GUIDE BOOK

To The
GEOLOGY IN THE VICINITY OF
JOPLIN, MISSOURI

Including
WESTSIDE-WEBBER MINE, OKLA.

CLAYTON H. JOHNSON
EDITOR

TENTH ANNUAL FIELD TRIP
SEPTEMBER 27 AND 28, 1963

Sponsored By The
GEOLOGISTS IN
THE TRI-STATE DISTRICT
MISSOURI-OKLAHOMA-KANSAS
ASSOCIATION OF MISSOURI GEOLOGISTS

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DEDICATION

to

George Malcolm Fowler

(1885–

)

To George Malcolm Fowler, whose many years of careful and detailed study and interpretation of the geology and ore deposits of the Tri-State District have contributed so greatly to the renewed and prolonged productive life of the district, we dedicate this volume.
INTRODUCTION

That the Tri-State District of Missouri–Oklahoma–Kansas has been among the leading producers of zinc and, to a lesser degree, of lead through two major wars is generally well known by Missouri geologists. Huge “chat” piles and old head frames had been familiar sights around Joplin, Webb City, Wentworth, Galena and Picher to many of us long before we became personally involved with geology. Most Missouri geologists are somewhat familiar with the general aspect of the Osagean and Meramecian stratigraphy of the district. However, few are familiar with the details of the lithology, weathering characteristics, and chemical make-up of individual rock strata and of the regional and local structures which have helped to control the deposition of ore minerals in this district. Therefore, we are extremely fortunate to have been invited by a group of geologists familiar with the area to study some of this detailed geology. We are doubly fortunate in having the opportunity to go underground in the Westside-Webber Mines of the Eagle-Picher Company.

The guidebook contains two road maps and accompanying road logs with specific stops indicated on each log. There also is a route map and a route log of the mine tour. Special papers on the general geology of the area and on the ore mineralization in the district are also included.

In order that the use of the guidebook can extend beyond this field trip, information concerning points of geologic interest not on the main routes has also been added.

Bibliographies and lists of references can be guides to more detail for those persons who desire more information than can be included in a guidebook designed for the purpose for which this was intended.
ACKNOWLEDGMENTS

Many persons and organizations contributed to the planning of this Tenth Annual Field Trip of the Association of Missouri Geologists. We do not intend to slight any of these, so a general acknowledgment is given to cover all possibilities.

The members of the field trip and local committees have worked hard to make the trip and meeting pleasant and educational. Their contributions to the guidebook are gratefully appreciated.

We especially appreciate the invitation of the Eagle-Picher Company to visit their Westside-Webber Mines and for their contributing the time and knowledge of their employees to act as guides in the mines. Chief among these are Douglas C. Brockie and Edward H. Hare who authored the road log and geologic notes for the mine tour.

The authors of the special papers on the general geology and the ore mineralization in the district are hereby thanked for these important contributions.
TENTH ANNUAL FIELD TRIP OF THE ASSOCIATION
OF MISSOURI GEOLOGISTS

Friday, September 27, 1963, Webster, Greene,
and Lawrence Counties, Missouri

The assembly time is 12:30 p.m. (CST). The assembly point is at the Spur Cafe at the junction
of U.S. Hwy. 66 and the Marshfield Spur on the west side of Marshfield, Missouri.

The trip will begin near the western boundary of the Ozarks and will proceed across the Eureka
Springs Escarpment onto the Springfield Plateau westward toward Joplin. The object of the trip is to
acquaint participants with the stratigraphy of the lower Mississippian in the area of the type sections of
the Northview and Pierson Formations. The Graydon Springs fault system will be crossed, and the Chesa-
peake fault will be studied in some detail at one locality.

Figure 2 is the Route Map from Marshfield westward past Springfield into Lawrence County.

ROAD LOG--1

<table>
<thead>
<tr>
<th>Cum.</th>
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<tr>
<td>0.0</td>
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<td>0.4</td>
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<tr>
<td>4.0</td>
<td>0.2</td>
</tr>
<tr>
<td>4.8</td>
<td>0.8</td>
</tr>
<tr>
<td>5.2</td>
<td>0.4</td>
</tr>
<tr>
<td>5.5</td>
<td>0.3</td>
</tr>
</tbody>
</table>

Assembly area--Spur Cafe--Junction Rt. 66 and Marshfield spur.
This location is near the western boundary of the Ozarks. The first stop will be on the
Eureka Springs escarpment, where you will be going up out of the Ozarks onto the Springfield
plateau.

“Swan Creek” sandstone. A 15 to 20 ft. bed of sandstone in the Springfield area is named
the “Swan Creek”, but this unit is not formally recognized because it is discontinuous and
is often confused with other sandstone beds at different stratigraphic positions in the Cot-

Jefferson City--Cotter dolomite. The Cotter is conformable on the underlying Jefferson
City, and because it is difficult to differentiate the two formations they are often design-

“Swan Creek” sandstone on right.

Upland gravels on right.

Jefferson City--Cotter dolomite.

East leg of Route B--continue on Route 66.

This sandstone is “Swan Creek”.
As you climb this hill you are going up out of the Ozarks.

STOP NO. 1--Northview Hill on the Eureka Springs escarpment. (See Section Descrip-
tion--1).

On Route B (formerly U.S. Highway 66), which is about 1/4 mile south of here, Compton
limestone is exposed in the gully opposite the spur to the town of Northview. The shale
in the cut along the west leg of Rt. B is more weathered than the shale in the new cut and
the typical limonitized fossils may be found on the surface. Above the shale, remnants
of the vermicular sandstone are present and some good cauda-galli markings may be
found in the float.

A good section of the Compton Formation is exposed about 7 miles south of here, along
Rt. B, where it crosses Panther Creek in the NW 1/4 sec. 17, T. 29 N., R. 19 W.

Still farther south and a little east in the NE 1/4 NW 1/4 sec. 3, T. 28 N., R. 19 W., is the
Devil’s Den or Panther’s Den, a large sink-hole or a small version of Oregon County’s
Grand Gulf. It is about 1/8 mile south of Rt. PP and about halfway up the hill east of Pan-
ther Creek. (Shepard, 1898, pp. 38-40) and (Bretz, 1956).
SOUTHWESTERN MISSOURI

FIG. I. GENERALIZED COLUMNAR SECTION.
FIG. 2. ROUTE MAP. FIRST DAY OF FIELD TRIP.
Holman Station--The Graydon Springs fault system, a major system extending northward from southeast of Mansfield to northwest of Eldorado Springs, crosses the highway.

Entering Greene County.

Mile Post 90 (miles from west State line). There will be mile posts for the next 20 miles. This is the beginning of Interstate Rt. 44. No stops are permitted on this highway, and we will try to maintain a speed of 65 to 70 miles per hour for the next 25 miles.

Strafford--Rt. 125 interchange. The type section of the Pierson formation is about 10 miles south (via Route 125 and D) at Turner Station. (See Section Description--2).

Mulroy overpass--After going under this bridge notice the ridge to the right. This is the surface expression of the Valley Mills Horst. This horst has placed Cotter rocks in juxtaposition with Burlington-Keokuk limestones. The Osage limestone which originally capped the horst have been removed by solution, and the resulting residual cherts have protected the underlying Northview shales from erosion leaving the horst as a low ridge. Likewise, the shale and chert make poor soil. Consequently, much of the ridge has not been cultivated and the trees left growing on it further accentuate the ridge, making a very pronounced topographic feature. (See paper on Valley Mills-Graydon Springs fault system by Beveridge, pp. 45-46).

Note water tower a mile to the south. This is the Griesmer Quarry and Security Warehouse (underground storage).

Future Rt. 65 interchange. Note numerous pinnacles of Burlington limestone in the backslope for the next several miles. This pinnacled surface on top of the Burlington makes it very difficult to predict the amount of limestone that will be encountered in a new highway route. It also influenced Joe Griesmer to go underground at his quarry. The spaces between the pinnacles are often too small for heavy earth-movers to get into so handwork with pick and shovel was quite expensive, especially in some of the very plastic clay (a test on similar soil in Springfield showed a plastic index of 49.1 with a liquid limit of 83.7). The openings left after the rock has been mined out made excellent storage rooms where Security Terminal has its warehouse.

Present Rt. 65 interchange--Springfield.

Mile Post 80.

Rt. 13 interchange.

Good place to collect fossils from Burlington formation. You cannot stop on Interstate 44. If at some other time you wish to look for fossils at this place, take the exit to Rt. 13. Cross Rt. 13 and continue west on the outer roadway for 1/2 mile. Park and walk over to the cut.

Rt. 66 interchange--Short Creek oolite is exposed in the old Brown Quarry in the NW 1/4 NW 1/4 SE 1/4, sec. 28, T. 29 N., R. 22 W., within the Springfield City limits (Kansas Geological Society, 1952, p. 46).

Note how the pinnacles have been blended into the interchange structure. The Melonechinous on display in the new Mo. Survey Building in Rolla came from this cut.

Rt. MM interchange. Four miles south, where Rt. MM crosses the St. Louis-San Francisco railway tracks are some shale waste piles where the old Kincaid coal mine was located. Shepard (1898, p. 211) describes a section of the shaft at this place (NW 1/4 section 10, T. 28 N., R. 23 W.) as follows:

<table>
<thead>
<tr>
<th>Shale and sandstone</th>
<th>68 ft.</th>
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<tbody>
<tr>
<td>Shale, dark, with fossils</td>
<td>3</td>
</tr>
<tr>
<td>Coal</td>
<td>2 1/4</td>
</tr>
<tr>
<td>Shale, light colored</td>
<td>12</td>
</tr>
<tr>
<td>Coal</td>
<td>2 1/3</td>
</tr>
<tr>
<td>Shale, black, with fossils</td>
<td>6</td>
</tr>
</tbody>
</table>
SECTION DESCRIPTION—1

TYPE SECTION OF NORTHVIEW FORMATION
SW 1/4 SW 1/4 Sec. 23, T. 30 N., R. 19 W., WEBSTER COUNTY
Section by T. R. Beveridge, 1950

This section starts north of the T junction of the Northview spur and old U. S. Highway 66 which is now supplementary Highway B, and continues westward up Northview Hill

(covered--probably Pierson; the Pierson-Northview contact is well-exposed in cuts on the newer highway where the thick-bedded brown, silty dolomitic Pierson forms an overhang at the contact with shaly Northview siltstone.)

