugged vibrators with their increased screening efficiency have undoubtedly come to stay and will be more generally used. Always first cost is a consideration as vibrators cost two to four times as much as the trommels used for the same duty.

JIGGING

After the rock has passed through the "dirt" screen operating in closed circuit with the return rolls it passes to some kind of a desliming device before being fed to the roughing jigs. Most commonly the product of initial crushing is passed through one-half inch round hole. A decade ago most of the product of initial crushing was passed through five-sixteenth inch and three-eighths inch but it has been learned that with various adjustments in jigging the coarser initial sizes permit just as much if not more effective, milling. Of course greater tonnages treated in the same time with the same amount of equipment was obtained.

Ten to twelve years ago the desliming before going to the roughing jigs was very inefficient in most of the plants. Often a box with an overflow for the slime and a spigot near the bottom to discharge the feed for the jig was in use; but such an arrangement at best removed only some of the excess water and a small portion of the slime. When attention was centered on the fact that a considerable amount of the zinc and lead values were in the fine sand and slime and that jigs could not recover efficiently the values from sizes finer than sixty-five-mesh, automatic desliming cones, such as the Wood, the Boylan and the De Mier, were introduced, greatly improving the removal of the fines and slime from the roughing jig feed.

Home-made drag deslimers of the Esperanza type have become very popular now and probably have superseded the cones to some extent. While the cones require no power, they need six or seven feet more head room and discharge their load at times in surges, whereas the drag deslimers discharge a fairly uniform quantity at all times and may even gain some headroom, which is always important in a mill. The home-made drag deslimers are not as efficient in removal of fines as some of the factory-made types, such as those of the Dorr and Akins, but again, low first cost is a major consideration.

The overflow of the deslimers, box, cone or drag types, pass to the table department and the coarse discharge goes to the roughing jigs, usually of six or seven cells, with thirty-six inches by forty-eight inches or forty-two inches by forty-eight inches dimensions. In every mill "unsized jigging," that is, no sizing of the mill feed other than desliming before jigging is practiced. Sizing before jigging has been studied, tested to some extent and admitted, at least in some quarters, to be somewhat more efficient, and yet it has not been adopted in this district. It has been blocked mainly because of failure to get thorough sizing with the screens in use. Sizing before jigging would complicate the milling operation by increasing the number of products to be taken care of and since no plant with such a flow sheet has been built nothing has been done to show the advantages or disadvantages of the method. However, it is still a question for warm debate in this district.

A roughing jig treats from twenty-five to fifty tons of deslimed feed per hour, the former figure being preferred. Overloading of the roughing jig is a common error. The extraction of free mineral in all sizes down to sixty-five-mesh is excellent, usually recovering above ninety-five per cent. Roughing jigs, of course, produce hutch products and bed material for retreatment on cleaning jigs. Interesting studies made on the products derived from roughing jigs show that with decreasing size the rejection of the gangue decreases so that although 95 per cent and more of the free mineral at thirty-five to thirty-eight mesh is recovered, more than 80 per cent of the gangue of this size also appears in the hutch products and must be rejected by subsequent treatment.

Middling products are usually removed from above the sieve level thru some kind of chat draw or "chatter," a common kind being an inch and a half or two-inch pipe with holes or one or more slots along its length, placed near the tailboard of the cell at right angles to the flow of the jig charge and projecting through the side of the jig. These middlings or chat products are sent to rolls for further grinding. The hutch products from the last one or two cells of the roughing jigs are generally ground through rolls or in a ball mill and treated further.

Many factors enter into the operation of a roughing jig as well as of other jigs. The size of opening in the sieve cloths on the respective cells, the depth of bedding material on the sieves, the total depth of material on the sieves, the length of stroke on each cell, the speed of the jig shaft, etc., all having influence. Each of these may vary thru some appreciable range and yet all of them may be correlated and balanced with many combinations which result in satisfactory operation. Roughing jig speeds vary from ninety r. p. m. to 120 r. p. m.

Hydraulic[69] water is usually added from open launders above the plunger and passes between the plunger into the hutch chamber. In some plants the water is now added under the plungers by individual pipe lines from a header lying behind the jig. Elimination of water overflow and more positive regulation with improved water action are secured by this arrangement.

The Harz type of jig predominates, those built of wood being in general use until recent years. The Harz jig built of steel and electrically welded throughout below the water line are now used in many plants. The steel jig has a cylindrical bottom which facilitates improved water action, is of less weight and free of leaks, and has a longer life. One concrete jig was built a few years ago but did not gain popularity, because of its great weight and the difficulty of making changes. The Bendelari jig introduced by F. N. Bendelari, Joplin, Missouri, has many attractive features, such as, no plunger compartment (the plunger being under the sieve), much less floor space and head-room required, more positive water action, and the opportunity afforded to remove middling products from both sides of a cell. This jig has been well received and its use should increase.

During the life of this district a great variety of jigs[70] have been tried. Nearly all types described in the treatises on ore dressing have been used but only several have been adopted. The Harz jig has survived, and whether the Bendelari jig is to supersede it in the future will be watched with much interest.

The tailings from the roughing jigs pass to desliming devices, such as automatic cones or home-made drags. A device used a great deal some years ago but now passing out of favor is the dewatering screen with about two-mm. openings (a one-section trommel screen receiving its feed on the outside of its jacket). The tailings, dewatered and deslimed, pass either to a tailing elevator or a belt conveyor for transportation to the waste piles. Until seven or eight years ago the use of a conveyor was unheard of in a Tri-State mill, but now they have replaced elevators for several tasks, the principal task being tailing disposal. First cost of a conveyor is nearly twice that of an elevator but head room or height is gained more efficiently with a conveyor. An elevator can handle all sizes of material including slime, whereas if a conveyor is employed for the coarser tailing, the sand and slime must be elevated or pumped to the waste pile. Every effort is made to operate the roughing jigs as efficiently as possible as they produce about 75 per cent of the total tailings. Usually it is possible to produce a roughing jig tailing containing less than 1.5 per cent blende.

The hutch products (except from the last one or two cells) and the bed material from the roughing jig or jigs are carried by an elevator to a desliming device, cone or drag type which in turn feeds to the cleaning jig (usually only one in a plant) having generally seven cells, thirty-six by forty two. This jig runs at about 160 r. p. m. a higher speed than for the roughing jigs and also with shorter plunger stroke. On the first cell, finished lead concentrate is produced. The second cell discharge is usually a lead-zinc middling which is returned to the circuit depending on the lead content of the mill feed, the third cell may or may not perform the same duty as the second. The remaining cells are devoted to the production of finished zinc concentrates, with the last cell at times making a middling product. The tailing from the cleaning jig is really a middling as all of it receives further treatment. It is dewatered in a box in an automatic cone, or over a dewatering screen. It may be sent to the table department in whole or in part or to a middling or to a chat circuit in the jig department.

The lead concentrates usually are shoveled into a car holding up to one and one fourth tons and the car pushed on an elevated track and dumped into the storage bin. Zinc concentrates may either be shoveled into a car or sent to an elevator which in turn discharges to a drag or an ordinary cone from which it passes to the concentrate car and thence to the bin.

Since much of the zinc mineral is not liberated from the flint gangue until ground to thirty-five mesh, hence varying quantities of middling ranging from three per cent or four per cent to fifteen per cent of the mill feed are drawn for further treatment. The middling or chat products from the roughing and cleaning jigs are ground and retreated by jigging, tabling and flotation. Many different circuits for these products may be noted in the various mills of the district. One of the major ore dressing problems in the mills is to improve methods for the isolation of the middling or chat grain from the barren gangue and for proper re-treating. Many types of chat draws have been devised for the removal of the middling from the roughing jigs, all of them being faulty in some respect, and so there remains much opportunity for improvement. A few of the many types of middling circuit will be described briefly.

(1) No middling rolls are used. All the roughing jig chats, cleaner jig tailing, last rougher hutch products and table middlings are sent to a rodmill (four inches by ten inches) operating in closed circuit with a 1.5 mm. screen at the beginning of the tabling process.

(2) The roughing and cleaning jigs are used for the recovery of the mineral and of only the very richest middling grains. All roughing jig tailing and cleaning jig tailing are dewatered, stored, and ground through one-fourth-inch in highspeed rolls. The minus 1.5 mm. portion is removed and the size between six mm. and 1.5 mm. portion (about one-half of this jig's feed) is jigged on a secondary roughing jig for production of a finished tailing and a middling which is ground in a rod mill (four inches by ten inches) in closed circuit with a 1.5 mm. screen. All of the minus 1.5 mm. material is sent to the table department.

(3) The roughing jig middlings, the cleaning jig tailings and the last rougher hutch products are sent without grinding to a secondary roughing jig where some finished tailing is made. The middling products from this jig are screened into plus and minus three-sixteenths-inch portions. Of these products the oversizes are ground in slow rolls three-sixteenths-inch mesh and the fine undersize material is ground in high speed rolls through two-mm. mesh. Both ground products are sent to a so-called "chat" roughing jig. The favorable feature of this particular flow is that the load on the fine or sand rolls is decreased as is also the load on the slow speed rolls handling the coarser product. This plan involves very heavy withdrawal of middling products from the first roughing jig, followed by rejigging of this material on another jig to eliminate some barren tailing without grinding.

(4) A large amount of middling products is withdrawn from the roughing jig and reground to pass through three-sixteenths-inch opening for subsequent treatment on a chat roughing jig. The middlings from the chat

roughing jig and the cleaning jig tailings are ground in high speed rolls to 1.5 mm. and returned to the chat roughing jig.

(5) A large amount of middling products are withdrawn from the roughing jig, divided into plus and minus three-sixteenths-inch portions, and each reground separately in slow speed rolls and both returned to the first roughing jig or sent to the reground sand product (through two-mm. opening) to the tables.

(6) The roughing jig middlings and the plus two-mm. portion of the cleaning jig tailing are ground through one-eighth-inch slow speed rolls for retreatment on a chat roughing jig, the first hutch products of which are passed to the cleaning jig and the last ones to the ball mill circuit. The undersized of the cleaning jig tailing passes directly to the table department and the contained middling grains eventually reach the ball mill circuit by way of the table middling products.

Some of the mills are equipped with what are called sand jigs, sluffing jigs or chat jigs, all of which are usually operated as roughing jigs to produce a finished tailing and prevent an undue load of sand in the table department. Other middling circuits varying somewhat from those described might be mentioned but the fact is evident that no accepted procedure has been adopted for these jig products.

Weakness of Jigging Practice

The following comments refer to the weakness in the present jigging practice. Too much barren flint is withdrawn as middlings and reground. The flint withdrawn is predominantly the coarse blocky pieces which are most difficult to grind. The flaky grains which contain blende are lost in the tailing. It is very difficult to remove from the roughing jigs the middling grains of the intermediate sizes, one-fourth to one-twelfth-inch. The roughing jig sieves are primarily screens for the sand sizes (-2mm.) in the jig feed, and as a result, heavy loads of sand are carried into the table and the flotation departments.

Much discussion has been devoted to the jigging department because it produces three-fourths of the mill tailing and although it often does not produce three-fourths of the concentrates it is of such major importance that any changes, even small, in this department may have more effect on mineral extraction than a much larger change in the table and the flotation departments.

TABLING

Usually all of the overflows and a portion of the sands from the jigging department pass to a type of desliming device: (1) a large home-made Esperanze drag; (2) three or four ordinary nine feet or ten feet diameter 60° cones; (3) two or three large automatic cones, or (4) a small thickener (about sixteen feet diameter) with a heavily constructed raking mechanism. The old rectangular sand tanks for this purpose have been largely abandoned because they gave the tables a very irregular feed. The overflows are sent to the large thickener serving the flotation department and the sand discharge passes to the table room elevator from whence it goes to a 1.5 to two mm. screen and thence to some type of classifying equipment. The screen oversize is usually "tramp" material and may be sent to a variety of places, such as (1) the jig room middling circuits; (2) the ball mill; (3) the rod mill or even (4) to the waste pile. Sending to the waste pile is poor practice because values are often lost because of fines remaining in the oversize.

A great many kinds of classifiers have been used, some of them home-made and others factory made. Many home-made classifiers have ordinary 60° cones of various sizes and are equipped with hydraulic water. The factory made classifiers are of the Dorr, Akins, Butchart, and modified St. Joseph types. Some operators believe in classification to the extent of producing eight to ten products for as many tables; others believe classification is sufficient if thorough removal of slime (150-mesh) is accomplished. Some maintain that tables operate more efficiently with a thoroughly deslimed but unclassified feed and have introduced many kinds of odd-shaped riffles and riffles running at various angles on the table decks. Others who favor classification prefer plain straight line riffles lying parallel to the line of motion of the table deck. Although theoretical considerations favor classification, no conclusive tests have been made in the district to prove or disprove the merits of classified or unclassified feed. If the minus 150-mesh portion of the table feed is removed quite thoroughly, the difference in zinc tenor in the tailing from an unclassified and a classified feed would doubtless be small. One advantage of the classified feed is that the middling grains are segregated in the coarser sizes on a few tables and can be sent in smaller quantities to the ball mill circuit than if the middling grains are scattered over all of the tables as is the case with an unclassified feed.

Finished zinc concentrates are usually produced on all the tables. In some cases the lead-zinc middlings are combined and retained on one table to produce a final lead concentrate. The zinc gangue middlings may be recirculated or may be sent to the ball or rod mill. The tailing cuts from the tables or other types are usually sent directly to the waste pile via an elevator or a sand pump. If classification is practiced the tailing from the first one or two tables may obtain so many middling grains that all of it is sent to the fine grinding unit or it may be roughed on a sand or sluffing jig and this jig's products passed to the ball-mill. Also with classification, if the tailings from the last one or two tables contain too much blende they may be passed to the flotation circuit for final treatment. These tailings are primarily fine sand and do not introduce an undue amount of coarse material into the flotation circuit. Good tabling practice produces a tailing containing 1.5, or less, per cent blende.

At several mills table departments have been eliminated and this sand load is sent to the flotation department because it is believed that an economy in operating costs is secured, that table size of mineral is floated readily and that tailing with lower mineral content is made. Such a procedure throws an increased load on the ball and the flotation machines. It is probable that in mills where the tables have been eliminated, excess capacity previously existed in both the ball mill and the flotation machines. Instances have been cited where the mineral content of the flotation tailing was as much as 2 per cent less blende than that in the table tailing, this being doubtless due to poor tabling practice.

Whether the elimination of tables becomes a general practice is doubtful as these machines serve excellently to bridge the gap between the jig room and the flotation machine. Tables serve their purpose well regardless of whether or not they produce a pound of finished product. They are valuable in recovering mineral which would otherwise pass to flotation. Often it is said that flotation will recover mineral as coarse as thirty-five-mesh but this is a "wide open" question. The practice of today will have to be improved before mineral of this size is floated readily and thoroughly. Very little blende above 100-mesh is now being recovered by flotation. The problem of grinding all of the sand from, say, twenty-mesh to even as fine as sixty-five-mesh must be approached slowly as the indicated size reduction is as great as from one-fourth-inch to (two mm.) (one-twelfth-inch). Flotation concentrates sell on a base price of $1.00 less per ton than that for gravity concentrates, this meaning a loss of about six cents per ton of crude ore. The benefits to be derived from tables in Tri-State mills will be a problem of controversy for many years.