11. Siltstone, buff, resistant, thick-bedded, vermicular, contains cauda-galli (rooster-tail) markings. Exposed in gullies on northside of highway ....................................... 16' 10"

10. Shale, blue gray, nonresistant, partly covered ....................... 3' 5"

9. Siltstone, buff, flaggy to thin-bedded ................................ 6' 5"

8. Siltstone, lithology like (11) ............................................ 2' 3"

7. Siltstone, buff, irregular bedding, platy to flagstone beds, forms overhanging ledge .......................... 3' 2"

6. Shale, like (4) but very silty in upper three feet ...................... 12' 2"

5. Limestone, gray to buff, in shaly calcitic lenses 1/16 to 1/8 inch thick. Appears to be partly secondary in origin. In a shaly matrix. .................... 1' 0"

4. Shale, like (3) but sparingly fossiliferous. Contains calcitic lenses like those in (5) four feet above base. Two feet below top is a four inch zone of buff slightly vermicular dolomitic siltstone in plates 1/2 to one inch thick with shale partings ....................... 14' 3"

3. Shale, gray to blue-gray, soft, slightly silty. Contains limonite-coated pyritized fossils, especially brachiopods .......................... 11' 6"

2. Covered. Clayey soil appears to be Northview ...................... 8' 8"

Total Northview 79' 8"

1. COMPTON FORMATION. Limestone, dolomitic, buff slightly crinoidal (covered) .......................... 2' 0"
SECTION DESCRIPTION--2

TYPE SECTION OF PIERSON FORMATION
NW 1/4 SW 1/4 SW 1/4 sec. 29, T. 29 N., R. 20 W.,
On north side of Highway D, at Turner Station, Greene County,
Section by T. R. Beveridge, 1950

(coversed, residual chert)

"GRAND FALLS"

14. Limestone, gray, fine-grained. Beds average one foot thick
and weather to rounded ledges and pillow-like shapes. Fifty to
75 percent chert. Basal three feet of limestone locally pitted.
Break with Pierson not clean cut .......................... 33' 6"

PIERSON

13. Limestone, gray, fine-grained, medium-bedded with 20 to 40 percent
chert in lenses parallel to bedding. Top of unit forms bench and dis-
tinct topographic break. ................................. 2' 1"

12. Limestone, like (13) but even-bedded, weathers to washboard edge.
Only slightly cherty but contains four-inch chert lens one foot from
base. .................................................. 9' 10"

11. Chert, dark gray to brown-gray; continuous lens .................. 0' 3"

10. Limestone, dolomitic, buff, cross-bedded, pitted and contains irregu-
larly sized and shaped solution openings. Contains 25 percent chert. 4' 10"

9. Limestone like (8) but weathers to pitted washboard vertical sur-
fase. Crinoidal and cross-bedded ......................... 4' 6"

8. Limestone, gray, weathers buff, slightly dolomitic, fine-grained
to sublithographic, contains 15 percent chert in lenses 3 to 8"

7. Limestone, slightly dolomitic, gray, weathers buff, non-cherty.
Cauda-galli exposed in ditch one foot from top ............ 1' 6"

6. Limestone, like (5) but stylolitic in basal two inches. Contains
scattered brown tripliotic chert nodules in upper six inches .... 2' 2"

5. Limestone, dolomitic, buff, single massive rounded bed with shaly
parting at the top, faintly crinoidal. Discontinuous coffee-brown
chert nodules one to three inches thick one foot from top of bed .... 2' 10"

4. Limestone, dolomitic, buff, shaly. Nonresistant and forms
slight reentrant ............................................. 0' 2"

3. Dolomite, earthy, gray, massive and weathers to buff rounded sur-
fase. Upper foot contains small crinoid columnals and calcite blebs.
Basal foot very silty, contains cauda-galli markings and is trans-
itional in lithology from Northview ........................ 4' 8"

   Total thickness of Pierson ................. 46' 0"

NORTHVIEW

2. Siltstone, buff-gray, dolomitic, weathers to thin beds. Contains
cauda-galli markings ................................. 2' 1"

1. Shale, silty, buff to green, nodular bedding .................. 2' 3"
Rock, Silico-calcareous
“knotted”.................. 12
Coal, covered by a thin layer
of shale, exposed ............ 1
Total depth of shaft .......... 110 ft.

The seams of coal are greatly inclined, having a dip of 45° NW.

32.5 0.2 Mile Post 70 (note—the odometer on the car used to make this log gained one mile in twenty)

35.4 2.9 Leave Interstate 44 - Bear right toward Rt. N. Turn left onto Rt. N, and cross over Int. 44. Three miles farther west on Int. 44 is a cut exposing very “chatty” limestone. There is a distinct demarcation between brownish stone above and grayish stone below. This may shed some light on the Grand Falls-Reeds Spring relationship. The following is taken from Howe and Koenig (1961, p. 63).

“Discussion of the Grand Falls is complicated by the fact that there is no definite agreement that the cherty limestone succession beneath the Burlington limestone in the eastern part of southwest Missouri is the same unit as that at the type section in Newton County where the Burlington limestone is absent. Some geologists regard the entire cherty limestone succession that lies between the Pierson and the Burlington in the eastern part of the area as the Reeds Spring formation, and some regard the upper part of the same succession as the Grand Falls and the lower part as the Reeds Spring. Those who believe the entire succession is Reeds Spring interpret the Grand Falls as being a lateral facies of the Reeds Spring that is restricted to the Joplin area. Those who regard the unit as being composed of both formations usually designate it as Reeds Spring-Grand Falls.”

38.1 2.7 Turn right onto Rt. TT.

40.0 1.9 Note karst topography.

40.5 0.5 County road. One mile south of this place is the Craig-Secrest iron mine (inoperative) where good specimens of limonite and/or geothite may be found.

41.5 1.0 STOP No. 2 - Outcrop of Carterville oolitic limestone in road ditch.

W. S. T. Smith and C. E. Siebenthal (1907, p. 5) describe the Carterville as follows:

“It consists of shaly, lumpy, somewhat conglomeratic and usually oolitic limestone; calcareous shales; light to dark argillaceous shale; arenaceous shale and shaly sandstone; massive indurated sandstone; massive hard sandstone and quartzite; in short, the whole category of sedimentary rocks, with the exception of chert and quartz conglomerate.”

The exposures in this area are considered to be sink-hole deposits.

41.9 0.4 Burlington limestone on the right.

43.0 1.1 Note “Grand Falls Snow” (white chert residuum) on the right.

43.5 0.5 Junction with Rt. PP. Turn left onto Rt. PP.

46.4 2.9 CAUTION - Rt. 166. Turn right onto Rt. 166

48.8 2.4 Entering Lawrence County.

50.6 1.8 Burlington limestone on left.

51.6 1.0 Pennsylvanian sandstone. Some of this sandstone contains enough petroleum to spoil the water from it.

51.9 0.3 STOP No. 3 - Chesapeake fault.

Clark (1931, p. 137) states: “Rutledge mapped this fault structure as a normal fault with a throw of about 300 feet. This faulting has inclined the beds, putting the Cotter dolomite in juxtaposition with Burlington-Keokuk.”
In a later publication (1937) Clark states: “The date of major diastrophic movements, particularly faulting, in southwestern Missouri, is more closely defined, being, namely, post-St. Louis and pre-Pennsylvanian.”

52.3 0.4 Turn left onto county road.
52.6 0.3 Abandoned quarry in Jefferson City–Cotter dolomite on left.
53.6 1.0 Turn left onto farm road.
53.7 0.1 Cemetery on left.
53.8 0.1 STOP No. 4 – Park and walk to quarry. Compton limestone has been sawed for building blocks from this place. There is 10 feet of Compton exposed. Above it is 3 1/2 feet of Northview shale which in turn is overlain by 6 to 8 feet of Pierson limestone. The Pierson is much weathered with from 0 to 5 feet of red clay and chert overburden.

Note cracks in the floor of the quarry which may be associated with the Chesapeake fault.

Return to cars and to Rt. 166.

55.3 2.5 CAUTION – Rt. 166 – Turn left on Rt. 166 for Joplin, which is approximately 50 miles west.

We will disband here and meet again in Joplin at Bob Cummings Motel, 6:30 p.m. for Annual Meeting.

REFERENCES


TENTH ANNUAL FIELD TRIP OF THE ASSOCIATION OF MISSOURI GEOLOGISTS

Saturday, September 28, 1963, Tri-State District, Missouri-Oklahoma-Kansas

The assembly time is 7:00 a.m. (CST). The assembly point is the parking lot of The Bob Cummings Motel. We will use commercial buses for this part of the field trip. Box lunches will be distributed about noon.

This day's trip affords the opportunity to study the ore-mineralized parts of the lower and middle Mississippian strata underground in the Westside-Webber Mine of the Eagle-Picher Company and to see the surface expression of some of these strata nearby. Although Fowler and Lyden subdivided the Warsaw, the Keokuk, and the Reeds Spring in 1932 into thin units for the purposes of description and to facilitate exploration for ore, many Missouri geologists do not have first-hand familiarity with these subdivisions. Descriptions of these subdivisions are included (p. 32) in the paper by W. F. Netzeband on the General Geology of the Tri-State District. Stratigraphic relationships of these subdivisions are shown in Figures 3 and 4 in the notes by Brockie and Hare on the Westside-Webber Mine Tour. The manner in which faulting, folding, shear, and solution slumping have influenced ore-mineralization is also well exhibited at several places along the route of the tour of the mine.

Please stay in your group and with your leader throughout the mine tour in order to facilitate the leaders' presentation of data and to assure regular schedule of groups at the stops.

The surface part of this day's trip will be taken in the reverse of the published road log. In other words, we will begin at the Westside mine shaft and proceed toward Joplin. It was deemed best to make the road log in its present form to facilitate its use by individuals in the future.

Geological Tour of the Westside-Webber Mines

By

D. C. Brockie1 and E. H. Hare1

Location and General Comments

The Westside and Webber Mines are located on portions of the Southwest Quarter, Section 7, Township 35 South, Range 24 East, and the Southeast Quarter, Section 12, Township 35 South, Range 23 East, Cherokee County, Kansas, respectively.

The two mines are approximately one-quarter to three-quarters of a mile north of the Kansas-Oklahoma State line, along the north-central edge of the Picher Field.

The temperature in these mines will be in the range of 60⁰ to 70⁰, and only a light field jacket will be required.

Since the mines are mechanized, there is an extensive road system throughout and, for the most part, we will be walking along these roads. Leather field shoes or boots should be ample protection from what little moisture or water will be encountered.

General Geology

It is not the purpose of this Tour Guide to describe the geology in detail nor to discuss the many controversial problems, but merely to point out the practical application of the mineralogical and structural controls as applied to underground prospecting, mapping and surface exploration.

An extensive bibliography is provided at the end of this Tour Guide for those who wish to delve deeper into the geological concepts expressed by the many authors who have commented on the geology of the Tri-State District and the Picher Field.

1 Geologist for the Eagle-Picher Company
### GENERALIZED STRATIGRAPHIC SECTION OF THE TRI-STATE DISTRICT

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<td>DES MOINES</td>
<td>MARMATON GROUP</td>
<td>Fort Scott Limestone Outcrops in southeastern Kansas.</td>
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<td></td>
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<td>PAWNEE LS.</td>
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<td>MARMATON-</td>
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<td></td>
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<td>FORT SCOTT LS.</td>
<td></td>
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<td></td>
<td></td>
<td>CHEROKEE SHALE</td>
<td>Cherokee Shale is surface formation in the Picher field.</td>
</tr>
</tbody>
</table>

**HIATUS** from CHESTER sediments to Des Moines
No Morrow Sediments Deposited.

<table>
<thead>
<tr>
<th>MISSISSIPPIAN</th>
<th>CHESTER</th>
<th>(UNCONFORMITY)</th>
<th>Very irregular in thickness and often missing in Picher Field.</th>
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<td>MERAMEC</td>
<td>CHERCHESTER LIMESTONE</td>
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<td></td>
<td></td>
<td>(MAYES)</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>(CARTERVILLE)</td>
<td></td>
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<tr>
<td></td>
<td>B BED LIMESTONE</td>
<td></td>
<td>Probably occurs as local lenses and pockets in Picher Field.</td>
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<tr>
<th>MISSISSIPPIAN</th>
<th>OSAGE</th>
<th>WARSW</th>
<th>C thru J beds = Warsaw</th>
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<td></td>
<td>KEOUK</td>
<td>J bed is Cowley Form. in S-E Kas.</td>
<td></td>
</tr>
<tr>
<td></td>
<td>REED SPRINGS</td>
<td>N Bed, Grand Falls Chert</td>
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</tr>
<tr>
<td></td>
<td>FERN GLEN</td>
<td>St. Joe Limestone is basal Fern Glen and therefore basal Boone.</td>
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<table>
<thead>
<tr>
<th>KINDERHOOK</th>
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<tr>
<td></td>
<td>COMPTON</td>
<td></td>
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<tr>
<td></td>
<td></td>
<td>Shelf</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Limestone</td>
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</table>

MAJOR HIATUS FROM LOWER ORDOVICAN SEDIMENTS TO BASAL MISSISSIPPIAN WITH THE EXCEPTION OF LOCAL POCKETS AND LENSES OF CHATTANOOGA (DEVONIAN?) SHALE.

<table>
<thead>
<tr>
<th>ORDOVICIAN</th>
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<tr>
<td></td>
<td>JEFFERSON CITY</td>
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<td></td>
<td>RIOUDBDOUX</td>
<td></td>
<td></td>
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<tr>
<td></td>
<td>GASCONADE</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>VAN BUREN</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>GUNTER SANDSTONE</td>
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<table>
<thead>
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<th>CAMBRIAN</th>
<th>OZARKIAN</th>
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<tr>
<td></td>
<td>PROCTOR</td>
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<tr>
<td></td>
<td>EMINENCE DOLOMITE</td>
<td></td>
<td></td>
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<td></td>
<td>POTOSI</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>BONNETTERRE DOLOMITE</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>LAMOTTE SANDSTONE</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

PRE-CAMBRIAN IGNEOUS AND METAMORPHICS

-16-
### Mississippian
- Beech - 100’
  - B Bed 0-3’
  - C Bed 25-32’
  - D Bed 18-22’
  - E Bed 5-8’
  - F Bed 12-15’
  - G Bed 10-20’
  - H Bed 15-20’
  - J Bed 0-40’ (Unconformity)
  - K Bed 0-40’ (Unconformity)
  - L Bed 0-35’
  - M Bed 0-70’
- Ch. Nodules in Light brown Ls.
- Cotton Rock Ch mostly dense Ch.
- Banded Ch. & Ls.
- Dense Ch.
- Banded Ch. & Ls.
- Dark Ch. Nodules in dark brown Ls.

### Pennsylvanian
- Cherokee 0-300’
  - (Unconformity)
  - Chester - 100’
  - (Unconformity)
  - B Bed 0-3’
  - C Bed 25-32’
  - D Bed 18-22’
  - E Bed 5-8’
  - F Bed 12-15’
  - G Bed 10-20’
  - H Bed 15-20’
  - J Bed 0-40’ (Unconformity)
  - K Bed 0-40’ (Unconformity)
  - L Bed 0-35’
  - Short Creek Quartz 2-10’
  - M Bed 0-70’

### Abbreviations
- Ls. = Limestone
- Ch. = Chert or Flint
- Dolo. = Dolomite
- Jasp. = Jasperoid

### Beds Unaltered
- Chalk
- Shale
- L. S.
- L. S. & Ch.
- Cotton Rock & Ch.
- L. S. & Ch. Nodules
- Cotton Rock & Ch.
- Thin bedded, banded dark grey & brown Ch. & brown Ls.
- Glaucite speckled Ls. with phosphate pebbles, some dark Ch. nodules.
- Ch. nodules in light brown Ls.
- Cotton Rock & Dense Ch.
- Ch. Nodules in light brown Ls.

### Beds Mineralized
- Cherokee
- Jasp. & Ore
- B Bed
- Jasp. & Ore
- C Bed
- Jasp. Ch. & Ore
- D Bed
- Ore where fractured
- E Bed
- Jasp. Dolo. Ch. & Ore
- F Bed
- Ore where fractured
- G Bed
- Jasp. Dolo. Ch. & Ore
- H Bed
- Jasp. Dolo. Residual Ch. & Ore
- J Bed
- Jasp. Dolo. Ch. & Ore
- K Bed
- Jasp. Dolo. Ch. & Ore
- L Bed
- Ore where fractured
- M Bed
- Jasp. Dolo. Ch. & Ore
- N Bed
- Ore where fractured
- O Bed
- Jasp. Dolo. & Ore (Replaces Ls. bands)
- P Bed
- Ore where fractured
- Q Bed
- Jasp. Dolo. & Ore (Replaces Ls. bands)
- R Bed
- Ore found in top 10-20’ of bed.
- Fern Glen
- Jasp. Dolo. & Ore

**FIGURE 4.**

*By J. P. Lyden, Geologist*

*May, 1949.*
FIG. 5. ROUTE MAP. MINE TOUR.
We are standing on the dolomite-jasperoid contact with the dolomite zone to the south and the jasperoid zone to the north. You will note the rather smooth, lack of open space appearance of the dolomite wall as compared to the bouldery uncemented appearance of the jasperoid wall. The shearing associated with this contact can be seen in the roof overhead.

Stop 1 to Stop 2

We are re-entering the jasperoid zone and, as we reach Stop 2, we will be standing again on the dolomite-jasperoid contact. Along this interval ore has been mined from M bed to and including GH bed.

Stop 2

The main purpose of this stop is to point out the strong shearing in the roof, which curves to the south and east and encircles a large dolomite core which we have been walking around since just before Stop 1. As can be noted from the Westside map, upper bed mineralization has been associated with this circular dolomite core.

Stop 2 to Stop 3

150 feet from Stop 2 is the Westside-Webber line. As we walk along this interval, we will have a few opportunities to observe the massive L bed chert horizon overlying M bed. When we turn south we will be walking along the east ore run associated with a dolomite core to the west and a jasperoid wall to the east.

As we approach Stop 3 we will be entering a crosscut that extends from the jasperoid wall into an essentially unmineralized limestone area.

Stop 3

Stops 3, 4 and 5 are separate stops on a section across a dolomite zone or core, and the associated orebodies, jasperoid zones, and unmineralized areas on either side. Here we can rather ideally see the relationship between limestone, jasperoid, ore, and dolomite areas. Stop 3 is at the eastern end of the crosscut in a limestone area.

As we move westward, we enter the jasperoid area and thence outward into the mined-out east ore run associated with the dolomite core to the west.

Stop 4

This stop is in the dolomite core or zone, and in this particular portion of it, the ore mineralization was not sufficiently intense to permit mining.

The tar that can be seen at this stop has migrated down the drill holes and shearing from the base of the Cherokee shale.

Stop 4 to Stop 5

As we proceed across the mined-out west ore run from this stop, we will be walking on some broken L bed chert. Note the sharp edges, which are a result of the conchoidal fracturing, and the tinkling sound that is made as we walk over the chert. Because of the above characteristics of this chert, the miners call it "butcher knife chert" and "musical flint".

The L-M bed contact may be seen on the west wall of the mined-out west ore run.

Just before we enter the west crosscut, note the curved fracturing in the roof near the west wall of the ore run.