The ball-mill and the rod-mill have been accepted in the Tri-State mills yet they have hardly found a definite duty to perform. Very few rod mills are in use but more than forty ball mills have been installed. One still observes the attitude and tendency to put everything, that cannot go somewhere else, into the fine-grinding unit. Rarely may one find any definite standard for performance of ball mills, yet ball mills are needed and doubtless will find a definite place in the flowsheet. Middling products from both the jig and table departments to the ball mill which operates usually in open circuit. The discharge is deslimed and returned to the tables. Ball mills from three feet to seven feet in diameter are in use with most of the well-known manufacturers represented. Ball milling is a debatable subject and a very lengthy discussion concerning its merits in the district could be made but space forbids.

FLOTATION

The overflows from the table department are thickened in thickeners (Butchart or Dorr) thirty feet to seventy-five feet in diameter and usually fed by means of a diaphragm pump, an elevator or a sand pump to the first flotation machine. Thickener overflows are sent to large settling ponds from which the water is recovered and returned to the mill pump sumps. These settling ponds gradually accumulate considerable quantities of fine slime which is periodically pumped to the flotation circuit.

The feed from the thickener is treated first with reagents for lead flotation, the lead being floated first and it may or may not be filtered. Oftentimes the lead froth is tabled to produce a high grade of concentrate (seventy-five per cent to eighty per cent). In many mills the quantity of lead in the flotation feed is so small that its recovery is almost a nuisance rather than an asset. If a low grade lead froth is withdrawn it is very difficult to filter and if filtered it is very difficult to dispose of either by mixing with the jig and table lead concentrates or by sale as such. Hence there is good reason for tabling the lead froth although this practice entails a high loss of the small quantity of lead concentrates treated.

The tailing discharge of the lead treating flotation machine passes to the flotation circuit where copper sulphate and other reagents are added. The zinc is floated and in every mill is filtered on either a disc type (American) or a drum type (Oliver) filter. The former has been far more popular because of opportunity for filtering both lead and zinc concentrates on the same machine and because of the ease of changing the canvas sectors while operating.

The Butchart horizontal cylindrical type of flotation machine is usually employed. Four of these machines of four cells each constitute a typical flotation plant, one being devoted to lead flotation and the other three to blende flotation. The last zinc unit produces a dirty froth which is returned to the head of the zinc circuit. A separate cleaning machine is used in some plants. The K & K Flotation machine is used in some mills. Pneumatic machines of several kinds have been tried at various times but generally have failed to give satisfaction. Machines with mechanical agitation are better adopted to the intermittent operating schedule in this district as most run on only one ten-hour shift per twenty-four hours and this interruption is a distinct drawback to successful flotation. Stopping and starting often are more detrimental to flotation than to jigging and tabling.

Pre-agitation or conditioning of the flotation pulp with reagents before floating is done to some extent in a few plants. Pumps have replaced elevators quite generally for lifting flotation products.

The Denver Sub-A type of mechanical agitation machine was introduced into the district about 1928 and has made some headway. It has some advantages in having steel wearing parts as compared to the wooden paddles of the Butchart and the K & K and it does not require draining at the end of each shift or in cold weather and it does not require any pumps to return products from one cell to another.

A variety of reagents are in use. Pine oil, the cresylic acids, the Barrett oils, Xanthates, aerofloat compounds, etc., are all used in the district. Probably the only reagent used in all of the plants is copper sulphate for the zinc flotation. The copper sulphate is most important and usually represents more than one-half the reagent cost which is usually ten cents to fifteen cents per ton of flotation feed treated.

Flotation tailing contains one per cent blende or less and this mineral content is a major argument with those urging increased use of flotation. Flotation has come to stay in the Tri-State mills. It now produces 18 to 25 per cent of the zinc concentrate of the district and this percentage may increase. Considerable work is being done on flotation of coarser material and on re-cleaning to very high grades of concentrates such as sixty-four per cent zinc and higher. Concentration problems revolve primarily about the isolation and the treatment of the middling product. But regardless of how processes may be improved and problems solved, jigging and flotation appear to be more effective methods of concentrating than tabling.

WATER SUPPLIES, POWER, SAMPLING AND TESTING

Water for milling purposes is obtained from creeks, wells or from the mines. It is stored in ponds and re-used. Much water is required when it is noted that forty gallons per minute per ton treated per hour is probably a close estimate of requirements. Many mills have independent pumping units serving the individual departments; others belt their pumps to the line shafts driving the concentrating equipment.

Both electric and gas engine power are used in the operations. The latter is usually regarded as cheaper but not as flexible. Many mines and mills are consuming only eight to ten kilowatt-hours per ton of crude ore mined and milled. This amount may be favorably compared to Western practice where the power for milling alone is often two to three times this figure. Most of the equipment in the mills is driven by belting to line-shafting, very few direct-connected units being in use.

Determination of the weight of mill feed is made from the number of "cans" tubs hoisted from the mine into the hopper. No automatic weight-

TABLE XXV. *Operating Costs* in Tri-State District*

OPERATING COST PER TON CRUDE ORE	MINING	MILLING	POWER	GEN'L	TOTAL	COST PER CENT
1. Labor	$0.690	$0.151	$0.017	$0.017	$0.875	49.13
2. Supplies and repairs	.131	.138	.013	.006	.288	16.17
3. Liability insurance	.039	.010	.001	.002	.052	2.92
4. Explosives	.144				.144	8.09
5. Exploration and development	.053				.053	2.98
6, 7, 8, 9. Power all classes			.180		.180	10.11
10. Fire & tornado insurance				.020	.020	1.12
11, 12. Management, office salaries, etc.				.091	.091	5.10
13, 14. Taxes (excluding fed. inc.)				.017	.017	0.95
15. Miscellaneous				.061	.061	3.43
16. Total cost, in dollars	$1.057	$0.299	$0.211	$0.214	$1.781	
Total cost in percent	%59.35	%16.79	%11.85	%12.01		100.00
If 50% of power is charged each to Mining and Milling—then percentages become	%65.28	%22.71		%12.01		100.00
and costs become	$ 1.163	$ 0.405		$ 0.214	$ 1.781	

Average mill recovery 6.411% (281,657 tons concentrates).
Crude ore tons hoisted per man per day 4.941 (Based on total men employed in mine, mill and miscellaneous surface labor).
Tons of concentrates produced per man per day 0.3168.

*For 4,393,133 tons of Crude Ore mined and milled in eight months, December 1928 to July 1929 inclusive. From Tri-State Zinc and Lead Ore Producers Association.

ometers are in use. Very little automatic sampling of mill products is done, hand sampling being still the usual practice.

No research laboratories are maintained and very little laboratory test work is done by the operators. When an idea for improvement occurs to one of the operating staff, it is usually "tried out" on full scale in the plant. The mill is generally the scene of most test work in this district. The Federal and State agencies, particularly those with headquarters at Rolla, Missouri, have done much in benefitting the concentration practice.

OPERATING COSTS

To give the reader a conception of costs in this district the following two tabulations are inserted. Table XXV presents costs during 1929 before the present business depression and when the concentrate markets and costs were relatively high. Table XXVI presents a picture of costs as in August 1931 after many economies had been effected.

The larger decrease in costs has been in labor and the smaller in supplies and power. Both tabulations indicate that costs must be kept down to permit any profitable operations; of course, during the depressed business conditions, very few mines can operate and pay operating expenses even with the costs shown in Table XXVI.

TABLE XXVI. *Operating Costs*[1] *in Tri-State District, August* 1931

	COST PER TON OF CONCENTRATES	PERCENT OF COST	COST PER TON OF CRUDE ORE	PERCENT OF OPERATING COST
1. Labor	$ 7.51	28.6%	$ 0.606	42.5%
2. Supplies and repairs	3.18	12.1	.257	18.0
3. Liability insurance	.39	1.5	.031	2.2
4. Explosives	1.59	6.1	.129	9.0
5. Exploration and development	.19	.7	.015	1.1
6, 7, 8, 9. Power, all classes	2.07	7.9	.167	11.7
10. Fire and tornado insurance	.43	1.6	.035	2.5
11, 12. Salaries and office expense	1.23	4.7	.099	6.9
13, 14. Taxes (excluding federal inc. tax)	.03	.1	.003	.2
15. Miscellaneous	1.05	4.0	.084	5.9
16. Total operating expenses	$ 17.67	67.3%	$ 1.426	100.0%
17. Amortization of capital cost				
Depletion	3.07	11.7%		
Depreciation	2.13	8.1%		
18. Royalty	3.40	12.9%		
19. Total cost of production	$ 26.27	100.0%		
Mining	$ 8.93		$ 0.722	50.6%
Milling	3.28		.264	18.5
Power	2.44		.197	13.8
General	3.02		.243	17.1
16. Total operating expenses	$ 17.67		$ 1.426	100.0%

20. Capacity of mills included in summary per 10 hr. day in tons, crude ore	5,830
21. Capacity per 10-hr. day at which mills operated in per cent	89.4
22. Crude ore hoisted per man per day in tons	5.1
23. Concentrates produced per man per day in tons	.41
24. Mill recovery, ZnS 7.03%; PbS 1.04%; total per cent	8.07

[1]Cost of production of 10,935 tons of concentrates (135,508 tons of crude ore.) Twelve mills included in summary. From Tri-State Zinc and Lead Ore Producers Association.

CHAPTER NOTES

67. Isern, Elmer, Central Milling in the Tri-State district: Eng. and Min. Jour., vol. 131, p. 49, 1931.
68. Keiser, H. E., Suspended Crusher Replaces Rolls: Eng. and Min. Jour., vol. 131, pp. 67-68, 1931.
69. Richards, R. H., Text Book of Ore Dressing, p. 189, McGraw-Hill Book Co., 2nd ed., 1909.
70. For more complete information concerning jig development in the district the reader may be referred to Henry Webb of Webb City, Missouri.

DESCRIPTION OF MINES

THE following description of thirty eight mines and mine groups includes about one-fourth of the mines in the Miami-Picher district. Most of the mines described are located within a zone or belt extending from the east to the west side of the district, in the general direction of the prevailing northwest dip of the strata. The observations noted in the mines concerning the geological features were later supplemented by data shown on mine maps and in drill records, kindly furnished by the mining companies.

While the mines are alike in their main features yet each one has a more or less individual character. The description of the mines are incomplete, a condition no one is more fully aware of than the author.

During the summer field season of 1927 the mines studied included the following: Anna Beaver, Beaver, Bingham, Birthday, Blue Goose, Brewster, Domada-Bethel, East Midas, Foch, Fort Worth, Golden Rod (group of mines), Goodwin, Grace Walker, Howe, Jay Bird, Lucy Syndicate, Malsbury, Netta, New Chicago (No. 1 and 2), New York, Oklahoma-Woodchuck, Otis White, Pioneer, Rialto, Ritz, Royal, Scammon Hill, Tri-State and Whitebird.

When field work was resumed in the summer of 1929 the additional mines investigated were as follows: Beck, Central, Crystal, Discard, Gordon, Harrisburg, Lion, Mudd, and Xavier. In addition to these further study was made of the Beaver, Blue Goose, Brewster, Pioneer, Rialto, and Scammon Hill mines.

Separate ground plans of the mines described are not included, except for a few of the mines, but the general outlines of the ground workings of all of the mines are shown on the map of the district, Plate II.

Anna Beaver Mine

The Anna Beaver Mine, Anna Beaver Mines Company, is located on a 200-acre lease, forming the NE. ¼ and the SE. ¼ NW.¼ of sec. 19, T. 29 N., R. 23 E. Mining was started in 1917 and the production from 1917 to 1928 was 108,469 tons of zinc concentrates valued at $4,463,928 and 36,719 tons of lead concentrates valued at $3,668,538.

The Miami syncline extends from the southwest to the northeast part of the 160 acres forming the NE. ¼ of Sec. 19. The mine workings are located on both sides of the syncline but to 1927 no ore-body had been developed in the bottom of the trough. Only the workings operated from shafts 1, 4, 8, 9, 11, and 15 were visited by the writer in 1927.

The principal mining level in shaft 8, located on the west side of the trough, is 215 feet below the surface, except in workings southeast of the shaft where the levels step down to 225, 235, and 245 feet below the surface in following the Boone strata as it dips southeast toward the axis of the trough. The stopes vary from twenty-five to 150 feet in width and from fifteen to sixty feet in height. The ore is mainly the jasperoid breccia, the floors of the stopes being in flint and the roofs in dolomitic limestone. Shale of Boone formation one to six feet thick occurs in a stope near shaft 4.

Shaft 9 is about 720 feet east of shaft 8 and on the eastern or opposite side of the trough. The mining level at the bottom of shaft 9 is 207 feet below the surface descending to a lower level of 230 feet southwest of the shaft as the bottom of the trough is approached. The Cherokee shale in the bottom of the trough between shafts 8 and 9 reaches a maximum thickness of 230 feet, as determined by drill records. The stopes northeast of the shaft ascend to a higher level of 180 feet. Where the level is 180 feet below the surface northeast of the shaft the shale has a thickness of seventy-five feet, and where it is 230 feet below the surface, southwest of the shaft, the shale has a thickness of 165 feet. The stopes have a usual width of forty to eighty feet and a height of twenty to thirty feet. The ore is partly jasperoid breccia associated with limestone.

In shaft 4, about 720 feet southwest of shaft 8, the principal mine level is 215 feet below the surface, the levels stepping down to the southwest, to 245 feet, in following the ore along the general dip of the Boone to the westward.

The mine level in shaft 11 on the east side of the trough varies from 209 to 240 feet below the surface. The stopes range from thirty to one hundred feet in width and from twenty to thirty feet in height.

The ore mined in the various parts of the lease appears to be in a zone about one hundred to 125 feet below the base of the shale. As there is usually thirty to fifty feet of Mayes formation between the Cherokee shale and the Boone formation the ore mainly lies in the upper beds of the Boone formation. In some places, however, the ore reaches up into the silicified Mayes limestone, the ore being mainly galena, in typical "sandspar." About 300 feet southeast of shaft 9 mainly lead ore occurs at 155 to 175 feet below the surface passing down into mainly zinc ore at 175 to 195 feet. In this locality, however, drill records show a thickness of only sixty-five feet of shale hence the lead ore is probably within the upper part of the Boone formation.

In exploring for ore in the area of the deep shale, in the bottom of the syncline, sufficient drilling should extend to depths of one hundred to 150 feet below the shale in order adequately to explore the ore-bearing zone in the Boone and Mayes formations which underlies the bottom of the trough, as previously suggested under prospecting.

Beaver Mine

The Beaver mine, Commerce Mining and Royalty Company, is on a forty-acre lease forming the SW. ¼ SE. ¼ sec. 19, T. 29 N., R. 23 E. The mine was started in 1916 and the production from 1916 to 1928 was 51,890 tons of zinc concentrates valued at $2,288,845, and 19,768 tons of lead concentrates valued at $1,820,378.85.

In the underground workings of the mine two major stopes have been developed, one trending NE. and the other NW., the two crossing in the central part of the mine, in the form of an X as indicated in the ground plan shown in figure 11A. The stope developed in the NE. trending ore body slopes down from the 240-foot (below surface) level at the northeast end, to the 258-foot level at the southwest end, as shown in "AA′," figure 11A. In mining the NW. trending ore-body the stope maintains a 258-foot level from the southeast end to the center but slopes down to the 274-foot level at the southwest end, as shown in "BB′," figure 11A.

The NE. and NW. trend of the ore-bodies conform to major fractures which trend NE. and NW. and the stopes, in following the ore, have a pitch or inclination to the westward in conformity with the westward dip of the strata on the east limb of the Miami syncline which extends through the adjoining Central mine on the west.

Where the floor of the stope in the northeast run drops from the 240-foot level to the 258-foot level there is a drop in the strata of about twenty feet in a horizontal distance of one hundred feet, the dip of the strata being somewhat greater than the change in slope level.

A down-fold in the strata in the southeast part of the mine carries the ore-body down eighteen feet within a horizontal distance of 200 feet, as shown in "BB′," figure 11B.

The central part of the ore-body is relatively "tight" with more broken ground near the border. The height of stope in the central part of the mine, at the 258-foot level, varies from thirty-five feet to ninety-five feet. The stope height in the highest (240-foot) level is about fifty feet, and that in the lowest (292-foot) level is generally from twenty to thirty feet. The stopes vary in width from twenty-five feet to over one hundred feet, the wide mined-out chambers being supported by high pillars consisting largely of ore-bearing rock. The floor or foot wall of the ore-body is mainly, if not entirely, of flint,

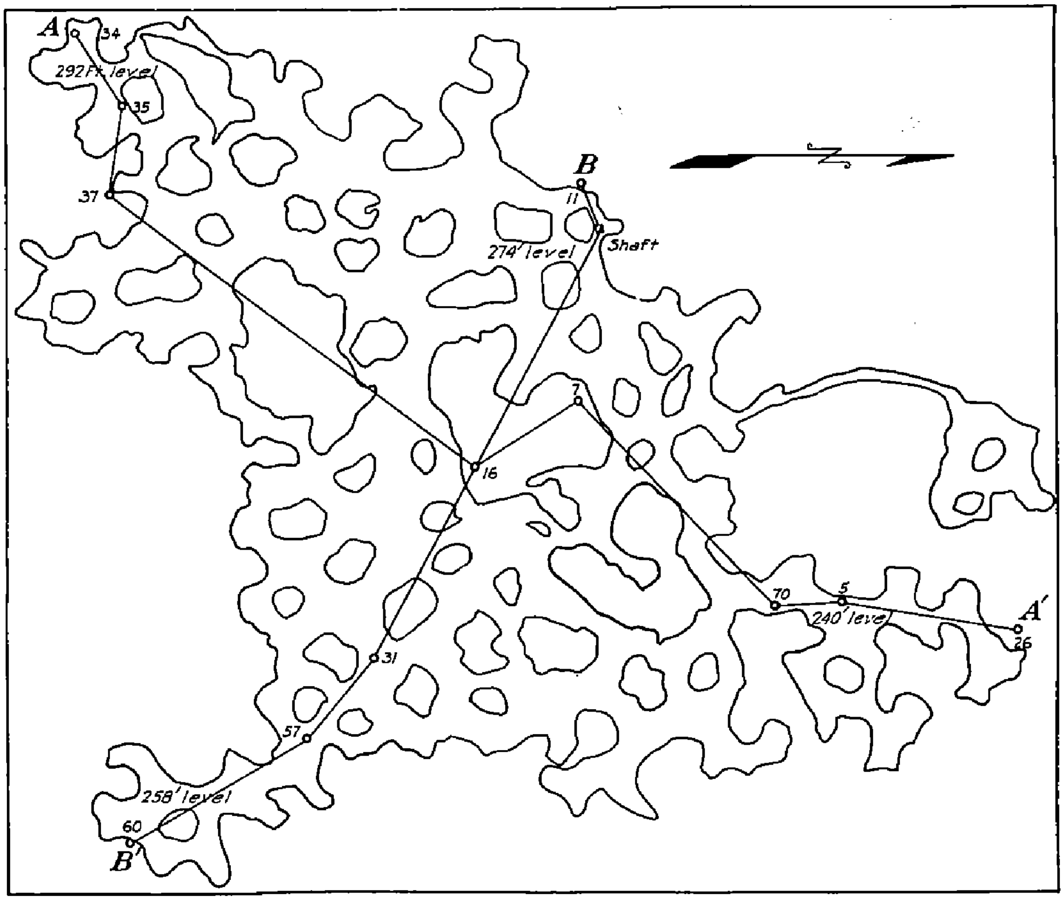


FIGURE 11A. Map of Beaver mine showing location of A-A′ and B-B′ sections.

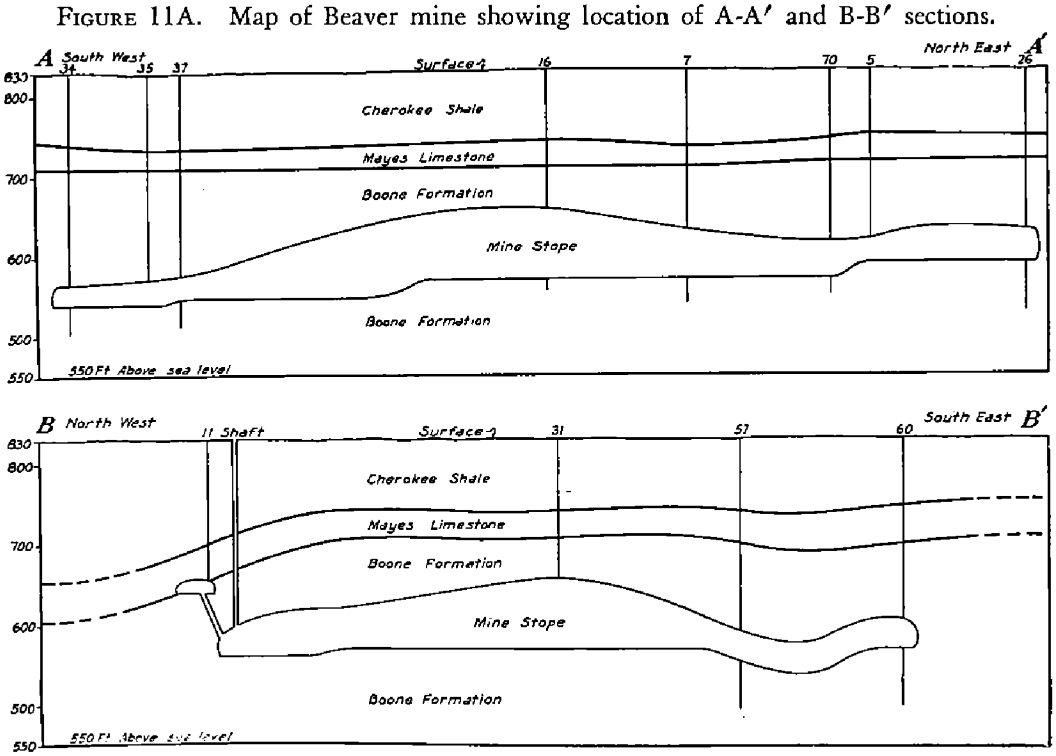


FIGURE 11B. Cross sections along A-A′ and B-B′ of Beaver mine showing shape and position of ore body in relation to geologic formations.

and the roof or hanging wall is mainly limestone grading in places into shaly limestone.

In July, 1929 a raise was put in extending seventy-five feet above the 274-foot level at the tram shaft to a 199-foot level from which an upper ore-body is being mined. In this locality, drill hole 71, the shale has a thickness of 130 feet, hence this ore-body at the 199-foot level is in the uppermost part of the Boone and probably the ore will be found to extend up into the overlying Mayes limestone.

Much tar was encountered in the ore in 1928 and 1929 at the 258-foot level extending southeast toward the Cardin station. The tar not only drips down from the roof but also oozes up from the floor of the stope. The upward movement of the tar may suggest that its source is in the underlying strata. However, the Beaver mine was started in 1916 at the 278-foot level and this part of the mine has probably been dewatered approximately down to the 274-foot level for at least ten or twelve years. During this period of dewatered condition of this part of the mine the tar probably has been seeping down through fractures from the overlying Cherokee shale; hence the tar now oozing up from the floor of the 258-foot level evidently originally came from the same source as that now dripping down from the roof.

Bingham Mine

The Bingham mine, Eagle-Picher Lead company, is located on an eighty-acre lease forming the W. ½ NW. ¼ sec. 21, T. 29 N., R. 23 E. The ore is mined separately on each forty acres, one mine being known as the North Bingham and the other as the South Bingham. The ore is concentrated at the mill located at the North Bingham. Mining was first begun in 1916 and the production from 1916 to 1927 was 67,080 tons of zinc concentrates valued at $2,801,020 and 25,090 tons of lead concentrates valued at $2,216,-400. The mine was not operated in 1928.

The ore is the South Bingham is mined from two shafts, the underground workings being at one level sloping down slightly to the east from 243 feet below the surface at the No. 22 shaft in the west part of the lease to 249 feet at the No. 15 shaft in the eastern part of the lease. In July, 1927 most of the pillars in the eastern part of the mine had been pulled and much of the underground workings had caved. The ore forms a very broad flat-lying body, the stoped-out chamber being eight to fifteen feet high, and having a wide lateral extension of 1,300 feet east and west and from 600 to 800 feet north and south. The mine workings extend under much of the south half of the forty-acre lease. The ore is in relatively "tight" formation of jasperoid and flint, the stopes having flint floors and roofs grading into dolomite and limestone walls.

The North Bingham ore-body is mined from a 264-foot level. The ore-body is a broad flat run, with height of stope of twenty to thirty feet, and a usual width of 200 to 400 feet extending east-west entirely across the north end of the forty-acre lease into the adjoining property. The ore is typical jasperoid breccia in relatively "tight" formation. The ore run in the North Bingham is therefore a much thicker but narrower run than that in the South Bingham. The jasperoid breccia forms a bed ten to fifteen feet thick grading down into white flinty ore at the bottom and likewise into white flinty ore above. The sidewalls of the ore-body in many places grade into nearly barren jasperoid breccia.

The shale, mainly Cherokee, maintains a uniform thickness of about fifty-five to sixty-five feet on the South Bingham lease and a thickness of sixty-five to seventy-five feet on the North Bingham. The ore-body on the two leases is probably about 150 to 175 feet below the top of the Boone formation.

Beck Mine

The Beck Mine, Beck Mining Company, is located on an eighty-acre lease, comprising the S. ½ of the SW. ¼ of sec. 15, T. 29 N., R. 23 E. The west forty-acre lease was formerly operated as the St. Louis mine. The Beck mine, east forty acres, was started in 1919. The combined production developed on the eighty-acre lease, to the end of 1928, was 88,440 tons of zinc concentrates valued at $3,698,205 and 4,549 tons of lead concentrates valued at $460,810.

The underground workings of the west forty-acres were operated at two distinct levels. The stopes in the lower ore-body in the south part of the mine were worked at a level of 235 feet below the surface. The height of the stopes varied between ten and twenty feet, and the width from fifty to 150 feet. The stopes in the upper ore-body, in the central part of the forty-acres were mined to depths ranging from 175 to 193 feet below the surface. The stopes in the upper ore-body varied from ten to twenty feet in height and from twenty-five to one hundred in width.

The east forty acres have been mined mainly on the lower level at about 230 to 235 feet below the surface. The stopes have a usual height of ten to twenty-five feet, and a width of fifty to 150 feet. In some places small stopes at a higher level are being mined from raises and in other places the ore at the lower level is nearly continuous with that at the upper 190-foot level.

An ore-body at the upper 190-foot level was being mined (August, 1929) from a new shaft northwest of the mill.

The ore-bearing formation is mainly "boulder ground" relatively "tight" rather than "open ground" especially at the lower level. The ore of the upper level, mainly lead ore, however, is usually in much fractured flint, the galena being in vertical as well as horizontal veins. The ore-body at the lower level on both the east and west forty-acre tracts follows the gentle dip of the strata to the west.

A cave located south of the mill shaft having flint walls lined with crystals of calcite has a lateral extension of twenty to thirty feet, and greatest height at the center of five or six feet. The shape and position of the cave opening (combined with the insoluble character of the flint walls) indicates its probable origin as due to arching and unequal settling of the strata associated with folding.

The shale thickness on the east side of the eighty-acre lease ranges from forty-five to sixty feet and on the west side from sixty to ninety feet. Below the shale is the usual thickness of twenty to forty feet of the Mayes formation overlying the flinty limestone of the Boone formation. The principal ore-level, at 230 feet, is apparently about 120 to 130 feet below the top of the Boone.

Birthday Mine

The Birthday mine, operated by F. W. Evans, is located on a twenty-acre lease forming the W. ½ NW. ¼ NW. ¼ sec. 28, T. 29 N., R. 23 E. The mine was started in 1920 and from 1920 to 1928 the production was 7,516 tons of zinc concentrates valued at $316,459 and 1,902 tons of lead concentrates valued at $177,567.

The mine was worked from three shafts, the mill shaft near the central part, a north shaft, and a south field shaft. The underground workings are of relatively small extent and are not connected, and only the workings at the mill shaft and at the south field shaft were visited in 1927.

At the mill shaft the ore was mined at 222 feet and 234 feet below the surface, the stopes on the upper level, however, being partly cut down to the lower. At the lower level the stopes are about eight feet high and at the upper level about fifteen feet. The ore formation is the usual jasperoid breccia type, the ore at the lower level being in relatively "tight" ground and that at the upper in much broken and more open "bouldery" formation. In places, however, the bouldery formation extends through both lower and upper levels.

At the south field shaft the ore was mined at levels of 167 feet and 157 feet below the surface. The ore-body forms a flat run from fifty to 150 feet wide with height of stope of twenty to thirty feet. The ore-bearing ground varies from relatively "tight" to much broken "bouldery" formation. Where the stope at the upper level slopes down to the lower level there is a zone of much broken bouldery ground showing an abrupt bend or dip in the strata, being apparent in the roof of the stope as well as in the floor.

Blue Goose and Angora Mines

The Blue Goose Mines, Commerce Mining and Royalty Company, No. 1 and No. 2 are located on the SE. ¼ NW. ¼ and the NE. ¼ SW. ¼ sec. 30, T. 29 N., R. 23 E. The Angora mine, now operated with No. 2 adjoins it on the west, the SW. ¼ NW. ¼ of sec. 30. The No. 1 opened in 1915 was one of the first mines to be operated in the Picher district, the production from 1915 to 1926 being 27,162 tons of zinc concentrates valued at $1,630,707 and 7,939 tons of lead concentrates valued at $782,397. In 1927 and 1928 only the tailing mill on No. 2 was operated from which 2,455 tons of zinc concentrates were recovered.

The No. 2 mine was opened in 1925 and the Angora on the adjoining lease in 1927. The combined production on the two leases from 1925 to 1928 was 19,768 tons of zinc concentrates valued at $829,650 and 3,824 tons of lead concentrates valued at $368,159.