Stop 5

This crosscut and a raise were driven to develop some upper bed mineralization to the west.
You will note that, as far as we go into the crosscut, the walls exhibit an uncemented to partially calcite-cemented breccia or chert. This condition is believed to be the result of post mineral solution activity. Approximately 300 feet to the west and southwest of Stop 5, M bed is composed of approximately 70 feet of limestone with very little chert.

If the atmospheric conditions are right, it will be possible to observe fibrous growths of goslarite (hydrous zinc sulphate).

- 1000

Stop 5 to Stop 6

We essentially retrace our steps to within 100 feet of Stop 6.

- 4400

Stop 6

We are now crossing the same dolomite core as at Stop 4 but farther to the north. From this point on northward, the mineralization was sufficiently intense to permit the core area to be mined.

- 700

Stop 6 to Stop 7

Tar that has migrated down the shearing from the base of the Cherokee Shale can be observed along fractures in the flat roof which is the base of L bed.

Although some ore deposition took place in the beds above L bed in this area, the mineralization is too low grade to mine.

- 5100

Stop 7

The dirt pile upon which we are standing represents an area of low grade mineralization in L, K, and GH beds. It was developed by long-holing from the previously mined M bed horizon and was brought down by shooting out the M bed pillars.

Looking south we can observe a vertical cross section of the rock column which exposes GH, J, K, and L beds. The pillars below L bed are in the M bed horizon. Note the thin banding and nodular chert characteristics of GH and K beds, respectively.

- 400

Stop 7 to Stop 8

We will walk through a crosscut which is located in a barren jasperoid leg between two ore mineralized areas.

- 5500

Stop 8

This is a large open room 500 feet long by 200 feet wide by 126 feet high (at the highest point) which was found to be mineralized from the base of the Chester limestone to the top of N bed. The mineralization was associated with a dolomite core and strong north-south shearing on both sides of the core, joined together by circular shearing on the south end.

- 500

Stop 8 to Stop 9

As we proceed northward we will pass the north end of the dirt pile that we climbed (Stop 7), and will again cross the dolomite core which we have followed north since Stop 4.

- 6000

Stop 9

This is only a brief stop to point out a pipe slump to the east. Although M bed, in this pipe slump, was somewhat mineralized, it was not high enough in grade to mine. See Figure 6 (Left hand pipe slump).

- 6400

Stop 10

Here is one of the few places on this Tour where we can observe the relationship between the massive N bed chert, M bed limestone, and the M bed jasperoid zone type ground extending above and outward over the limestone.

-22-
WEBBER MINE, VERTICAL SECTION, A - B

LETTERS REFER TO DIFFERENTIATED BEDS IN MINERALIZED HORIZONS

ERTICAL & HORIZONTAL SCALE:

FIGURE 6.
Stop 11

We are now standing at the right hand pipe slump shown in Figure 6. Note the zone of circular shearing showing vertical slickensiding. The displacement of the down-dropped beds within the pipe slump is approximately 40 feet. The pipe slump is represented by L bed occupying approximately the same horizon as M bed outside the slump. M bed is not mineralized in this pipe slump, as compared to the one pointed out at Stop 9. As no drill holes have prospected any of these slumps beyond N bed, we do not know in which horizon the solution caverns developed into which these roughly circular areas slumped.

Stop 11 to Stop 12

We are walking through an area of low grade mineralization that was mined during the subsidy period of World War II.

Stop 12

This crosscut is located in a limestone area which lies between two extensively mineralized areas. At the northwest end of the crosscut the change between jasperoid zone type ground and the limestone is rather abrupt, whereas at the southeast end of the crosscut the change is gradual, and evidence of post mineral solution activity can be seen as we approach the mined-out area.

Stop 12 to Stop 13

We are walking along the edge of a synclinal area to the west. The general dip of the mined-out area itself reflects this condition. In places J bed roof will be observed as we approach an area where K (?) and L bed, in addition to M bed, have been mined.

Stop 13

In this area J bed forms the roof of the mine, and large J bed slabs may be seen along the edge of the roadway. J bed in some areas is characterized by shaley partings, and the changing humidity in the mine causes these partings to deteriorate, resulting in large slabs falling with little warning. More fatalities have probably resulted from this type of roof condition than any other. Hence, if you are superstitious, and this being Stop 13, you might wish to continue on to the Westside Shaft without stopping.

Stop 13 to Westside Shaft

We are continuing to walk along the east edge of the synclinal area referred to previously.

Westside Shaft (End of Tour).


FIG. 7. ROUTE MAP. SECOND DAY OF FIELD TRIP.
ROAD LOG 2

Cum.   Diff.
0.0     START--Intersection 7th St. (Rt. 66) and Maiden Lane in Joplin, Missouri
        Stop Light
        Proceed south on Maiden Lane

0.6     0.6     Four-way stop--13th St.

1.1     0.5     Four-way stop--20th St.

2.1     1.0     Intersection with County Line road
        Leave Jasper County--enter Newton County
        Note numerous mine dumps on both sides of road
        This ore is shallow (60-100 feet deep) in the lower portion of M bed.

3.4     1.3     Y-intersection--bear left onto blacktop road

3.6     0.2     Intersection with blacktop road
        Proceed ahead into McClelland Park

4.3     0.7     Note Grand Falls chert in Shoal Creek on the left
        This is the type area for the Grand Falls Formation
        The chert exposed here is near the top of Fowler and Lyden’s N bed.

4.7     0.4     STOP 1--Entrance to Jeffries-Kirschman (formerly Spiva) Quarry on Shoal Creek
        The stratigraphic section at this quarry was described by Joe M. Thiel in 1933 and
        the description was revised in 1963 by W. F. Netzeband and W. J. Newby.
        (See Section Description--3.)

5.3     0.6     Stop Sign--Turn left onto McClelland Blvd.

5.5     0.2     Slow--Intersection with Schifferdecker Road
        Continue on McClelland Blvd.

5.9     0.4     Fillmore Bridge over Shoal Creek
        Note chert outcrops on both sides of road
        This represents the top of N bed--Grand Falls Formation
        Highway is at or near top of N bed for the next four miles

6.4     0.5     STOP 2
        Mine dumps on the left show typical Reeds Spring limestone and chert—also mineralized Pierson (?) limestone. This formation has been designated Fern Glen by Fowler. The Missouri Geological Survey tentatively correlates the Pierson of southwestern Missouri with the Fern Glen of southeastern Missouri.

The following drill record indicates the section cut by the shaft:

<table>
<thead>
<tr>
<th>From</th>
<th>To</th>
<th>Formation</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>10</td>
<td>Surface, soil and gravel</td>
</tr>
<tr>
<td>10</td>
<td>15</td>
<td>Yellow Clay and flint fragments</td>
</tr>
</tbody>
</table>

GRAND FALLS FORMATION

| 15   | 25 | White flint                     |
| 25   | 30 | White flint, yellow clay openings |
| 30   | 35 | Brown and blue flint            |
| 35   | 40 | Light blue flint, black lime    |
| 40   | 45 | Light blue flint                |

REEDS SPRING FORMATION

| 45   | 60 | Black and blue flint, black lime |
| 60   | 65 | Dark blue flint, gray lime       |
10. Red Clay and white chert residuum .................. 8'

9. Light brown oolitic limestone ........................ 5'

8. Limestone, light to medium gray, fine to coarsely crystalline, crinoidal, fossiliferous. Long flat nodules white chert, 6 to 15 inches thick, 6 to 12 feet long ................. 30'

Quarry floor

7. Limestone, medium gray, fine grading upward into coarse grain crinoidal, fossiliferous, stylolites fairly abundant; white chert beds 2 to 4 feet thick, many with cores of dense gray limestone .......... 40'

6. Limestone, medium gray, massive, coarsely crystalline, crinoidal; few white mottled chert nodules 6 inches thick, 12 inches long .................. 15'

5. Limestone, medium to dark gray, fine-grained, black calcite zone at lower contact; white mottled chert nodules ............. 4'

4. Limestone, medium gray, coarsely crystalline, crinoidal; few chert nodules 4 to 6 inches thick, two feet apart in the bed .... 5'

3. Light gray chert nodules .................. 0–12" 15'
   Limestone, medium gray, fine-grained crinoidal ........ 4'
   Light gray chert band .................. 0–12" 4'
   Limestone, medium gray, fine-grained, crinoidal; few light gray chert bands .............. 4'
   Long, light gray chert bands .................. 5'

2. Light gray, blue and white chert bands .................. 0–12" 17'
   Limestone, light gray, dense; few gray, blue and white chert nodules, 2 to 3 feet apart in the bed ................. 8'
   Light gray, blue and white chert bands .................. 0–12" 7'

1. Light gray and blue chert band .................. 6–12" 10'
   Limestone, dark gray, dense .................. 4'
   Limestone, dark gray, dense; dark blue gray and black mottled chert nodules making up 50 percent of bed ........ 5'

Above section starts about 18 feet above normal water level in Shoal Creek.
65  70  Dark blue flint, black lime
70  75  Dark blue and black flint
75  90  Brown lime, black and blue flint
90  95  Brown lime, brown flint
95  100  Brown lime, blue flint
100  105  White lime, blue flint, white selvage
105  130  Gray lime, blue flint
130  140  Light gray lime, blue flint
140  150  Light gray lime
150  155  Light gray lime, green shale, marcasite, zinc shines

PIERSON FORMATION  (?)