The main mine level in No. 1 and No. 2 is 290 feet and in the Angora 300 feet below the surface. A still lower level at 313 feet was developed in the older workings in the No. 1 mine. The stopes in No. 1 reach, in a few places, a height of eighty feet above the 313-foot level. The stopes in No. 2 reach from thirty to sixty feet above the 290-foot level, and in the Angora the stopes, so far developed, are thirty-five to forty feet high. The width of the stopes is variable but is usually between twenty-five and ninety feet.

The ore-bearing rock is much broken. The ore is the usual black jasperoid, containing many small openings filled with ore mineral and calcite. The earliest breaks are healed and cemented with the jasperoid-ore and the ore-formation contains the old white chert blocks and nodules broken and tilted at various angles to 90°. The latest fracturing still preserves the slickensided surfaces and affects both the latest jasperoid flint as well as the older white flint. Limestone "bars" in places extend across the ore-body along both the foot-wall and the hanging-wall.

Galena crystals, covered with an alteration of white and yellow incrustation containing anglesite were collected from the floor and roof of a stope at the 290-foot level in the northwest part of the No. 2 mine. The alteration of the galena to anglesite is at a depth of 250 to 290 feet, under 130 to 150 feet of shale and far below grand water-level. The anglesite is not associated with any such secondary ores as smithsonite or calamine which are characteristic of the weathered zone of oxidized ores above ground water-level in some of the mines about Lincolnville and in Peoria.

The Miami syncline extends northeast across the central part of the Angora forty-acre lease, the center of the trough containing 250 to over 300 feet of shale as shown by drill records. As the mill shaft and mine workings are on the southeast side of the syncline it was necessary, in order to reach an ore-body on the northwest side, to put in a cross cut through the bottom of the trough. The cross cut, as shown in figure 6, extends northeast about 1,000 feet from the mill shaft at the 304-foot level, passing through the Mayes shale from 500 feet to 750 feet from the shaft. The Mayes limestone formation may be seen on both limbs of the syncline to overlie the flint rock of the Boone formation, and dip with steeply inclined strata under the Mayes shale in the center of the trough. The ore-body on the northwest side of the trough lies directly under the Mayes shale, the latter in places forming the roof of the stope.

Brewster Mine

The Brewster mine, Federal Mining and Smelting company, is located on an eighty-acre lease forming the S. ½ SE. ¼ sec. 15, T. 29 N., R. 23 E. The mine was begun in 1919 and the production from 1919 to 1928 was 112,098 tons of zinc concentrates and 14,957 tons of lead concentrates, the total value of lead and zinc concentrates being $6,235,313.

The mine was operated from four shafts, No. 1 and No. 2 on the west forty acres, and No. 3 and No. 4 on the east forty acres. The collars of the shafts have an elevation varying between 831 and 834 feet. The mining levels in the various shafts are nearly at the same depth, being 231 feet at shaft 1, 219 feet at shaft 2, 211 feet at shaft 3, and 214 feet at shaft 4, below the surface. The ore-body throughout is in the same stratigraphic horizon of the Boone formation, showing a slight slope to the west in conformity with the regional westward dip of the strata.

The width of the stopes is usually from fifty to one hundred feet, but their height is greater in the eastern than in the western part of the mine, being twenty to sixty feet high in the eastern and ten to thirty feet in the western part.

Two types of ore-bearing ground may be recognized at the same level. In the western forty acres of the lease the ground is relatively "hard" and "tight." In the eastern part, near shafts 1 and 2 and the ground is "open" and "bouldery." The boundary between the "tight" and "open" ground is relatively sharply defined by a much fractured zone of rock trending north and south.

The trend and dip of fracturing in the Brewster mine is shown on the fracture map, Plate III. Most of the prominent fractures trend slightly west of north and in this direction the stopes are relatively high and narrow. In general contrast the stopes trending nearly E-W are low and wide.

About 250 feet southwest of shaft 3 anglesite, altered from galena, occurs in a flat thin seam of galena in flint rock, the seam having a lateral extension of one hundred to 150 feet in the upper part of a pillar. The anglesite is not associated with any oxidized ore of either sphalerite or galena.

In the southeast part of the mine, southeast of shaft 4, the temperature of the air is higher than normal because of the oxidization of marcasite.

Black shale, mainly Cherokee, in the eastern part of the lease is thirty to forty feet thick and in the western part fifty to sixty feet. The Mayes formation of brown and gray limestone, twenty to thirty feet thick, lies between the black shale and the Boone. The oolite horizon is at a depth of 170 to 180 feet, about 125 feet below the top of the Boone.

Central Mine

The Central mine, operated (1929) by the Commerce Mining and Royalty Company, is located on a twenty-acre lease comprising the E. ½ of SE. ¼ of SW. ¼ of sec. 19, T. 29 N., R. 23 E. The mine was formerly operated by the Central Lead and Zinc Company. The mine was opened in 1917 and the production from 1917 to 1928 was 7,906 tons of zinc concentrates valued at $282,115, and 6,987 tons of lead concentrates valued at $625,544. This mine is unusual in producing almost as much lead as zinc.

The Central mine is in the Miami syncline, the Cherokee shale being 185 to 215 feet deep in a zone extending from the southwest part to the north central part of the lease. The underlying Mayes formation, in which the upper ore body at about 233 feet below the surface was developed, has a thickness of about fifty feet, the ore being in the lower and middle part of the formation and undulating somewhat with the folding of the strata. The lower ore, in the upper part of the Boone, at about 310 feet below the surface, seems to be separated from the upper ore by twenty to thirty feet of nearly barren rock wherever the latter lies under the former.

The workings at the upper 233-foot level extend entirely across the lease, the stopes having considerable width, fifty to over one hundred feet, but are usually only ten to twenty feet in height. Some of the ore, predominantly galena, is in fractured "sandspar" rock, but most of it is in finely fractured flint. Much fractured limestone and shale lenses occur in close association with the ore-bearing rock. The limestone lenses in the shale are much broken and boulder-like and are enclosed within the broken and tilted shale. Marcasite is common in the shale, but the lead and zinc ore is confined to the "sandspar" and flint rock which are highly silicified phases of the calcareous sandstone and limestone of the Mayes formation.

The ore mined at the lower 310-foot level occurs only in the northeast part of the lease. The ore-body at this horizon is known to occur at greater depth at various places in the western part of the lease under the thick shale. The ore is typical jasperoid, relatively "tight" formation but fractured and much broken in places. The stopes are forty to 150 feet wide and usually from thirty to sixty feet high. The lower ore-body, as stoped out, trends slightly west of north.

Crystal Mine

The Crystal mine operated until 1929 by the Crystal Mineral Trust, is a twenty-acre lease forming the W.½ of SE.¼ of SW.¼ of sec. 19, T. 29 N., R. 23 E. In 1929 it was operated by the Canam Metal Corporation. The production, under the Crystal Mineral Trust, from 1917 to 1928 was 15,253 tons of zinc concentrates, valued at $567,208 and 11,969 tons of lead concentrates valued at $1,106,244.

The mine levels are somewhat irregular and uneven, but three main levels may be distinguished, the deepest at 300 to 306 feet, the middle at about 240 to 260 feet, and the upper ranging between 185 to 220 feet, below the collar of the mill shaft at 835 feet elevation.

Most of the workings of the mine are in the bottom of the Miami syncline, and the yield of lead ore is nearly as large as that of zinc ore. The west side of the trough extends across the northwest corner of the lease where the shale has a thickness of about one hundred feet. On the remainder of the lease, however, the shale is much thicker generally, 150 to 250 feet. The trough in this vicinity below the sub-shale surface is nearly one-half mile wide and about one hundred to 200 feet deep, the axis of the syncline being in the Central Mine adjoining on the east.

Ore on the upper level has been mined on both the east and west sides of the lease but the middle and lower ore levels are developed only on the west side.

The lowest mine level, at 300 to 306 feet, has been worked mainly on the southwest side of the lease. The stopes are generally from twenty-five to seventy-five feet wide and from twenty-five to fifty feet high. The ore-bearing rock is the typical jasperoid breccia of the Boone formation.

The middle level ranging from 240 to 260 feet lies above most, but not all, of the ground mined on the lowest level. The stoped-out chambers are generally from fifty to one hundred feet wide and from forty to sixty feet high.

Only the mine workings of the upper level at approximately 190 to 220 feet were examined by the writer (in August, 1929). The stopes at this level vary from twenty-five to 110 feet wide and from fifteen to forty feet high. The ore-bearing rock is much crumpled and folded and also much shattered and fissured. The prominent fractures trend NE. and NW. and the ore tends to follow the fractures as well as the undulating strata. Where the stopes in the upper level were forty feet high the ore near the floor was in the typical jasperoid breccia of the Boone formation but higher up the ore was in more finely bedded flint much fractured and fissured. Near the roof of the stopes the ore is in calcareous shale, the typical shaly limestone of the Mayes formation. In many places the ore extends to the shale overlying the Mayes limestone, and much of the shale in the roof of the stopes has caved in.

The upper part of the ore-bearing rock at both the middle level and the upper level is mainly in the Mayes formation, and in places the ore-body as above stated is mined up to the overlying shale. The two upper levels vary in depth with their relative position on the limb of the syncline. The ore at the lower (300-306 feet) level is apparently in the upper part of the Boone formation.

Discard Mine

The Discard mine, Century Zinc Company, is located on a forty-seven-acre lease, forming the SW. ¼, NW. ¼ of Sec. 17, T. 29 N., R. 24 E. It was formerly worked as the Vantage No. 2 mine. Mining on this lease began in 1921 and the production of zinc concentrates, 1921 to 1925 (Vantage No. 2) was 8,990 tons of zinc concentrates valued at $318,735 and 2,327 tons of lead concentrates valued at $214,740. The mine was not operated from 1926 to 1928, the Century Zinc Company beginning operation in 1929.

The collar of the mill shaft is at an elevation of 837 feet; the upper mine level formerly worked as the Vantage No. 2 is at 691 feet, the 146-foot level; and the present working lower level of the Discard mine is at 656 feet, the 180-foot level.

The ore-body at the upper, 146-foot level, was in relatively "tight" ground, in thinly bedded dark flint and white chert, finely fractured, but in a few places it graded into open "boulder" ground. The ore-bearing rock follows the bedding, the floor of the stope undulating slightly with the dip of the strata. The upper stopes are one hundred to 150 feet wide and from ten to twenty feet high.

The lower mine level about 180 feet below the surface, then being worked, is located southeast of the mill shaft, the ore being pulled through a 500-foot crosscut in light cherty limestone formation which extends under the upper 146-foot mine level. The ore-body mined at the 180-foot level is mainly in "open boulder" ground, quite unlike the "tight" ground worked at the 146-foot level. The boulders vary from less than a foot to four or five feet in diameter, the ore being within the smaller boulders as well as in the matrix between the boulders.

The stopes in the boulder ground are sixty to eighty feet high, but are usually narrow, or in pocket-shaped form. Good ore-bearing boulder ground southeast of the mill shaft extends in places far above the 146-foot level worked as Vantage No. 2, reaching nearly to the top of the Boone formation. The boundary between the "tight" ground and the much-broken "boulder" ground apparently trends in a NE. direction, parallel with the greatest extension of the ore-body as worked out at the 146-foot level. The boundary may be seen in the crosscut at the 180-foot level about 260 feet southeast of the mill shaft, and also along the southeast side of the underground workings on the upper 146-foot level where inclined fractures are developed along the contact, the fractures trending NE. and dipping to the NW. toward the area of relatively "tight" ground. The area of "tight" ground, therefore, extends farther southeast on the upper level than on the lower level where the crosscut is located.

The geologic section at the Discard mine beginning at the top shows up to 50 feet of soapstone, and five to twenty feet of relatively soft limestone, overlying the flinty limestone of the Boone formation at depths of fifty or sixty feet. The soapstone and soft limestone grade into one another both parallel with and across the bedding and are probably Mayes formation. The oolite horizon has been recognized in drill cuttings at various depths of 130 to 160 feet on the lease, and most of the ore is probably above the oolite horizon of the Boone.

Domado-Bethel Mine

The Domado-Bethel mine, Domado Lead & Zinc Company, is located on a 40-acre lease forming the SW. ¼ NW. ¼ sec. 29, T. 29 N., R. 23 E. Formerly the north half of the forty acres was the Domado mine and the south half the Bethel mine and were started in 1919.

The level of the mine in the southwest part of the lease is 208 feet below the surface, with stope-height of eighty feet near the shaft. The ore is in a much broken "bouldery" formation, with angular "boulders" ranging in size from three to four inches to four or five feet in diameter. The ore is mainly jasperoid breccia filling the space between the "boulders." The ore minerals also cover the walls of open cavities.

The ore-body at the Bethel mill shaft is a thick flat run with stopes about 300 feet wide and sixty to eighty feet high. The ground in the northeast part of the lease was mined from field shaft 3 at 232 feet and at 217 feet below the surface. Much of the ore in this part of the mine is in relatively tight, white, gray, and black flint, very much fractured, with the pronounced fractures trending N. 20° to 30° W. and N. 40° to 50° E.

The thickness of the shale on the Domado-Bethel tract is usually between forty and sixty feet. However, about 200 feet west of field shaft 3 the shale has a thickness of ninety-five feet and the ore-body was seen to be pitching down under this shale basin.

East Midas Mine

The East Midas mine, Childress Lead and Zinz Company, is a 20-acre lease forming the E. ½ NE. ¼ NW. ¼ sec. 28, T. 29, R. 23. The mine was started in 1918. The production is included with that of the Fort Worth mine.

The ore north of the shaft is mined at a 240-foot (below surface) level and that south of the shaft at a 232-foot level. The width of the stopes varies between twenty-five and fifty feet and the height from eight to fifteen feet. The ore-body varies from slightly broken to much broken "bouldery" ground. The ore-bearing rock is mainly the typical jasperoid breccia. The rise in elevation of the ore at the shaft from the 240 to the 232 foot level takes place in a zone of much broken "bouldery" formation in which many of the large blocks show a steep dip to the south. Elsewhere there is only a slight pitch of the ore-body to the northwest, in conformity with the regional dip.

A shallow cave extends out from the roof of the stope in the northwest part of the mine. The roof of the cave slopes slightly down to the northwest. The maximum height of the central part of the cave is about four feet and laterally it is about seventy-five to one hundred feet long and twenty-five feet wide. The roof of the cave consists of a massive bed of flint. The floor is composed of loose broken bouldery flint, a continuation of the formation in the adjacent roof of the stope. It is essentially barren of ore mineral.

Foch Mines

The two Foch mines, known as the Alexander-Foch mine and the Foch mine, located on cornering forty-acre leases were operated (in 1927) by the Golden Rod Mining and Smelting Company. The mines were opened in 1919 and from 1919 to 1928 produced 19,730 tons of zinc concentrates valued at $863,292 and 1,976 tons of lead concentrates valued at $184,710.

The Alexander-Foch mine is located on the SW. ¼, NW. ¼ sec. 19, T. 29 N., R. 23 E. The ore-body in the western part of the lease trends northwest and southwest. The ore is mined at a level of 268 feet below the collar of the shaft and varies only slightly from this level in various parts of the underground workings. The ore-body as stoped out was from twenty to forty feet in width, and from ten to thirty feet in height, reaching thirty feet a short distance southwest of the field shaft. The ore is mainly in much broken flint and some dolomitic limestone.

The Foch mine is located on a forty-acre lease forming the NE. ¼ NW. ¼ sec. 19, T. 29, R. 23. The ore from the mill shaft is mined at a 240-foot (below surface) level, dropping near the bottom of the shaft to 255 feet. The usual height of stope developed in the ore-body is ten to twenty feet, and the width from ten to forty feet. At the shaft, however, there was a body of ore leading up to a higher level mined at a 230-foot level, having a stope height of thirty-five feet, hence the vertical range in the ore-body near the mill shaft is about sixty feet. The ore in the upper stopes contained considerable tar, but that in the main lower stope contained none. The ore is in close association with both flint and dolomitic limestone.

A large open cave was broken into, about 600 feet southwest of the mill shaft, thirty feet in greatest height, one hundred feet in length, and seventy feet in width. The cave has a much wider ceiling than floor and the sloping walls consist of huge angular tilted blocks of flint coated on the surface with calcite and some ore mineral.

The shale on the Foch leases is generally about one hundred feet thick but reaches 140 to 160 feet in places.

Fort Worth Mine

The Fort Worth Mine, Childress Lead and Zinc Company, is located on a twenty-acre lease, forming the S. ½ SE. ¼ NW. ¼ sec. 28, T. 29 N., R. 23 E. Mining was begun in 1918. The total production, including that of the East Midas mine from 1918 to 1928 was 27,486 tons of zinc concentrates valued at $1,209,109, and 4,366 tons of lead concentrates valued at $444,894.

The mining operations in 1927 were confined to the southeast part of the lease. The earlier workings, in the western part, operated at 226 feet below the surface, had been shut down for some time. In 1927 the mine was worked at a 202-foot level, except in a small area southeast of the shaft which was worked at a 210-foot level. The ore-body is a broad flat run, the stopes ranging from 150 to 200 feet wide, and usually from ten to twenty feet high. A crosscut extends west of the shaft about 300 feet to a pocket of ore which has a width of fifty feet and height of thirty feet. The jasperoid ore is mainly in broken "bouldery" formation of white flint. The crosscut is through similar broken white flint, which, however, is barren of ore mineral.

The overlying shale has a thickness shown by drill records of fifty to sixty-five feet. The ore-zone is between one hundred and 125 feet below the top of the Boone formation.

Golden Rod Mines

The mines of the Golden Rod Mining and Smelting Corporation include a group of mines, most of which in active operation during the season of 1927, were visited briefly by the writer. Most of the Golden Rod mines are located near Cardin where the main mine office is situated.

The ore from eight mines located in SE. ¼ of sec. 20 and NE. ¼ of sec. 29, T. 29 N., R. 23 E. is separated at mill 4. The leases are designated as follows: mine 1, twenty acres; mine 2, forty acres; mine 4, forty acres; mine 6, twenty acres; mine 9A, twenty acres; mine 16, forty acres; mine 9B, twenty acres; mine 10, twenty acres. These various mines were started during the period of 1917 to 1923, and the combined output from 1917 to 1926 was 119,311 tons of zinc and lead concentrates. The relative proportion of zinc concentrates to lead concentrates was about five to one.

Mine 4 is a forty-acre lease (now combined with No. 1) located in the SW. ¼ SE. ¼ sec. 20, T. 29 N., R. 23 E. This mine began production in 1918. The ore is mined at a level which ranges from 210 to 220 feet below the shaft curb. The ore-body is in the form of broad flat runs with stopes eight to fifteen feet high, and five to sixty feet wide. The ore is the usual jasperoid breccia type and is in ground that is much broken. Open ground with cavities amounting to fifteen or twenty per cent of the rock is quite common. In places there are broken square blocks of flint three to four feet in diameter coated with crystals of ore and gangue mineral. The fractures trend in a northeast direction. The shale on this lease has a fairly uniform thickness of fifty to sixty feet. The ore is probably near the horizon of the oolite, although no definite data was available.

The following is a very brief generalized description of mines 2, 6, 9A, 9B, 10, and 16, located in the NE. ¼ sec. 29, T. 29 N., R. 23 E.

The ore-bodies in these mines are in the form of runs ten to sixty feet wide, and five to thirty-five feet high. The ore is mined at one level, ranging from 220 to 240 feet below the surface at the shaft. The ore is the usual chert breccia type, in ground very much broken in places.

A large cave of ore 140 to 160 feet long, five to thirty feet wide and from two to ten feet high was mined in the east part of 9B. The cave is lined with "boulder" formation of flint blocks reaching six to twelve feet in diameter. Some of the boulders were rich in zinc ore and others only coated with ore mineral. A cave in the west part of mine No. 6, varying from one to six feet in height is lined with flint blocks covered only with marcasite and "dogtooth" calcite, and carried only traces of ore. Marcasite "mundic" cups are a characteristic feature of this cave. Aragonite altered to calcite was noted in considerable abundance in the walls of a drift in broken ground a short distance northwest of the bottom of shaft No. 9. The aragonite formed nodular masses up to six inches in diameter and was closely associated with the zinc ore filling the open cracks in the broken flint ground.

The thickness of shale and surface soil on mine leases 10, 6, and 2 is from ten to sixty feet, with an average thickness of forty feet; but on 9, 9B, and 16 the shale is much thicker, usually more than thirty to sixty feet, reaching over one hundred feet in a few places on No. 16.

Mine No. 5 is located on a forty-acre lease forming the NW. ¼ SE. ¼ sec. 20, T. 29 N., R. 23 E. The mine was started in 1918 and from 1918 to 1926 produced 54,191.51 tons of zinc concentrates valued at $2,468,192.36 and 3,370.15 tons of lead concentrates valued at $331,214.68.

The ore is mined mainly at one level, about 220 feet below the surface. The ore-body is in the form of a broad flat run, the stopes being five to fifteen feet high and from twenty to sixty feet wide. An exception is the unusually high stope of 105 feet, a short distance south of shaft 5. The ore is the usual type, a brecciated white flint cemented with jasperoid. In places the ore is in dolomitic limestone and flint. The shale has a variable thickness of forty to seventy feet on this lease. The ore at the 200-foot level is probably near the horizon of the oolite.

The No. 8 mine is located on a forty-acre lease forming the NE. ¼ SW. ¼ sec. 20, T. 29 N., R. 23 E., and was started in 1917. The ore is separated at mill 7 and is combined with the output of mine 7 and 3. The total production of the three mines from 1917 to 1926 was 61,739 tons of zinc and lead concentrates.

The ore-body in mine 8 is mined at one level, ranging from 200 to 215 feet below the shaft curb. The ore-body, as indicated by the mined-out ground, ranged from five to twenty feet high and from five to sixty feet wide. The ore is the usual jasperoid breccia type, in fairly massive chert formation. The ore-bearing ground is usually "tight," but in some places there is open ground with small caves, lined with calcite, dolomite, and the ore minerals. The ore-body is slightly undulating in conformity with the undulating bedding structure of the Boone formation. Some shale in the Boone was noted of varying thickness from less than one foot to five or six feet. Not much limestone was noted in the ore-body but the formation adjacent to the ore is limestone or flint formation. The walls of the mine stopes are much fractured and broken, but no well-defined fracturing in narrow zones was observed. Where fracturing is regular, however, the trend of the fracture systems is northeast and northwest. The shale on this lease has a fairly uniform thickness of fifty to sixty feet.

Mine 26 is on a lease of 200 acres, forming the entire SE. ¼ and the SE. ¼ SW. ¼ sec. 23, T. 29 N., R. 23 E. Mining was begun in 1926. The mine level at shaft 26A varies slightly from 203 feet below the curb, ranging from 206 feet to 195 feet. Some stopes are ten to twelve feet high but the average height is about five to six feet. The mine level at shaft 26B is 220 feet below the curb, and at shaft 26C there was an upper level of ore at 180 feet and additional ore at a 225-foot level. The ore throughout the 200-acre tract forms relatively narrow runs and small pockets in a white chert formation which contains some jasperoid with much white dolomite in veins and cavities. The ore is mainly zinc blende with a very small amount of galena. The shale has a usual thickness of forty feet on this lease but reaches one hundred feet in a few places in the south part.

Goodwin Mine

The Goodwin mine, Eagle-Picher Lead Company, is located on a fifty-acre lease forming the NE. ¼ NE. ¼ sec. 17, T. 29 N., R. 23 E. This mine was opened in 1917 and the production from 1917 to 1928 was 71,016 tons of zinc concentrates valued at $3,294,202 and 5,536 tons of lead concentrates valued at $542,651.

The ore is mined at three levels, approximately 190 feet, 215 feet below the surface at the shaft. The ore from the upper level is mainly in white flint and some jasperoid, much fractured in places, not "bouldery" but containing a few small cavities. The stopes in the upper level are generally from fifty to one hundred feet wide.

The ore-body in the middle level at 215 feet, is characterized by much white flint and also much jasperoid but is relatively "tight" as in the upper level. The stopes at the middle level range from fifteen to twenty-five feet in height and from fifty to 150 feet in width.

The ore-body at the lowest, 260-foot level, is characterized by much jasperoid, in a broken "bouldery" formation and is richer in mineral than at the upper levels. Cavities are abundant and many small caves lined with "tiff" and ore mineral have been opened. The stopes in the lower level are generally from twenty to thirty feet high and from fifty to 200 feet wide.

The ore runs at the three levels maintain an approximate horizontal extension and the wide stopes extend over much of the eastern half of the lease. The roof and floor of the stopes at the two upper levels are united in places. The lower run of ore, however, is distinctly separated from the overlying middle run by fifteen to thirty feet of barren rock.

The shale is quite uniformly between sixty and eighty feet thick. The thickness of the Mayes formation can not be definitely determined but is probably between twenty and forty feet.

Gordon Mine

The Gordon mine, Federal Mining and Smelting Company, is located on a 210-acre lease in the eastern part of sec. 18, T. 29, R. 23 E. That part of the lease forming the ten-acre fraction in the NE. ¼, SE. ¼ of sec. 18 was formerly worked as the Whiskbroom mine; that part included in the SE. ¼, NE. ¼ sec. 18 formerly comprised the Burnham mine (twenty acres) and the Tiger mine (twenty acres); and the NW. ¼, SE. ¼ was formerly the Chicago-Miami mine (forty acres). The present 210-acre lease now worked as the Gordon mine, including the estimated production of the earlier mining operations above mentioned to the close of 1928 was 22,775 tons of lead concentrates, and 50,693 tons of zinc concentrates, having an estimated total value of $4,075,026.

The Gordon mine was worked (1929) from fifteen or sixteen shafts. The mine level in the northern part of the lease is somewhat deeper than farther south, at 260 to 290 feet below the surface. In the SE.¼ of sec. 18 the mine level is at 220 and 250 feet.

In the old Whiskbroom mine, shaft 6, the general mining level is at 280 to 290 feet below the surface. The ore is in much broken "boulder" ground. The stopes in places have a width of one hundred feet, and a usual height of ten to twenty feet. In the old Burnham mine the stopes are higher reaching to twenty and forty feet in many places. The roof of the stopes is relatively tight flint ground, but in general there is more "boulder" ground in the Whiskbroom than in the Burnham farther south.

In shaft 2, the old Chicago-Miami mine, the main mine level is at 250 feet. The ore is mainly in coarse boulder ground. The stopes are usually twenty to forty feet wide, and from twenty to forty feet high, but in places, as near shaft 2, the stope reaches a height of one hundred feet.

In the NE. ¼, SE. ¼ of sec. 18, about 400 feet northwest of shaft 3, the ore-body follows a sharp dip of the strata to the northeast, the dip carrying the formation down twenty feet in one hundred feet horizontal distance. Some small caves occur in the sloping ground, the roofs of the caves pitching with the dip of the strata.

In shaft 7, on the east side of the Beulah B, twenty acres, the mining level is at 250 feet. Tight flinty ore-bearing ground characterized the lower parts of the stopes, with more broken bouldery ground above, between the tight flinty ground of the floor and the roof. The stopes are twenty to forty feet high, increasing to fifty or sixty feet adjacent to the Howe mine on the east. Anglesite developed on galena, occurs in the walls of the stopes adjacent to the Howe mine.

In the mined-out stopes of shaft 6, the Whiskbroom, iron sulphate, melanterite, is being deposited. The melanterite forms so called "icicles" where ground water, containing the iron sulphate in solution has dripped down through the roof of the stopes. Both stalactitic and stalagmitic forms are developed and it is reported that in places these may be joined together forming pillars having a thickness of over a foot. The melanterite stalagmites collected by the writer from the floor of the stope were four to six inches in height and two or three inches in diameter.

Tar is encountered to some extent in the workings of the Gordon SW. forty-acre lease and the ore is treated by roasting before being crushed and milled.

In the abandoned stopes at the "Tar Shaft" the rate of accumulation of tar dripping from the roof is estimated at five to six barrels per week from a roof area of about one hundred by twenty feet. The rate of accumulation varies somewhat, being greater during and immediately following rainy seasons. The tar is collected by the Picher Roofing Company and treated for use as roofing tar.

Grace Walker Mine No. 2

The Grace Walker No. 2, Commerce Mining and Royalty Company, is located on a forty-acre lease forming the SE. ¼ SW. ½ sec. 21, T. 29 N., R. 23 E. The mine was first opened in 1919 and the production from 1919 to 1928 was 23,399 tons of zinc concentrates valued at $938,047.68 and 3,436 tons of lead concentrates valued at $319,567.

The mine is being worked from two shafts, the No. 5 shaft located on the west side of the lease and the No. 6 shaft on the south central part.

The mine workings at both shafts are operated at a level 240 feet below the surface, the ore-body forming an irregular-shaped flat run. The mine stopes near the No. 5 shaft usually range from ten to fifteen feet high, but near the No. 6 shaft are somewhat higher, reaching to thirty-five or forty-five feet, the highest stopes being located to the southeast. The width of the stopes is quite irregular, ranging from fifty to three hundred feet. The ore is in typical jasperoid, the formation varying from relatively "tight" to much fractured rock with small openings and crevices. Minute crystals of barite were noted on galena in a small cavity.

A shallow cave was opened on a level with the top of the stope 300 feet northeast of shaft No. 5. The cave is a broad flat chamber about one hundred feet in horizontal extension and from one to three feet in height. The floor and ceiling of the cave consists of the typical jasperoid flint, the floor being covered with many good sized crystals of galena encrusted with coxcomb marcasite.

The shale in this locality reaches a thickness of fifty to seventy feet, and the ore is apparently in the lower part of the upper half of the Boone formation.

Harrisburg Mine

The Harrisburg mine, operated until April, 1927 by the Harrisburg Mining Company is located on a forty-acre lease comprising the SW. ¼, SW. ¼ of sec. 19, T. 29 N., R. 22 E. It was (1929) operated as a part of the Lion Mine by the Velie Mines Corporation. The mine was started in 1917 and the production from that year to 1927 was 10,518 tons of zinc concentrates valued at $425,024 and 5,708 tons of lead concentrates valued at $434,157.

Two separate ore-bodies were mined, one located in the northeast part and the other in the southwest and west part of the lease.