155  165  Light green shaly lime, flint, pink dolomite, zinc ore
165  170  Light green shaly lime, flint, pink dolomite,
170  175  Light green shaly lime, dark flint, zinc shines

9.4  3.0  Outcrop on the left exposes the lower portion of M bed. The M-N contact has been identified in the bottom of the road ditch. Debris now covers the contact.
Section description in SW 1/4 SW 1/4 sec. 25, T. 27 N., R. 33 W., follows:
Clay residuum with chert and limestone fragments .................. 2-6'
Limestone, gray, crystalline grading upward into coarsely crystalline
  crinoidal; white to light gray chert nodules ..................... 3-5'
Massive white and gray chert ................................. 3'
Soft white cotton rock--breaks into small fragments ................ 3'
Massive, 12 to 18 inch beds gnarly white and light gray chert with occasional
  lenses of dense limestone near upper contact with cotton rock .... 9'

9.7  0.3  Missouri-Kansas State line
Leave Missouri, enter Kansas
Sharp turn to left
Proceed up hill
Rock exposures on the right are coarsely crystalline, crinoidal, fossiliferous M bed
limestone with occasional chert nodules

10.1  0.4  35 mile Speed Sign
Short Creek oolite member of M bed exposed on right
White chert residuum lying above the Short Creek
oolite is probably L bed chert

10.3  0.2  Sharp turn to right at top of hill

11.4  1.1  Stop sign--Intersection with Kansas Rt. 26
Proceed straight ahead joining U.S. Rt. 166

13.2  1.8  STOP 3--The only known surface exposure of J bed is found in the backslope on the right.
This exposure is a crystalline glauconitic limestone. Nodules of K bed chert exposed
in the road ditch are the top of the Keokuk Formation according to Fowler and Lyden.
Residual float in the back slope indicates about 5 feet of J bed overlain by thin-bedded
G-H chert. Fowler and Lyden have determined that J bed is the base of the Warsaw
formation. The highly irregular contact with the underlying Keokuk is due to the irregu-
lar weathered and erosional surface on the Keokuk.

16.0  2.8  Bridge over Spring River.
Baxter Springs, Kansas

16.9  0.9  Stop light--Junction U.S. Rt. 166 and U.S. Rt. 66
The Tri-State District lies on the northwest flank of the Ozark uplift in a more or less continuously mineralized belt up to 30 miles wide and nearly 100 miles long, extending from Springfield, Missouri, to Miami, Oklahoma. The rock strata generally dip toward the northwest at the rate of 15 to 20 feet per mile. This low dip is not uniform, but is characterized by local warping and folding, forming undulating small, irregularly distributed depressions and elevations of the beds.

There are four major structural features to which ore deposition shows some relationship. These are the Chesapeake fault, the Joplin anticline, the Seneca syncline, and the Miami shear and fault. Ore mineralization is minor along the Chesapeake fault.

STRATIGRAPHY

"Lafayette" gravels:

The youngest rocks exposed on the surface are Tertiary "Lafayette" gravels capping low-lying hills in the Miami, Oklahoma, area. "Lafayette" gravels are also reported east of Springfield, Missouri.

Cherokee Formation:

Cherokee shales and sandstones of Pennsylvanian age are the surface rocks over most of the Oklahoma and Kansas portions of the area, and occur as sporadically distributed outliers over the Missouri portion of the area. The thickness of the Cherokee Formation ranges from 0 to 250 feet.

Carterville Formation:

The youngest rocks of Mississippian age are assigned to the Chesterian Carterville Formation composed of sandstones, limestones, and shales, which occur as outliers as far east as Springfield, Missouri, and underlie the Cherokee Formation in the western portion of the area. Only a few isolated surface exposures are known in the Joplin and Springfield areas. Most of the knowledge of this formation has been obtained from mine shafts and prospect drill holes. The formation is composed of clay and conglomerate with occasional boulders or lenses of oolitic limestone embedded in a shale matrix. Some sandstone, in part quartzitic, and dark gray to black fissile shale also occur in the formation. The irregularly sized, generally flattened ooliths are readily distinguishable from the uniform sized, well rounded ooliths of the Short Creek oolite member of the Keokuk Formation. The formation is extremely variable in thickness, especially in the Missouri area, where it is confined to local sinkholes and depressions in the older Mississippian rocks. Maximum thickness is reported to be over 200 feet in some sinks. Where more fully developed (Barry and McDonald Counties) the Carterville correlatives are Fayetteville, Batesville, and Hindsville Formations.

The Missouri Fayetteville may represent only the lower part of the formation which is more nearly completely developed in Oklahoma and Kansas. There it is a black, fissile, carbonaceous shale interbedded with dark gray to black limestone. In southwestern Missouri, the Fayetteville is conformable with the underlying Batesville Formation. The total thickness of beds identified as Fayetteville in Missouri is about 20 feet.

The Batesville Formation is a yellowish-brown, fine-grained, calcareous sandstone which contains discontinuous thin beds of gray, medium-grained, oolitic limestone. The contact with the underlying Hindsville is transitional. Locally, especially in Missouri, the Hindsville may be absent and the Batesville lies unconformably on the Osagean Keokuk Formation. In Missouri it is 35 to 50 feet thick.

1 Geologist for the Eagle-Picher Company
The Hindsville is a light to dark gray, medium-grained, oolitic limestone. In places, glauconite gives the rock a greenish tinge. The formation unconformably overlies the Keokuk with a contact that is irregular and is marked by a chert-pebble conglomerate which contains fish teeth. The first chert is used as a marker in churn drill prospect holes to determine the contact between the Keokuk and the Carterville. The thickness of the formation ranges from 0 to 50 feet.

Boone Formation:

In southwestern Missouri, the Meramecian Warsaw and Osage Keokuk-Burlington Formations are grouped together and are designated the Boone Formation. Fowler and Lyden (1932) have sub-divided the Boone Formation, on the basis of lithology, into 16 distinct beds designated by letters of the alphabet from B through R, omitting "I" which letter is easily confused with the numeral 1. The characteristics of the units are given in the classification which follows. The relationships of these units are shown in Figure 4.

There has long been a dispute as to whether the Warsaw Formation should be assigned as the lowest formation of the Meramecian Series or the top formation of the Osagean Series. Because the Warsaw Formation has dominantly clastic lithology common to formations in the Meramecian Series and in contrast to the predominantly calcareous lithology of the formations in the Osagean Series, many geologists assign the Warsaw to the Meramecian Series. Geologists have placed the Warsaw at the top of the Osagean Series because the Warsaw fauna resembles the Keokuk fauna in many respects. In many areas the boundary between the Warsaw and Keokuk is obscure. Spreng, in Howe and Koenig (1961), considers the Warsaw to be the basal formation of the Meramecian Series. As thus defined the Meramecian Series is considered conformable with the underlying Osagean Series.

### STRATIGRAPHIC CLASSIFICATION, BOONE FORMATION - TRI-STATE DISTRICT

<table>
<thead>
<tr>
<th>Thickness</th>
<th>Characteristics</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bed</td>
<td>in feet</td>
</tr>
<tr>
<td><strong>Warsaw Formation</strong> - Thickness variable everywhere in the Tri-State District due to erosion. In Oklahoma-Kansas mining field erosion was confined largely to strata above C bed.</td>
<td></td>
</tr>
<tr>
<td>B</td>
<td>0-40 Limestone and dolomite, light gray and brown; some white and blue chert.</td>
</tr>
<tr>
<td>C</td>
<td>0-32 Gray to brown limestone; white and blue chert; commonly more chert in basal 10 ft.</td>
</tr>
<tr>
<td>D*</td>
<td>0-25 Limestone, cotton rock, and chert; limestone light brown; cotton rock, white; chert white and dense; contains commercial ore bodies in a few mines.</td>
</tr>
<tr>
<td>E*</td>
<td>0-8 Limestone and chert; limestone brownish locally; chert gray and brown; an important ore bed in a few mines.</td>
</tr>
<tr>
<td>F</td>
<td>0-15 Limestone, light brown; chert; cotton rock.</td>
</tr>
<tr>
<td>G*</td>
<td>0-20 Limestone, gray and brown; mostly thin-bedded; chert brown and gray to white; resembles H bed; an important ore horizon.</td>
</tr>
<tr>
<td>H*</td>
<td>0-20 Limestone, gray and brown, and chert, brown and gray, in alternating bands, mostly 2 to 5 in. thick; an important ore horizon in many mines and mined with G bed in some areas.</td>
</tr>
<tr>
<td>J</td>
<td>0-50 Limestone, brownish to very dark gray, slightly greenish and shaly; contains some chert; very glauconitic. Usual thickness 3 to 5 feet, but absent in a few localities where the Keokuk Formation above normal elevation of this bed.</td>
</tr>
</tbody>
</table>

**Disconformity**

**Keokuk Formation**

<table>
<thead>
<tr>
<th>Bed</th>
<th>Characteristics</th>
</tr>
</thead>
<tbody>
<tr>
<td>K*</td>
<td>0-10 Limestone, gray, crinoidal; contains abundant nodules of chert; an important ore zone.</td>
</tr>
<tr>
<td>L</td>
<td>0-30 Limestone, gray, medium to coarsely grained, massive; and massive gray chert or cotton rock.</td>
</tr>
</tbody>
</table>
Limestone, gray; and top 4 to 6 ft. oolitic (Short Creek), but oolitic texture is seldom recognized in areas of mineralization; chert occurs largely in rounded nodules; the important ore horizon in the Oklahoma-Kansas mining field. Solution and erosion removed parts of K, L, and M in some areas.

Limestone, massive; gray, somewhat mottled, chert occurs in bands and in large nodules 1 ft. thick by 5 to 15 ft. in diameter. This bed is 20 ft. thick in most of the Oklahoma-Kansas mining field and is generally barren. It gradually thickens to the east, being about 50 ft. in the vicinity of Baxter Springs, Kansas, and about 80 ft. thick around Stark City, Mo., and is an important ore horizon in some mines in these localities.

Some limestone and abundant chert; gray, dense, in bands and round, flat nodules; an important "sheet ground" ore zone.

Chert, gray, in bands, and large flat nodules; some limestone; mineralized locally.

Chert, gray, dense; and limestone, gray, massive; mineralized locally. Beds N, O, P, and Q are equivalent to the Grand Falls chert horizon.

Unconformity

Limestone, dark bluish, medium to fine-grained; thin to medium beds and abundant chert occurs as irregular-shaped nodules and thin beds alternating with limestone.

An important ore bed 7 to 10 ft. thick a few feet below the top of this formation in the vicinity of Oronogo, Mo. This bed has many characteristics in common with a similar ore bed in the Paxon, Garrett, and other mines in the Oklahoma-Kansas field.