The ore in the northeast part of the lease was mined from two levels. The ore run mined at the lower level ranges from 246 feet below the surface at the northwest end to 262 feet at the southeast end. The width of stope is twenty-five to fifty feet and the height usually from twenty to thirty feet. The ore in the lower level, mainly in "boulder" ground, is mainly zinc blende and is in the Boone formation.

The upper ore-body was mined at a level of 186 to 190 feet below the surface, the stope inclining slightly to the southeast. The width of stope developed in the upper level was 150 to 200 feet, and the height from thirty to fifty feet. The ore, mainly galena, in the upper ground was in stratified, much fractured, "sandspar" and flint and is in the Mayes formation.

The ore-body mined in the southwestern and western part of the lease was worked on one level, corresponding to the lower level of the workings in the northeast part of the lease. The ore-body forms a long run trending northwest across the entire lease. The stope at the northwest end is at a 245-foot level, and at the southeast end at a 263-foot level (below the surface). However, the bottom of the ore at the southeast end has not been reached and it may extend to 285 feet. The width of the stopes is generally from thirty to sixty feet, but in one place reaches 200 feet. The height of the stopes is usually from twenty to thirty feet, but where the stope has a width of 200 feet it has a height of fifty feet. The ore, mainly zinc blende, is in "tight" rather than "open boulder" ground, and is in the Boone formation.

The shale varies from 120 feet in thickness in the northwestern part to 170 feet in the southeastern part of the lease. The ore-bodies follow the dip of the Boone and Mayes strata and pitch to the southeast toward the Miami syncline. The ore also follows the major fractures which trend to the northwest, making short turns with the fractures trending northeast.

Howe Mine

The Howe mine, Howe Mining Company, is located on a forty-acre lease forming the SW. ¼ SW. ¼ sec. 17, T. 29 N., R. 23 E. It began operating in 1918 and the production from 1918 to 1928 was 17,420 tons of zinc concentrates valued at $748,681 and 10,608 tons of lead concentrates valued at $1,008,988.

This mine has four stope levels, the highest at 130 to 135 feet, one at 155 to 160 feet, one at 180 to 210 feet varying in different parts of the mine, and the lowest at 235 to 240 feet, below the surface. The mine is in a shallow part of the Miami syncline.

The highest ore-body at 130 to 135 feet, is in the basal beds of the Mayes limestone formation. The ore at this upper level is developed in the north central part of the lease where the shale reaches a thickness of 115 to 129 feet and the underlying Mayes limestone has a thickness of about twenty or thirty feet. The ore is mainly in the typical "sandspar" characteristic of the ore-bearing rock in the Mayes formation, and is closely associated with dolomitized limestone and dolomitized shaly limestone.

The next underlying ore-body, at the 155 to 160-foot level, is about twenty feet from the top of the Boone formation, the ore being in a rather "tight" flint formation. The ore-body in this horizon is located in the north central part of the lease under the ore-body in the Mayes formation.

The ore run, on the 180 to 210-foot level, is 70 to 90 feet below the top of the Boone, apparently being somewhat higher in the Boone under the Mayes ore-body than elsewhere. The ore at this level is the typical jasperoid and white flint ore, relatively "tight," but containing much fractured rock and flint. The ore-body at this horizon is worked in all parts of the mine, underneath the ore in the Mayes and elsewhere.

The lowest, or 235 to 240-foot level, is worked only in the southwest part of the mine, and is about 135 or 140 feet below the top of the Boone. The stopes at this level are from ten to twenty feet high, and the ore is broken "bouldery" jasperoid formation. All of the ore-bodies in the Boone follow slight undulations in the dip of the strata, and in some cases at least, follow the prominent fractures.

Jay Bird Mine

The Jay Bird mine, Commerce Mining and Royalty Company, is located on a forty-acre lease forming the SW. ¼ NW. ¼ sec. 30, T. 29 N:, R. 23 E. The mine was started in 1917 and the production from 1917 to 1928 was 37,519 tons of zinc concentrates valued at $1,740,292 and 5,093 tons of lead concentrates valued at $499,585.

The ore is mined mainly from the 313-foot (below surface) level. Near the mill shaft, however, the floor of the stope descends to the 323-foot level and at the southeast corner of the lease adjoining the Woodchuck mine, it ascends to the 292-foot level. The ore-body is in the form of a run from fifty to 150 feet in width and from thirty to sixty feet in height. The greatest height of stope developed to 1927, fifty to sixty feet, is in the western part of the mine. Near the bottom of the mill shaft the ore-body is relatively thick and eventually the ore-body when mined out will develop a stope forty to fifty feet high. The ore-body in the southwest part of the mine following the dip of the strata pitches down to the southwest in conformity with the increased depth of shale to the southwest. At the higher 292-foot level the ore-body in the southeast part of the mine is likewise due to an upward flexure of the Boone strata, being arched upward about twenty feet in 240 feet of horizontal distance.

A prominent system of fractures is developed in the western part of the mine trending northwest with minor fractures trending northeast. The ore-bearing rock is mainly jasperoid, relatively "tight" and much fractured in some places, but broken irregularly into "boulder-like" formation in other places. Small cavities are common and a few caves lined with calcite were noted.

The ore-body throughout the mine occupies essentially the same horizon, about 170 to 190 feet below the top of the Boone. The thickness of the shale, mainly Cherokee, overlying the lease varies from seventy to 135 feet, the strata of the Boone formation descending beneath the deeper shale, and ascending under the shallower shale.

Lucky Syndicate Mine

The Lucky Syndicate mine, operated since 1924 by the Federal Mining and Smelting Company, is located on an eighty-acre lease, forming the N. ¼ SW. ¼ sec. 17, T. 29 N., R. 23 E. The mine was opened in 1918 and the production (including Producers-Hopkins, estimated) from 1918 to 1928 was 21,538 tons of zinc concentrates and 13,425 tons of lead concentrates, the total valued at $2,034,367.

The ore is mined at two levels in the western part of the mine, and at three levels in the eastern part adjoining the Otis White mine which is also mined at three levels. The ore-bodies overlie one another and in the western part of the lease the two levels are at 180 feet and 233 feet, and in the eastern part the two most important levels are approximately at 200 and 230 feet below the surface. The ore runs vary greatly in height and width. In the southwest part of the east forty-acre lease at shafts 3 and 6 the ore formed a wide flat-lying body at the 185-foot level, the stopes having a variable height of five to twenty feet, and a width of fifty to over 200 feet. In other parts of the mine the width of stope generally ranges between forty and 160 feet.

The shale reaches a thickness varying from eighty to 120 feet over most of the lease, but in the southwest part of the NW. ¼ SW. ¼ section 17 the shale is 170 feet thick.

The ore-body is apparently near the oolite horizon. The driller's log of the Lucky Syndicate deep well (which is) located near shafts 3 and 6 reports "lime" at ninety to 140 feet and "lime" and "flint" from 140 to 475 feet, with black shale at 475 to 480 feet. The "lime" at ninety to 140 feet is probably the Mayes limestone and the "lime and flint" from 140 to 475 feet probably should be interpreted as Boone formation, and the five feet of black shale, from 475 to 480 feet, probably represents the Chattanooga shale. Apparently about 335 feet of lime and flint represents the Boone formation. As it is usually from 110 to 135 feet below the top of the Boone, the oolite horizon would be penetrated at a depth of 250 to 275 feet below the surface, indicating that the lower ore-bodies are probably located near the oolite horizon as above stated.

Malsbury Mine

The Malsbury mine, Century Zinc Company, is on a forty-acre lease forming the NW. ¼, NE. ¼ of sec. 19, T. 29 N., R. 24 E. The mine was opened in 1924 and the production to 1928 was 37,726 tons of zinc concentrates valued at $1,648,238 and 10,630 tons of lead concentrates valued at $1,054,903.

The ore-bearing rock forms a nearly flat run or broad sheet-like body extending over a large part of the south half of the lease. The ore is mined on one level, from 120 to 130 feet below the surface. The mine stopes range from five to twenty feet in height and reach in several places over 500 feet in width. The ore is in typical jasperoid breccia in siliceous dolomitized limestone. The tenor of much of the ore-bearing rock was ten to twenty per cent in zinc and lead concentrates, being not only richer in zinc but relatively higher in lead than in the mines of the surrounding locality of the eastern part of the district.

The Boone formation lies very near the surface, generally being overlaid with only five to twenty feet of shale and surface formation. The stratigraphic position of the ore-body is in, or very near, the oolite horizon of the Boone.

Mudd Mine

The Mudd mine, Anna Beaver Mines Company, is on an eighty-acre lease forming the N. ½ of the SE. ¼ of Sec. 23, T. 29 N., R. 22 E. This company also operates the Xavier mine on the forty-acre lease on the west. The ore from the Mudd mine which began operating in 1927 is milled at the Adams mine. The production in 1927 and 1928 was 13,766 tons of zinc concentrates valued at $512,530 and 3,427 tons of lead concentrates valued at $274,543.

In June, 1929 the east sixty acres of the Mudd lease was being mined from the No. 1 and the No. 2 field shafts which have underground connection. The west twenty acres is mined from the No. 3 shaft.

The principal mine level at the No. 1 shaft is 256 feet below the surface at the shaft. The stopes are usually from thirty to thirty-five feet high and from twenty to eighty feet wide. About one hundred feet north of shaft 1 the stope is chimney-like and reaches up to a height of over one hundred feet, the ore in the top of the chimney being mined at a high level. The ore-bearing rock in the lower ground is very coarse and "bouldery" up to fifty feet or so, but above this it grades into tighter and more distinctly stratified flinty and dolomitic ore-bearing rock.

The bouldery ore below and the less broken ore ground above continues westward to the No. 2 shaft which is mined at a 262-foot level. Another high chimney-like ore-body reaching one hundred feet above the 262-foot level is located about 300 feet southwest of shaft 2.

At the No. 3 shaft, at the west end of the eighty-acre lease the ore is mined at a 237-foot level, the vertical range of ore being irregular, with stopes in places reaching forty feet high.

In the Mudd mine as above indicated, the upper beds are relatively "tight" and also much more finely shattered than the lower "boulder" ground. The trend of fractures in the upper ground varies, but is mainly in an east-west direction. The overlying shale, mainly Cherokee, is from one hundred to 120 feet thick. The ore is apparently mainly in the upper part of the Boone formation, however, in the high chimneys it may reach up into the overlying Mayes limestone.

Netta Mine

The Netta mine, Eagle-Picher Lead Company, is located on a 200-acre lease forming the N. ½ NE. ¼ sec. 20 and N. ½, NW. ¼ of sec. 20, and SW. ¼, SE. ¼ of sec. 17, of T. 29 N., R. 23 E. This mine, opened in 1916, was one of the first to be operated in the Picher district and produced to 1928, 117,931 tons of zinc concentrates valued at $5,780,341 and 30,591 tons of lead concentrates valued at $1,662,438.

The ore occurs in flat runs at three fairly well-defined levels, at 200 feet, 235 to 240 feet, and 270 feet below the surface. The mine workings in the N. ½, NE. ¼ of sec. 20, visited in 1927 extended under about one half of this portion of the lease. The height of the stopes ranged from ten to twenty-five feet and their width fifty to more than 500 feet. The ore follows the bedding and also follows very closely the fairly well-defined fractures which trend in a northeast and northwest direction and dip at a high angle. Lenses of black Boone shale three to four feet thick were observed in the stopes.

The ore is the typical jasperoid breccia varying from much broken and brecciated "bouldery" masses to slightly shattered formation. The less broken formation is crossed with numerous vertical fractures filled with calcite and some lead ore. Along the vertical fractures there are vertical displacements from a fraction of an inch to several inches with well developed slickensided surfaces nearly vertically striated.

Aragonite, altered to calcite, occurs as a filling in small openings at the lower level. It is developed upon the ordinary form of "dog tooth" calcite, on white flint, and on zinc blende.

Several caves have been opened in the Netta mine, one of the largest being about one hundred feet in lateral extension and about four feet in greatest height at the center, narrowing down to a knife edge about the border. It has a domed ceiling and a rough uneven floor, both being covered with large calcite crystals. The cave adjoins a stope and is entirely barren of ore.

A smaller cave in another part of the mine is shaped like a flat funnel, seventy-five feet wide at the top, with domed ceiling rising five to seven feet above the floor in the central part, the open space narrowing down to a knife edge about the border. The floor is covered with calcite and the ceiling, composed of flint rock, is covered with some galena in addition to calcite.

The shape of these caves as well as the character of the flinty rock in which they occur suggest their origin by arching of the strata combined with subsequent settling underneath, rather than by solution.

The thickness of the Cherokee shale in the locality ranges from seventy to 120 feet, but is usually from ninety to one hundred feet.

New Chicago Mines

The New Chicago mines, No. 1 and No. 2, the New Chicago Mining Company, are located on two leases, No. 1, 160 acres, forming the NE. ¼ of sec. 28 and No. 2, eighty acres, forming the NE. ¼, SW. ¼ and the SE. ¼, SW. ¼ of sec. 28, of T. 29 N., R. 23 E. Mining on the two leases was begun in 1918 and the combined production from 1918 to 1928 was 85,811 tons of zinc concentrates valued at $3,507,415 and 14,770 tons of lead concentrates valued at $1,472,645.

The ore in 1927 was being mined from nine shafts. The shafts 3 and 8 were located on the NW. ¼ NE. ¼ sec. 28, shafts 5, 7, and 9 on the SE. ¼ NW. ¼ sec. 28, and shaft 6 on the NE. ¼ SW. ¼ sec. 28. The ore was being mined principally at levels ranging from 203 feet below the surface in some of the shafts to 214 feet in others, and in a few places, at a higher level, thirty-five to forty feet above the lower, at about 175 feet below the surface. The ore is typical jasperoid, in more or less broken "bouldery" ground, the broken ground being cemented with a mixture of jasperoid and ore. The much broken ground also contains many small cavities, a few large enough to be called caves, which are lined with ore mineral, dolomite and calcite. Straight or ramifying veins of dolomite, calcite and ore mineral extend throughout the broken ground. Mineralized veins of galena, or of galena mixed with dolomite, were noted in places which were obviously of somewhat later deposition than the prevailing jasperoid ore forming the principal part of the matrix or cement of the boulder ground.

The mine stopes worked from the above shafts have a usual height of six to fourteen feet, but in a few places they reach twenty feet. The width of stope is variable, usually from twenty to sixty feet, but in many places they are over one hundred feet in width. The slightly undulating roofs of the stopes are supported by rock left as pillars or by timber. The narrow runs generally follow the trend of the main fractures. "Limestone bars" extend through the ore runs in a few places. Crumpled shale lenses are intercalated between limestone strata showing the effects of pressure and folding.

The mill shaft, or shaft 1, is located in SE. ¼ NE. ¼ section 28. The main mining level there and in the western part of the mine worked from this shaft is 143 feet below the surface. The stope level rises to 135 feet in the eastern part of the workings. The ore-body is in the form of a broad flat run with stopes from fifty to 250 feet wide and from ten to fifteen feet high. The ore-bearing rock as stoped out has a flint or jasperoid floor and a ceiling of shaly limestone, "green lime" or "chloritic lime." The ore formation is somewhat "bouldery." Fracturing is common and the ore tends to follow the fracturing. This lease is overlaid with only twenty to thirty feet of shale (Cherokee or Mayes) below which is generally twenty to thirty feet of gray limestone of the Mayes formation. The ore-body at the 135- to 143-foot level is between sixty and eighty feet below the top of the Boone and is immediately under the "green lime" horizon. The ore is approximately in or above the oolite horizon.

Shaft 2 is located in the northeast part of the SE. ¼, NE. ¼ section 28. The eastern part of the mine workings is on the 143-foot level the same as that of shaft 1 but in the central and western part, the stopes are inclined, the ore-body pitching down either with the dip of the strata, or with the inclined fractures. One stope in following the ore pitches down to the northwest, from 143 feet down to 191 feet, where the ore is being delivered through an ore chute to a hopper, being dropped twenty-five feet to the 216-foot level of the stopes in the No. 3 shaft. Another stope pitches down to the west from the 143-foot level to a 170-foot level. The ore-body in both stopes pitches down along inclined fractures which trend N. 30° to 40° E. and N. 30° to 40° W. The ore-body in the inclined stopes is mainly broken "bouldery" ground with good ore filling the openings between the "boulders." The stopes are from twenty-five to 125 feet wide and eight to ten feet high with a few "chimneys" twenty to forty feet high.

The ore south of shaft 4 is mined from the 188-foot (below surface) level and that north of the shaft from the 202-foot level, the north stope gradually pitching down to a 228-foot level 350 feet north of the shaft at the property line. In pitching down to the north the ore-body follows a local northward dip of the strata and also the general northeast and the northwest trends of the fracturing. An ore-body 600 feet southeast of the shaft is mined from a 194- to 201-foot level. The stopes developed in the mine workings of shaft 4 are twenty-five to one hundred feet wide and ten to fifteen feet high.

New York Mine

The New York mine, Cortez-King Brand Mines Company, is on a forty-acre lease forming the SW. ¼, SW. ¼ sec. 21, T. 29 N., R. 23 E. Mining was started in 1922 and the production to 1928 was 37,726 tons of zinc concentrates valued at $1,536,790 and 5,964 tons of lead concentrates valued at $588,667.

The principal mine level at the mill shaft, in the eastern part of the lease, is 238 feet below the surface at the shaft. A large body of ore was worked about 350 feet north of the mill shaft at a 190-foot level. A downward pitch in the ore body 200 feet northwest of the mill shaft is being mined at the 263-foot level. While the main ore-body lies nearly horizontal, near the 238-foot level, it pitches down in various places in conformity with the dip of the strata. The ore-body mined on the upper 190-foot level is in a horizon some forty-five feet above the main ore-body mined at 238 feet. The ore-bearing rock is the typical jasperoid formation, and is the much-broken "bouldery" type in the southern part of the lease, and relatively "tight," much fractured flint in the northern part. The ore-body is in the form of flat runs with many pockets. The runs have a usual width of fifty to 150 feet and a usual height of fifteen to twenty feet, increasing in a few places up to fifty feet. The floor and ceiling as well as the side-walls of the stopes are mainly flint rock.

The shale has a usual thickness on this lease of thirty-five to sixty feet. In some places, however, it is less than twenty feet, and in others more than seventy feet. Below the shale there is generally a variable thickness of thirty to fifty feet reported as brown or gray "lime" representing in part the Mayes limestone. The main ore-body ranging between 263 and 238 feet below the surface apparently lies about 140 to 165 feet below the top of the Boone.

Oklahoma-Woodchuck Mine

The Oklahoma-Woodchuck mine, Oklahoma-Woodchuck Lead and Zinc Company, is on a forty-acre lease forming the SE. ¼ NE. ¼ sec. 30, T. 29 N., R. 23 E. The mine was started in 1917 and operated by the Commerce Mining and Royalty Company, until 1926 when the present operating company leased the mine. The production from 1917 to 1928 was 79,610 tons of zinc concentrates valued at $3,361,992 and 20,052 tons of lead concentrates valued at $1,799,814.

The ore has been mined at several levels, the lowest about 283 feet and the highest at 245 or 250 feet below the collar of the shaft. The ore-body is in the form of a large irregular run, twenty-five to 150 feet wide, and thirty to 120 feet high. The ore-body in certain parts of the mine is continuous from the lowest to the highest level and where the roofs of the lower stopes have been mined out, open chambers are formed 118 to 120 feet in height.

The ore-body is a much broken and "bouldery" formation. The lower portion contains much dark jasperoid, but the higher portion is characterized by much spotted white and gray flint with smaller amounts of dark flint. The floor of the stopes is usually flint, and the ceiling in the low stopes of thirty to forty feet high usually reach into flint. The walls of the stopes are flint, or flint with broken limestone. Rich lead ore predominates in the upper eight or ten feet of the high levels.

Small and large cavities in the ore-body are common, and many are lined with white aragonite crystals in mammillary and kidney-shaped forms, ranging in size from one inch up to five or six inches in diameter. The aragonite, changed to calcite, occurs from the bottom to the top of the mine workings through a vertical range of over one hundred feet.

Large fractures trending about N. 25° E. were noted in the roof of stopes in the west central part of the mine. A map showing fracturing in the Woodchuck mine made by G. M. Fowler is shown in Plate IV. The fractures are curved and dip at angles of 55° to 90°. Most of the ore formation is so much broken that the bedding planes of the rock formations are difficult to recognize.

The thickness of shale varies from fifty to seventy-five feet on the eastern side of the lease and eighty-five to 130 feet on the western. The logs of drill holes usually indicate forty to fifty feet of Mayes formation between the shale and underlying Boone. The sub-surface of the shale is quite uneven, the undulations in the sub-surface, in part at least, being due to flexures in the underlying formation and developing the pitching ore-bodies with sloping stope floors as seen in the mine workings. The ore-bearing ground is within the upper part of the Boone. The lowest mine levels approximate the oolite horizon but the upper ore reaches nearly to the top of the Boone and may possibly extend up into the basal portion of the overlying Mayes limestone.

Otis White Mine

The Otis White mine is located on a forty-acre lease forming the NW.¼ SE.¼ sec. 17, T. 29 N., R. 23 E. It was opened in 1922 by the White Mining Company and operated until 1926. Since 1927 it has been operated by the Tri State Zinc, Inc. The production from 1922 to 1928 was 30,268 tons of zinc concentrates, valued at $1,288,057 and 7,765 tons of lead concentrates valued at $752,264.

The ore-body is in the form of fairly well defined runs, mined on three levels at 160, 190, and 230 feet below the surface. The upper levels directly overlie the lower, and their position obviously is controlled by the nearly vertical fracture zones that affect the Boone formation. The mine stopes on each level range from five to twenty-five feet in height and in places the workable ore extends from one level to another. The width of the stopes usually ranges between twenty and forty feet but in a few places reaches one hundred feet.

The ore-bearing rock is in chert and jasperoid breccia. In the upper stope some tar, seeped down from the overlying Cherokee shale, is found in the ore.

The shale has a usual thickness of sixty to seventy feet at this mine. The green shale (glauconite) horizon occurs at depths ranging from 180 to 190 feet in some parts of the lease to 215 and 225 feet in other parts. The oolite horizon occurs forty to fifty feet below the green shale as shown by the drill records in Table VIII. Therefore the ore-body lies in the zone occupied by the oolite and green shale, and extends both above and below these horizons.

Pioneer Mine

The Pioneer mine, D. L. Larsh and Company, is on an eighty-acre lease forming the SE. ¼ NW. ¼ and the NE. ¼ SE. ¼ sec. 25, T. 29 N., R. 22 E. The mine was started in 1918 and the production to 1928 was 24,300 tons of zinc concentrates valued at $963,485 and 13,176 tons of lead concentrates valued at $1,292,759.

The underground mine workings located on the south half of the eighty-acre lease were started in 1927 from shaft 3, the principal mine level being 313 feet below the surface. An upper level at 277 to 283 feet was mined for a time but subsequently the upper ground was broken down to the lower level. The ore is typical jasperoid much broken and fissured. The ore-body follows the slope of the bedding and dips mainly to the south. The fractures and fissures run north-south and nearly east-west but the dip of the strata and the fracturing tends to converge downward toward the bottom of a deep shale trough located to the southwest of the (1927) workings. The dip of the bedding is not uniform but varies from nearly horizontal to short steep flexures having a dip of forty to fifty degrees, the change in dip being abrupt. The vertical range of the ore is about 140 feet, from 200 feet down to 340 feet below the surface over the entire lease, but the highest stope in any place usually does not exceed 105 feet.

In June, 1929 the mine was being worked from a field shaft in the south part of the north forty-acre lease. The workings above the 315 foot level showed the ore-body dipping to the north in conformity with the northward dip of the Boone in the limb of a structural basin adjoining on the north.

In the mine workings of the south part of the north forty-acres there is a large cave with floor and roof sloping down to the southwest, conforming with the steep 40° to 45° dip of the strata in this part of the mine. The cave is T-shaped with the main extension about 250 to 300 feet in length. Being on a slope the cave may be said to have a hanging-wall and a foot-wall. The distance between the sloping floor and sloping roof is only one to four feet, as compared with its great lateral extension of 250 to 300 feet. Both floor and roof of the cave consist of flint rock and are covered with large crystals of "dog tooth" calcite. The lower end of the cave, about one-third of the cavity, is water-tight and is used as a reservoir, into which water from the north part of the mine is drained naturally and into which water from the lower south end, from a sump, is lifted by a small pump and is then pumped out of the cave for a few hours a day by a large pump. When the northern end of the mine is shut down the water level in the cave is usually twenty-five to thirty feet above the level of ground water in the south part immediately adjacent.

The fact that the walls and floor of the cave are essentially impervious as indicated by its present use as a natural reservoir for underground water storage shows that the cave at present at least is not a water course. The origin of the caves of the district as stated elsewhere is believed to be due to deformation of the rock strata rather than solution by underground water.

The thickness of the shale ranges from about one hundred feet to 160 feet. The bottom of the shale is very undulating, and the steeply dipping and folded strata shown in the mine workings coordinate with the uneven sub-surface of the shale.

Rialto Mine

The Rialto mine, Rialto Mining Company, is located on a sixty-acre lease, twenty acres forming the S. ½, NE. ¼, NE. ¼ and forty acres forming the SE. ¼ NE. ½ sec. 29, T. 29 N., R. 23 E. The mine was started in 1922 and a large production had been developed from 1922 to 1928, exact figures for which were not furnished.

The mine level at the mill shaft is 233 feet below the surface. However, an upper level near this shaft was worked at about 200 feet for a short time. The main ore body at 233 feet is a "flat run" with stopes fifteen to thirty feet high, and fifty to 250 feet wide.

About 300 feet southeast of the mill shaft the ore pitches down to the southeast, being mined in July, 1927 on a 247-foot level, and in June, 1929 at 275 to 285 feet. The ore-body is a much fractured formation in this stope and the pitch of the ore to the southeast apparently follows abundant fractures in relatively tight flint, rather than bedding planes, the fractures trending NE. and dipping 25° to 30° SE.

The ore in the underground workings of the southwest part of the lease, at field shaft 4, is mined at a 236-foot level. The stopes are from twenty to fifty feet high and from one hundred to 250 feet wide. The ore-body and stopes pitch to the eastward conforming with the Boone strata as it dips toward a basin structure adjacent on the east. The ore-bearing rock is fractured and "bouldery" and small caves are common, especially where the rock is folded. The caves have their greatest extension parallel to the dip of the strata. Aragonite occurs in this part of the mine. Nearly flat-lying veins or sheets of galena and sphalerite one to three inches thick fill the fractures in the flint, the galena being above the sphalerite in the veins.

The shale over most of the lease has a usual thickness of thirty to sixty feet. However, about 110 feet south of the mine office the shale has a thickness of more than one hundred feet and the underground workings of the mine on the west side of the deep shale show the ore-body pitching down to the eastward, toward the deep shale basin.

Ritz Mine

The Ritz mine, Kansas Exploration Company, is located on a sixty-acre lease forming the NE. ¼ NW. ¼ and the W. ½ NW. ¼ sec. 30, T. 29 N., R. 23 E. Mining on this lease was begun in 1920 by Smith, Davis and Company. The present company began operations in 1926. The production from 1920 to 1928 was 28,213 tons of zinc concentrates valued at $1,042,543 and 7,260 tons of lead concentrates valued at $674,061.

The ore in the southeast part of the west forty acres and that of the east twenty acres is mined from the mill shaft, at a level 287 feet below the surface, rising to 280 feet farther out from the shaft. Considerable ore is also mined ten to twenty feet below the 287-foot level. The height of the stope in places reaches eighty feet, giving a vertical range to the ore of about one hundred feet. In most places, however, the stopes are twenty to thirty-five feet high. The ore is typical jasperoid, in places closely associated with limestone. The ore-bearing rock is usually much fractured, containing many small cavities and a few caves, lined with the usual crystals of ore and gangue mineral. A fairly pronounced dip in the ore-body and associated strata occurs in the stope wall about 240 feet east of shaft 2.

The shale has a fairly uniform thickness, about one hundred feet, over the southeast part of the lease, but in the northeastern part of the west forty acres is the Miami syncline in the bottom of which the shale reaches a thickness of 200 feet.

Royal Mine

The Royal mine, United Zinc Smelting Corporation, is a forty-acre lease located in the SE. ¼ SE. ¼ sec. 21, T. 29 N., R. 23 E. The mine was started shortly before 1920, but was not operated by the above corporation until October, 1920. During the period October, 1920 to 1928 the production was 41,470 tons of zinc concentrates valued at $1,107,748 and 1,700 tons of lead concentrates valued at $99,047.

The ore at the mill shaft is mined 230 feet below the surface. The mine level west of the southeast field shaft is 208 feet, and east of it 213 feet. The ore-body is in the form of flat runs from twenty-five to 150 feet wide, and from eight to fifteen feet high. The ore-bearing rock varies from coarse "bouldery" formation to relatively "tight" flint ground. The bouldery ground contains many small irregular cavities and a few large fracture caves. The floor and roof of the stopes undulate, following the dip of the strata, the depth of the ore-body below the surface conforming closely to the varying thickness of the overlying shale. The thickness of shale above the 208-foot level varies from twenty-seven to thirty-three feet, over the 213-foot level from thirty-three to forty feet, and over the 230-foot level from forty-five to fifty-three feet. The ore zone is approximately 135 to 145 feet below the top of the Boone formation.

Scammon Hill Mine

The Scammon Hill mine, Commerce Mining and Royalty Company is located on a 160-acre lease forming the W. ½ SE. ¼ and the E. ½ SW. ¼ sec. 36, T. 29 N., R. 22 E. The mine on the east eighty acres was first opened in 1922 and the production to 1928 was 7,706 tons of lead concentrates valued at $714,118 and 4,674 tons of zinc concentrates valued at $136,-088. This mine, up to 1930 has been mainly a lead mine and in this respect is unusual, not only within the Miami district, but also within the entire Joplin region. However, when the underlying ore-body below the present working level is mined out a little more zinc ore than lead ore will probably be produced as in other mines in the syncline.