Fowler and Lyden (1932) have determined that a disconformity exists between H and K beds. They state that J bed is the base of the Warsaw Formation and occupies the hiatus between the Warsaw and Keokuk Formations. They confirm this statement from recorded observations in dozens of mines and from thousands of drill holes in the Oklahoma field, drill holes in southwestern Missouri and southeastern Kansas, and several scattered surface exposures in these two states. Their many observations show that J bed has been eroded or never deposited in most of southwestern Missouri. Where present in the Oklahoma field its usual thickness is 3 to 5 feet but it varies in thickness from a fraction of an inch to 30 feet or more in eroded depressions in the Keokuk limestone. The only observable J bed exposure may be found 2.8 miles east of Spring River bridge (Baxter Springs, Kansas) on U. S. Highway 166. This exposure is indicated at STOP 3 on Route Map, Figure 7. All the above observations are recorded in the Fowler and Lyden paper (1932) or in numerous later published papers by G. M. Fowler and other associates who have worked in the field with him.

The Warsaw Formation, which in Newton and Jasper Counties is over 150 feet thick, contains B through J beds of Fowler and Lyden. This series includes the "Carthage Marble", an ornamental building stone. The formation is also quarried locally for agstone and road metal. The limestone is dense to fine-grained, gray to brown in color with abundant chert in the lower part, E through H beds of Fowler. Several horizons are "cotton rock" a soft, white, siliceous limestone, not the dense dolomite of the Cotter-Jefferson City Formations.

The Keokuk Formation is characteristically a bluish-gray, medium to coarsely crystallized, medium bedded limestone which contains abundant light gray chert in the form of layers and nodules. Some limestones of the formation in the southwestern part of Missouri are finely crystalline and some parts in the same area are extremely crinoidal. Stylolites are common and are especially pronounced at the contact of coarse and fine limestones.

*Indicates ore-mineralized bed, locally or regionally.
The chert in the Keokuk is irregularly distributed throughout the formation but appears to be more concentrated in the lower and upper parts. It is dense and light gray and is tripolitic at margins of nodules. The chert weathers to buff or reddish brown.

The Keokuk is used for road metal and occasionally for building stone. Agstone is made from the less cherty parts of the formation. Tripoli is mined from weathered K bed chert at Seneca in western Newton County.

Throughout southwestern Missouri and adjacent areas of Oklahoma and Kansas, a thin, persistent, but not continuous, bed of oolitic limestone, 2 to 8 feet thick is present near the top of M bed. This is known locally as the "Short Creek Oolite". In the Springfield area this oolite is considered to be near the top of the Burlington formation. Fowler believes that M bed may be correlated with the Burlington which thins rapidly to the west. Drilling west of Melrose, Kansas, shows about 5 feet of M bed, represented almost entirely by oolitic limestone. The Short Creek member is a single massive bed and is sometimes used as a datum in field mapping. It has been chertified in much of the mineralized area to the extent of losing its original character. The ooliths are usually less than one millimeter in diameter, uniform in size and round in cross section. The matrix in which the ooliths are embedded is a white to light gray limestone which may contain scattered grains of glauconite.

The Burlington is considered to be absent in the Joplin area, unless, as Fowler believes, M bed in the Joplin area correlates with the Burlington in the Springfield area, where the formation is more than 100 feet thick. The Burlington consists of white to light buff, very coarsely crystalline, fossiliferous, crinoidal limestone. Layers of chert nodules are common, especially in the upper part. The less cherty parts of the formation are quarried for agstone, road metal, and lime manufacture, especially in the Springfield area.

The Burlington in southwestern Missouri lies either on the Pierson or the Reeds Spring-Grand Falls unit. The contact with the overlying Keokuk is obscure, but is considered conformable.

The Grand Falls Formation is identified only in southwestern Missouri, and in adjacent parts of Oklahoma and Kansas. It pinches out north of Springfield, Missouri. It consists of fine-grained, gray limestone with abundant chert. The chert is nodular, massive bedded and varies in color from white to gray to brown.

In the type area in the vicinity of Joplin, the formation is 24 to 40 feet thick. Chert has replaced much of the limestone and the brecciated chert has a distinctive gnarly appearance. The Grand Falls Formation includes N, O, P, and Q beds.

The Reeds Spring Formation, R bed, consists of alternating bands of hard, fine-grained, gray or bluish-gray, slightly argillaceous limestone and chert. The chert is nodular and irregularly bedded and is usually a bluish-black color with a distinctive light gray border. Light tan or mottled tan and gray are also common chert colors. Chert nodules make up one to two-thirds of the formation and are most abundant in its upper part. A thin, green to brown sandy shale marks the base of the formation in some places.

The formation varies in thickness from less than 100 feet in its type area to more than 150 feet in the Joplin area and southward into Arkansas. It lies with apparent conformity on the Pierson Formation.

**Pierson Formation:**

The Pierson Formation in its type area contains two units, a lower medium to massively bedded, brown dolomite, 5 to 20 feet thick, and an upper cherty limestone and dolomitic limestone unit about 35 feet thick. The upper limestone is medium bedded and contains cream colored chert in the form of nodules.

The Pierson Formation is similar to the Fern Glen Formation of east-central and southeastern Missouri and the St. Joe Formation of northern Arkansas. Fowler and Lyden in several of their papers have designated the rocks underlying the Reeds Spring Formation in the Joplin area as Fern Glen.

The Pierson Formation is underlain by the Northview Formation in southwestern Missouri, except in the extreme southwest portion and in adjacent Oklahoma and Kansas where the Northview and Comp-ton appear to be absent. In such areas the Pierson may rest upon the Chattanooga shale.
Chouteau Group

The Chouteau group in the Springfield area is represented by the Northview and Compton Formations; the middle Sedalia Formation is not recognized. To the south and west the Northview and Compton Formations thin and in many areas are entirely missing.

Northview Formation:

The Northview Formation consists of brown, buff, occasionally blue siltstone and blue or bluish–green shale. In its type area it is about 80 feet thick and is divided into two parts; a lower part which is predominantly shale and an upper part which is predominantly siltstone, with subordinate shale. See Section Description--1.

The lithologic character of the Northview together with the formation’s tubular-shaped perforations (worm burrows) and abundant “rooster tail” markings (Taonurus caudagalli), are factors for the formation being named the “Vermicular siltstone” in earlier reports.

Compton Formation:

The Compton Formation is a finely crystalline to sublithographic, finely crinoidal limestone. It is thinly bedded, and the beds are separated by green shale partings. Where the formation is locally dolomitic, it is brown and massive. Chert is locally present, but not abundant. The chert is bluish–gray to bluish–black with a white rim.

The Compton Formation is about 12 feet thick in most of southwestern Missouri, except towards the vicinity of Joplin where it is absent.

REFERENCES


TABULAR REVIEW OF THE GENESIS OF
TRI-STATE ORES

By

Richard D. Hagni\textsuperscript{1} with Oliver R. Grawe\textsuperscript{2}

The discovery of lead ore in southwestern Missouri in 1848 and the subsequent discovery of the more abundant zinc mineralization about 1870 led to the development of one of the few mining districts of the world which have produced more than a billion dollar's worth of ore. As mining of the zinc-lead ore expanded beyond Missouri, into Kansas and Oklahoma, the term, Tri-State district, came into use in reference to the producing area. As the importance of the district grew, more and more geologists included it in their field of study. Most of these studies were brief, but they led to a vast literature of speculation concerning the origin of the ores. Here was a vast area of approximately 2000 square miles underlain by sulfides of copper, iron, lead and zinc with no visible source for these metals. Here were ore bodies in nearly horizontal "sheets", in anastomosing channels or "runs" and in shale pockets of "circles" without apparent structural control. Here were deposits which began at the surface, extended downward only a few hundred feet, none deeper than 450 feet, and underlain by barren sediments not significantly different from the limestones and shales in which the ore occurred.

In time, the importance of the district became recognized not only for its economic value but for its geological significance as well, and hypotheses for the origin and occurrence of the ore bodies sprang up. Never were more diverse conclusions reached from the same set of facts. Controversies led to many variants of the principal theses. One hypothesis, proposed first by Jenny in 1893, maintained that the ores were deposited from upward-moving warm solutions derived from an undisclosed deep-seated source. The next year, Winslow announced that the ores were formed from downward moving meteoric waters of normal surface or near-surface temperatures. Thus, two widely different schools of thought arose and since 1894 each has attracted its share of scholars. In the following tabulation, these schools will be referred to as the hydrothermal school and the meteoric school. The facts and deductions presented by these schools are presented in 13 major categories in accordance with the nature of the data involved. The compilation of this summary has involved certain difficulties, some of which have been only partially resolved. The reader should be aware of the many variations of the two main hypotheses which have been proposed. These variants are not conducive to sharp classification. The appearance of an investigator's name in both columns of the classification may be confusing to the reader, but if an author has noted a feature in opposition to his own view, his name will be found in both columns. If an author has left doubt concerning his interpretation of a feature, his name may have been omitted under that feature. No attempt has been made to evaluate the validity or importance of an investigator's observation or opinion based upon the length or intensity of his study.

The most interesting point revealed by the compilation is the dual interpretation placed upon so many of the observed facts. This keeps the controversy going.