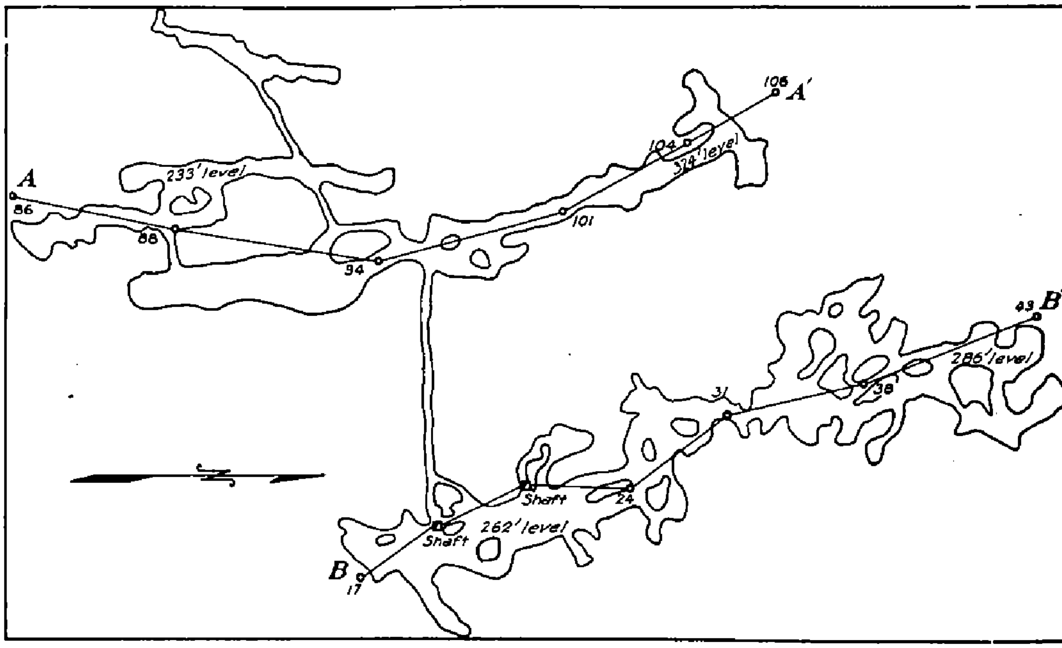
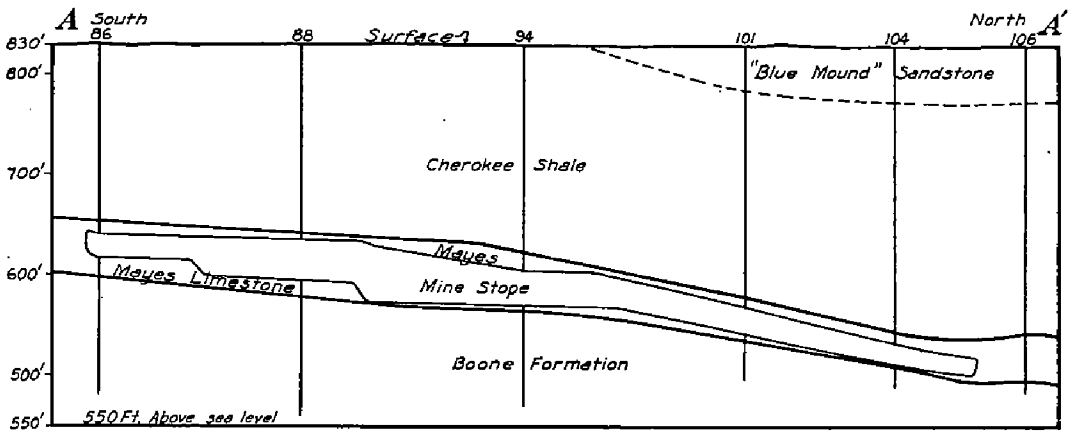


FIGURE 12A. Map of Scammon Hill mine, located in east limb of Miami syncline



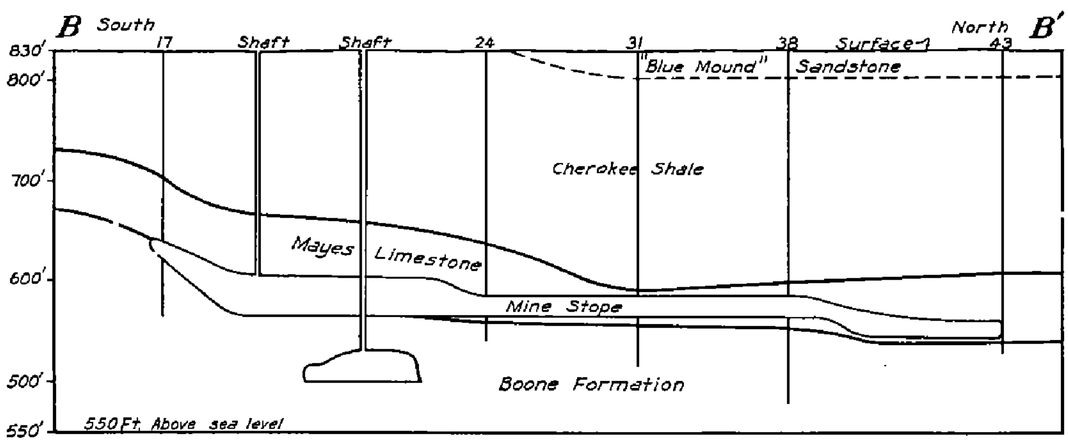


FIGURE 12B. Cross sections aolng A-A′ and B-B′ of Scammon Hill mine showing position of ore-body (mainly lead ore) in the upper Boone and the Mayes formations. The "Blue Mound" Bluejacket sandstone is in the central part of the syncline.

The underground workings of the east eighty-acre lease is located on the southeast limb and in the bottom of the Miami syncline.

The ore is mined 262 feet below the surface at the mill shaft. The ore-bearing rock forms two parallel runs each trending about 15° west of north as shown in figure 12A, and each run sloping down to the northwest as shown in figure 12B, the stopes varying from the 262-foot level in following the stone. The two parallel runs as stoped out have a width of twenty-five to fifty feet. The eastern run has a usual stope height of eighteen to twenty feet, and the western run a stope height of twenty-five to forty-five feet. The eastern run as stoped out has only a gentle slope, except at the south end, where the stope rises forty feet reaching 220 feet below the surface. The western ore run, however, follows a fairly uniform pitch and is mined at a level of 213 feet at the southeastern end of the run and at 324 feet at the northwestern end, having sufficient pitch to carry the stope down 110 feet to the northwest in a stope length of 750 feet.

The ore mined from inclined stopes is mainly, if not entirely, in the Mayes formation. The ore-bearing rock is mainly a sandstone-like formation, usually called "sandspar" by the miners. Below the sandspar and interstratified with it, is a variable thickness of limestone more or less cherty and silicified. Dark colored shale overlies the sandspar and limestone, either representing shale of the Mayes formation or the basal beds of the Cherokee. The sandspar varies from five to fifteen feet in thickness and the limestone likewise. These two types of rock obviously grade into each other both parallel and normal to the strata. The ore "makes" in both types of rock, in the broken and brecciated sandspar and in brecciated silicified limestone. The lead ore is especially abundant in the sandspar. Very generally beds of thinly laminated white or gray chert interstratified with thin limestone occur in the bottom of the stopes lying in places upon more massive beds of chert, the latter probably representing the top of the Boone formation.

The position and shape of the ore-bodies is apparently largely controlled by the structural features of folding and fracturing of the strata. Being on the southeast limb of the syncline the two ore-bodies pitch down to the northwest in following the dip of strata. The ore also follows the most prominent fracturing which trends about 15° west of north. The ore also widens out where cross-fracturing is developed and in places short ore runs extend along the less prominent cross-fractures that trend in a northeast direction.

Near the mill shaft an ore-body has been opened up on a lower level at 330 feet. The ore is the jasperoid breccia type, relatively high in zinc blende and is in the underlying Boone formation. The bottom of the ore-body in the Boone is about sixty feet below that in the Mayes. The ore in the Boone formation has a workable thickness of about thirty feet in the vicinity of the shaft.

In July, 1929 mining was in operation from a west field shaft located on the south part of the west eighty-acre lease, the crude ore being hauled by surface tramway 1,500 feet east to the mill. The underground mine workings at the west field shaft are on the northwest side of the syncline, the ore being mined at 300 feet below the surface, mainly from sandspar rock in the Mayes formation. The stope (July, 1929) is about 400 feet long, with width of fifty to one hundred feet and a height of ten to thirty feet. The bottom of the stope is approximately along the contact between the underlying Boone flinty formation and the overlying sandspar and siliceous limestone of the Mayes formation. The ore in the sandspar is ninety to ninety-five per cent galena, and that in the underlying flint about seventy-five per cent zinc blende.

Although the stope trends nearly north and south the pitch of the ore-bearing rock is to the southeast in conformity with the southeast dip of the strata in the northwest limb of the syncline. The shale at the west field shaft has a thickness of 240 to 250 feet, but in the middle of the syncline it has a probable thickness of over 300 feet. The ore will probably be irregular in its distribution but will tend to follow the bedding and the fracturing and extend under the shale in the bottom of the syncline.

Tri-State Mine

The Tri-State mine, Tri-State Mining Company, is located on a forty-acre lease forming the NW. ¼ NW. ¼ sec. 19, T. 29 N., R. 23 E. The mine was started in 1925 and the production from that date to 1928 was 10,186 tons of zinc concentrates valued at $407,614, and 701 tons of lead concentrates valued at $62,330.

The ore has been mined from three levels, 201, 243, and 262 feet below the surface. The ore is mainly in jasperoid breccia but is very closely associated with dolomitic limestone rock. Considerable lead ore was mined in the highest level (201 feet), possibly in the Mayes formation. The mine (in 1928) was being worked on the two lower levels, the stopes at the 201-foot level being of small extent. The ore-bearing rock mined in the lower runs was characterized by numerous large and small openings. The stope on the 262-foot level was between fifteen and thirty feet high and that on the 243-foot level generally from twenty to forty feet high. The width of stope on the two lower levels was quite variable, but usually narrow, widening out in places to thirty or fifty feet.

One of the largest caves known in the Miami-Picher district lies on the west side of the stope at the 243-foot level and extends out to the west on the adjoining property. This cave has a steeply sloping, much broken and very uneven, jagged floor pitching down to the westward and has a vertical range in height of forty-five to fifty feet with the open space measured at right-angles to sloping floor and roof being only five to twenty feet. It has a horizontal dimension of over 300 feet in length and from twenty to fifty feet in width. The floor is made up of large blocks with very irregular distribution, the bedding lines in the blocks dipping at various angles as though they had fallen at random from the roof. The rock formation is mainly cherty limestone except where it grades into the ore formation along the stope on the east side. The sloping floor, walls and roof are covered with calcite, except at the lower end of the cave where the steeply sloping roof is covered with coxcomb marcasite. A much smaller cave on the 201-foot level (250 feet long and about twenty-five feet wide) extends east and west about 240 feet north of the shaft.

Velie-Lion Mine

The Velie-Lion mine, the Velie Mines Corporation, is located on an eighty-acre lease comprising the N. ½ of the SW. ¼ of sec. 19, T. 29 N., R. 23 E. The mine was opened in 1917, producing to 1928, 70,299 tons of zinc concentrates valued at $2,883,330, and 18,153 tons of lead concentrates valued at $1,629,295. The Harrisburg mine was (1929) being operated as a part of the Lion mine, but the above production and the following description refers only to the lease above described. A brief description of the Harrisburg mine is given on an earlier page.

The Lion mine has been operated on two levels, but in 1929 the main production was from the lower level at 235 to 265 feet, but in places down to 270 and 280 feet below the surface. The width of stopes was usually between fifty and 150 feet, and the height ranged from ten to forty-five feet usually between twenty and thirty feet.

The ore at the lower level is mainly "tight boulder" ground, rather than "open" formation. The walls and roofs of the stopes are mainly limestone or barren "boulder" formation. Between the limestone bars and the boulder ground is a zone of much fractured rock. In mining, the fractures are followed, the roofs of the stopes showing the fractures running parallel with the stopes. The ore-body also follows the dip of the strata, the general pitch of the ore being to the southeast in the direction of the Miami syncline to the southeast.

The ore at the upper level, mined from shafts 5 and 7, occurs about seventy-five feet above the lower level and contains much galena. The stopes at this level are narrow and only five to ten feet high. At shaft 5 the lead ore horizon occurs at 200 to 205 feet below the surface and above the lead ore a deposit of mainly zinc ore was reported to have been mined at 165 feet.

The thickness of shale, mainly Cherokee formation, is about 110 to 140 feet over most of the lease, but in the southeast part, in the Miami syncline it reaches a thickness of 180 to 200 feet. The ore at the lower level is in the upper part of the Boone, above the horizon of the oolite. The upper level, predominantly lead ore, is in the lower part of the Mayes limestone, the ore to some extent being in typical "sandspar" rock.

Whitebird Mine

The Whitebird mine, Eagle-Picher Lead Company, is located on a forty-acre lease forming the SW. ¼ SW. ¼ sec. 16, T. 29 N., R. 23 E. The mine was started in 1915 and the production from 1915 to 1927 was 26,528 tons of zinc concentrates valued at $1,321,515 and 6,145 tons of lead concentrates valued at $555,708. In 1928 the Whitebird was consolidated with the Swift mine.

The ore is mined at three levels, the upper level at 272 to 279 feet, a middle level at 295 feet, and a lower level at 303 feet below the surface. The ore-body is a continuous broad flat run that occupies the same horizon in the Boone, stepping down from the higher to the lower levels in conforming to the 5° to 10° dip of the beds.

The stopes have a height of ten to twenty-five feet and a width of fifty to 250 feet. In the southwest part of the mine the ore body is continuous with that of the North Bingham and Netta mines. The ore is mainly jasperoid breccia grading downward as well as upward into relatively much fractured white and gray flint ore, much of the ore filling the fractures.

The thickness of shale on the lease is generally between seventy-five and one hundred feet, but is greater than one hundred feet in a small basin in the west central part. The ore appears to be about 175 to 200 feet below the top of the Boone formation.

Xavier Mine

The Xavier mine, Anna Beaver Mines Company, is a forty-acre lease, the NE. ¼, SW. ¼ of sec. 23, T. 29 N., R. 22 E., adjoining the Mudd lease on the west and is located on the east side of the lease. The ore is milled at the Adams mine. Mining on this lease began in 1928. Its location is farther west (farthest out in the shale area) than any other mine (in 1929) of the district.

The collar of the Xavier No. 1 shaft is at 832 feet and the stope rail at 580 feet, the mine level being at 252 feet below the surface. A short distance east of the shaft the stope rises fifteen feet to the 237 foot level in the No. 3 shaft of the Mudd mine. The stopes are twenty-five to fifty feet wide and from fifteen to thirty feet high. The ore-bearing rock varies from "open boulder" ground in the bottom of the stopes to relatively "tight," much fractured, dolomitic flint ground at the top. The ore-bearing rock contains black shale lenses, and "sandspar" pockets which are also characteristic of the ore formation in shaft 3 of the Mudd mine.

The overlying shale, mainly Cherokee formation, has a usual thickness of 110 to 120 feet. The ore mined from the 252-foot level is apparently in the upper part of the Boone formation.

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