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TABULAR SUMMARY OF THE USE OF FACTS
BY THE TWO OPPOSING SCHOOLS OF GEOLOGIC THOUGHT
CONCERNING THE ORIGIN OF TRI-STATE ORES

THE HYDROTHERMAL SCHOOL

I. SOURCE OF ORE

Igneous rocks projecting through sediments are exposed at: Rose Dome, Kansas; Decaturville, Missouri; and Spavinaw, Oklahoma. These exposures suggest magmatic intrusion. (Fowler, Giles, Lyden, Shepard, Weidman)

Sulfides associated with the igneous rock at Rose Dome, Kansas suggest a magmatic source for the Tri-State ores. (Bastin, Behre, Knight, Landes)

Pegmatitic granite containing Pyrite and fluorite at the Bird Dog well is intrusive into the sediments and indicates a magmatic source of sulfides. (Fowler, Lyden, Weidman)

The hydrothermal solutions came from great depth and were not related to exposed igneous rocks. (Moore, Nason)

The sediments are an inadequate source of the Tri-State ores. (Bastin, Behre, Fowler, Jenny, Lyden, Shepard, Weidman)

II. NATURE OF THE ORE-BEARING SOLUTIONS

The ore-forming constituents were carried by hydrothermal (telethermal) solutions. These alone are adequate to form the Tri-State ore deposits. (Bastin, Behre, Jenny, Ridge, Tarr, Weidman)

THE METEORIC SCHOOL

The igneous exposures are too far from the ore to be related to it. (Buehler, Clerc, Hagni, Haworth, Jenny, Keyes, Naething, Ohle, Robertson, Siebenthal, Snider, Winslow)

The conglomeratic arkose on top of the granite at Spavinaw, Oklahoma shows that the granite is not intrusive into the overlying sediments but that it is older than the oldest sediment, the Cotter dolomite. (Dott, Hamm, Landes, Tolman)

Radiometric dating has assigned a Precambrian age to the pegmatite at Decaturville, Missouri. (Davis, Tilton, Wetherill) The Tri-State ores are post-Pennsylvanian.

The Bird Dog granite has not been proven to be intrusive and probably is Precambrian like the granite at Spavinaw and Decaturville. (Hagni, Landes, Tolman)

The mineralizing solutions are unrelated to any igneous source. They derived their metallic constituents from the exposed sediments of the Ozark dome. These are known to contain sulfides like those of the Tri-State district. In places the quantity of these sulfides has been sufficient to mine on a small scale. (Bain, Buckley, Buehler, Haworth, Keyes, Robertson, Siebenthal, Smith, Stewart, Winslow)

The ore-bearing constituents were transported by meteoric groundwater at temperatures prevailing at or near the surface at the present time. Given sufficient time, even very dilute solutions are adequate to transport enough metal to form an ore deposit. (Bain, Buckley, Buehler, Grawe, Hagni, Haworth, Keyes, Robertson, Siebenthal, Smith, Stewart, Winslow)

Metallic ions are carried by mine waters at the present time. Springs in the district carry zinc sulfate. (Hagni, Siebenthal, Smith)
Deposition of sulfides on man-made objects is the result of post-ore alteration by meteoric waters. (Bain, Shepard, Spurr, Van Hise)

The temperature at which primary two-phase fluid inclusions become homogeneous is 90° – 135° C. (Newhouse, Schmidt) This is assumed to be the approximate temperature of the ore solutions.

The iron content of Joplin sphalerite is indicative of a crystallization temperature of less than 138° C. (Kullerud)

III. CIRCULATION

The ore-bearing solutions flowed from a region of high pressure as well as high temperature within the earth to a region of lower pressure and lower temperature near the surface. (Bastin, Behre, Jenny, Shepard, Spurr)

In the Picher field the ore-bearing solution flowed from the Miami trough, as indicated by the asymmetry of the deposits (Stoiber) and by the lower range of crystallization temperatures of sphalerite deposited away from the trough as compared to that of sphalerite deposited near the trough. (Schmidt)

Gravitative settling from very slowly moving solutions gave a downward asymmetric component to mineral deposits. (Stoiber)

IV. CAUSES OF DEPOSITION

Decrease in temperature. (Bastin, Behre, Brown, Ridge, Shepard, Weidman)

Decrease in pressure. (Bastin, Behre, Shepard, Weidman)

Neutralization of acid hydrothermal solutions. (Bastin, Behre)

Hydrothermal solutions usually are alkaline. (Grawe)

Neutralization of acid groundwater (Buckley, Buehler, Siebenthal)

Mixing of groundwater with connate water. (Bastin, Stewart)
Dilution with groundwater.
(Garrels)

Mixing with petroleum and salt water.
(Spurr)

Precipitation by hydrogen sulfide.
(Tarr)

Mixing of groundwater of different compositions
(Buckley, Buehler) Mixing of artesian water
with connate water (Bastin) or with ground-
water. (Bain, Van Hise)

Precipitation by organic matter. (Bain, Buckley,
Buehler, Robertson, Van Hise, Winslow)

Precipitation by hydrogen sulfide.
(Buckley, Buehler, Naething, Stewart)

Loss of carbon dioxide from groundwater.
(Siebenthal)

V. STRUCTURAL CONTROL

Deposits occur on flank of Ozark dome, a tec-
tonically active area where hydrothermal
solutions rose.
(Fowler, Jenny, Lyden)

Deposits occur on flank of Ozark dome down which
groundwater moved from a higher and larger
area of solution to lower and smaller area of
ore deposition. (Buckley, Buehler, Grawe,
Hagni, Hawthor, Keyes) The circulation may
have established an artesian flow in the Tri-
State district. (Haworth, Siebenthal, Smith)

The association of some ore deposits with an-
ticlines suggests upward moving solutions.
(Fowler, Lyden, McKnight)

Ore is not confined to anticlines but occurs equally
well in synclines and on the flanks of folds.
(Siebenthal, Smith)

The Miami trough was the main conduit for
the ore solutions. (Fowler, Lyden, Sales,
Schmidt, Stoiber, Tarr, Weidman)

Many mines even in the Picher field are not near
the Miami trough. (McKnight)

The presence of great faults suggests that deep
seated sources of metals were tapped.
(Emmons, Jenny, Shepard, Spurr.)

Faulting had nothing to do with the emplacement of
the ore. The major faults are not highly min-
eralized. (Bain, Buckley, Buehler, Clerc,
Haworth, Keyes, Naething, Nason, Siebenthal,
Smith, Snider, Spurr, Winslow) Even the pre-
ence of deep faults does not prove that hydro-
thermal ore-forming solutions rose along them.
(Leith)

Faults and fractures were the channel-ways for
the ore solutions. (Emmons, Fowler, Jenny,
Lyden, Spurr, Stoiber, Tarr, Weidman)

Fractures are not deep-reaching, (Haworth, Wins-
low) and simply provided avenues and open
spaces along which groundwaters moved as they
deposited the ore. (Haworth, Robertson, Wins-
low)

Sink structures were favorable loci for hydro-
thermal deposition.
(Fowler, Lyden)

Sink structures are common where groundwater
circulates through limestones near the surface.
Such mineralized structures suggest deposition
from groundwater. (Buckley, Grawe, Naething,
Snider.) When blocked they may impede move-
mament of solutions (Clerc, Keyes) or may form
loci of mixing of groundwater. (Siebenthal)

VI. HOST ROCKS

Vugs were formed by hydrothermal solution of
the limestone (Ridge) or by deformation
(Weidman) and became loci of ore deposition.

Vugs were formed by solution of limestone by
groundwater. (Buckley, Buehler, Robertson,
Tarr, Winslow)

Breccias formed principally by tectonic forces
followed by solution. (Bain, Fowler, Jenny,
Lyden, McKnight, Ridge, Weidman)

Breccias formed by solution of cherty limestones
by groundwater. (Buckley, Haworth, Leith,
Leonhard, Sales, Schmidt, Snider) Some were
basal conglomerates. (Buckley, Buehler,
Leith, Siebenthal, Smith, Snider)
Limestones carry fractures and bedding planes along which hydrothermal solutions moved (Fowler, Jenny, Lyden) and spread laterally beneath a Pennsylvanian shale cover. (Bastin, Behre)

The Pennsylvanian shale formed an impervious barrier to the upward moving solutions. (Bain, Bastin, Behre, Brown, Emmons, Fowler, Spurr, Tarr, Weidman)

Limestones, bedded and fractured, were partially dissolved by groundwater prior to or during the flow of the ore-bearing solutions.

Most of the Tri-State district is not covered by Pennsylvanian shale. The Picher field is associated with an area of marked shale disturbance, especially in the Miami and Bendelari troughs. (Hagni)

If the ores were hydrothermal and their rise was stopped by the Pennsylvanian shale, ore deposits should occur beneath the undisturbed Pennsylvanian Shale to the west. (Naething)

Most of the ore is not immediately beneath the shale but in several zones well below the shale. (Naething)

Groundwater flowed principally beneath the shale (Siebenthal) but some of it permeated the shale, especially in sink structures giving rise to ores in the shale composed of the same sulfides as those in the limestones. (Grawe)

VII. POSITION OF ORE BODIES

The ore bodies occur beneath the Pennsylvanian shale which formerly covered the district. (Bastin, Behre, Emmons, Siebenthal)

The ore bodies occur close to the surface because of the existence of a suitable host rock (Jenny, Shepard) and lack of a suitable host at depth. (Fowler, Lyden, Shepard)

The ore bodies are close to the surface because groundwater action prior to mineralization prepared the channels vugs and other open spaces for the flow of hydrothermal solutions. (Jenny, Tarr)

The ore occurs in the upper part of the sedimentary section where temperature and pressure were sufficiently low to permit ore deposition. (Weidman)

Small amounts of sulfides do occur at depth. (Evans, Fowler, Knight, Lander, Lee, Lyden, Ohle)

The ore deposits occur within 475 feet of the surface. Many of them were close to or even at the surface, as would be expected in deposits formed by downward moving solutions. (Buckley, Buehler, Hagni, Keyes, Moore, Robertson, Winslow)

Ore deposition does not occur at depth because the ore-solutions did not penetrate that far. (Buckley, Buehler, Winslow)

VIII. MINERALOGY OF THE ORES

The minerals of the Tri-State ores are found in other hydrothermal deposits. (Graton, Harcourt, Jenny, Weidman)

The sulfides found at depth may have been there before the ores were formed. (Stewart)

Deep aquifers are not ore horizons. (Winslow)

Not a single mineral in the Tri-State ore is found only in hydrothermal deposits. (Haworth, Grawe, Siebenthal)

The presence of chalcopyrite, galena, pyrite and sphalerite in salt domes indicate that these sulfides are not always hydrothermal. (Siebenthal)
Chalcopyrite is not a characteristic supergene copper sulfide. (Bastin, Behre, Ridge)

Absence of chalcopyrite in blebs and stringers in sphalerite is characteristic of a meteoric origin. (Teas)

Enargite is typical of hydrothermal ores. (Bastin, Behre, Graton, Harcourt, McKnight, Ransome, Riddle)

Enargite occurs in anhydrite cap rock of salt domes. (Dana)

Tourmaline in the chert and jasperoid is indicative of a hydrothermal origin. (Agar, Weidman)

All the tourmaline found in Tri-State ore is detrital and part of the sedimentary host rock. (Bastin, Behre, Roy)

The presence of sericite in jasperoid and in massive chert suggests that these forms of quartz are hydrothermal. (Roy)

Sericite has not been observed in Tri-State ore by Hagni.

The dolomite in the ore was formed by hydrothermal alteration of limestone. (Fowler, Jenny, Lyden, Weidman)

Dolomite crystals line open spaces in many limestones and dolomites not associated with ore deposits. (Grawe) The dolomite of the Tri-State ores is a product of groundwater alteration of limestone. (Buckley, Buehler, Hagni, Haworth, Winslow) Some hold to its being formed by artesian water. (Bain, Siebenthal, Smith, Van Hise)

Jasperoid is a hydrothermal form of quartz and similar to that in other hydrothermal deposits. (Fowler, Graton, Harcourt, Lovering, Lyden, Weidman)

Jasperoid is not indicative of hydrothermal solutions. Its quartz crystals are not unlike those formed in cavities in limestones everywhere. (Buckley, Buehler, Grawe, Hagni, Haworth, Siebenthal, Smith)

Chert is a product of very early replacement and is more abundant in the Tri-State district than outside. (Agar, Fowler, Lyden, Giles, Gregory, Weidman) Chert pebbles in the Cartherville conglomerate indicate that it was formed early in the hydrothermal replacement. (Giles, Weidman) The occurrence of more chert near the ore bodies suggests that the chert-forming solutions and the latter ore-solutions followed the same paths. (Fowler, Lyden) The presence of more chert in the lower part of the Boone formation than in the upper part suggests that the solutions came from below. (Giles, Weidman)

Chert is a common product of sedimentation, especially in areas of limestone deposition. The chert of the Tri-State district is similar to other sedimentary cherts. Replacement features in the Tri-State cherts are the same as those in cherts not associated with ore deposits. They antedate the ore. (Buckley, Buehler, Ellis, Grawe, Hagni, Haworth, Hovey, Laney, Leonard, McKnight, Schmidt, Siebenthal, Smith, Spurr, Tarr) The chert may have formed by the groundwater alteration of limestone. (Buckley, Buehler, Dake, Leighton, Leith) Chert pebbles in the Cartherville limestone prove that chert was formed before the conclusion of Paleozoic sedimentation. (Hagni, Tarr) Intrationnal chert conglomerates also prove that chert was formed during the sedimentation cycle. (Grawe, Hagni)

Amino acids in the chert indicate that the chert is of sedimentary origin and could not have been formed by hydrothermal processes. (Barney)

Cherty zones, being more brittle than limestones or shales, were more easily fractured by tectonic movement and subsequently allowed better flowage of the mineralizing solutions. (Haworth, McKnight, Smith, Spurr)
IX. ZONATION

Broad regional zones of different metals are arranged about the Ozark dome and the St. Francis Mountains in accordance with a temperature gradient falling off with distance from the Ozark core. (Emmons)

Zonation in particular mineral run has been reported. (Lyden, McKnight, Siebenthal)

Lead/Zinc ratios were stated to be highest near the Miami trough, a site of rising hydrothermal solutions. (Weidman)

The leaner character of the ores to the east may be due to removal of higher, richer ore-bodies by erosion. (Williams)

The occurrence of galena above sphalerite is typical of zoning in hydrothermal deposits. (Bastin, Behre, Emmons, Fowler, Jenny, Lyden, Weidman)

The reversed solubility relations indicated by the occurrence of galena above sphalerite could be due to the high chloride ion content of the solutions. (Garrels)

X. FLUID INCLUSIONS

Fluid inclusion studies indicate that the ores were deposited at 90° – 135° C. (Newhouse, Schmidt) Such studies indicate that the ores at Joplin and at Picher were deposited at a higher temperature than those at Granby, suggesting a temperature zonation. (Newhouse) Higher ranges of temperature deduced from inclusion studies of ores near the Miami trough as compared to those elsewhere suggest a possible systemate variation. (Schmidt)

The brine content of the inclusions is too high to be of meteoric artesian or marine origin. (Newhouse, Roedder)

The solution of limestone from cherty zones led to the development of chert rubble zones, chert filled channels and fractures. Such chert zones contained suitable open space for ore deposition and thus the chert is most abundant in the ore bodies. (Grawe, Hagni)

The greater quantity of chert in the lower part of the Boone formation is not the result of hydrothermal replacement but is due to the character of the primary sedimentary deposit. (Giles, Grawe, Hagni)

Any reference to regional zoning must consider the ages of the ores with respect to one another and to the rocks from which they supposedly were derived. Emmons did not do this. (Grawe)

Evidence is lacking of any zonation of the ores in the Tri-State district, either vertically or horizontally. (Grawe, Hagni) Statements have been made that the ores were richer near the Miami and Bendalari troughs than farther east. This was interpreted as suggestive of the westward movement of groundwater (Ellis), but these areas are zones of maximum tectonic disturbance and have been very favorable for migration of ore solutions and for ore deposition. (Grawe, Hagni)

Lead lags behind zinc due to a difference in solubility of their sulfides. Galena was deposited before sphalerite from descending groundwater. (Buckley, Buehler, Siebenthal)

Galena occurs with sphalerite in the lowest mineralized zones as well as in the highest. (Hagni, Haworth, Siebenthal, Smith)

The use of fluid inclusions in ore thermometry is open to question since it postulates an initial single phase system. (Grawe) Fluid inclusion studies of supergene "pebble jack" and "ruby jack" yield the same range of temperature as other sphalerites. (Smith) Fluid inclusion studies of halite crystals from the Kansas Permian indicated that they were formed from warm water. (Dreyer, Garrels, Howland)

Halite crystals which formed upon breaking the fluid inclusions show that NaCl was a primary constituent of the meteoric ore solutions, (Head)
The Ca, Na and Cl content of the inclusions is similar to that of fluid inclusions in other hydrothermal ores. (Bastin, Behre, Buerger, Newhouse)

The high Ca, Na, Cl content and the low Mg, K, S and CO₂ content of the fluid in the inclusions in the ore minerals of the Tri-State district is similar to the abundance of these elements in oil field brines of the Na-Ca-Cl type. The composition of the included fluid is unlike that of volcanic or magmatic water. (White)

The composition of the fluid in the inclusions suggests a connate origin. (Siebenthal, Stewart, White)

XI. PARAGENESIS

The minerals occur in an orderly and unrepeated sequence with only minor local variations. (Bastin, Behre, Fowler, Jenny, Lyden, Robertson, Rogers, Shepard, Siebenthal, Snider, Smith, Tarr, Weidman, Winslow)

The minerals in the Tri-State ore deposits were deposited during 7 periods of mineralization, each characterized by its own sequence and mineral suite, and each separated from the next by a period of tectonic activity, a period of solution, a hiatus of deposition or by a returning to the crystallization of earlier formed minerals. Local variations of the general paragenetic sequence have been noted but systematic deviations either geographically or stratigraphically could not be detected. The general character of the ore-bearing solutions seems to have been essentially the same throughout the district. (Grawe, Hagni)

XII. TRACE ELEMENT DISTRIBUTION

The cadmium, germanium, gallium and indium content of Tri-State sphalerite is similar to that of sphalerites of hydrothermal origin. (Graton, Harcourt)

Many elements occur in Tri-State ores in very small quantities, usually expressed as parts per million. Of these, only the silver in galena and the cadmium, gallium, germanium, and indium in sphalerite are reliable for distribution studies. The variations of these 5 elements are large from specimen to specimen but are unrelated to the paragenetic, stratigraphic or geographic position of the host mineral. The ore-bearing solutions exhibited no tendency to change qualitatively as they traveled through the district or as they moved from one stratigraphic horizon to another. (Grawe, Hagni, Marshall, Joensuu)

The low silver and gold content of Tri-State galena is that expected in a galena of meteoric origin and wholly unlike that of galena of hydrothermal origin. (Robertson, Winslow)

The trace elements of Tri-State ores are similar to those found in sedimentary rocks and in supergene iron sulfides. (Cooke, Grawe, Stewart)

Fluorine in the Tri-State zinc concentrates is a common element in hydrothermal deposits. (Weidman)

Fluorine is a ubiquitous element. It is not confined to igneous sources. Only Weidman reports its presence in Tri-State ores.

XIII. ISOTOPIC DISTRIBUTION

Fluorine in the Tri-State zinc concentrates is a common element in hydrothermal deposits. (Weidman)

Fluorine is a ubiquitous element. It is not confined to igneous sources. Only Weidman reports its presence in Tri-State ores.

Tri-State ores exhibit a wide range of lead isotope ratios, not a narrow range, as is characteristic of hydrothermal ores. (Cumming, Farguhar, Russell)
A single galena crystal from the Joplin field exhibited a progressive variation in lead isotope ratios from the center outward, indicating that it grew during a period of 125 million years or from late Paleozoic time to early Tertiary. (Antweiler, Buck, Cannon, Pierce)

The impossible future dates calculated from lead isotope ratios of Joplin-type galena are as enigmatic as the ore deposits themselves. (Antweiler, Buck, Cannon, Pierce)

The variation in lead isotope ratios in Tri-State ores indicates that the lead was derived from various sources and that it was not all of the same age. Before its redeposition in the Tri-State it has undergone fractionation. This is consistent with a meteoric but less consistent with a hydrothermal origin. (Grawe)

The wide range of sulfur isotope ratios ($^{32}\overline{S}/^{34}\overline{S}$) in Tri-State sulfides is suggestive of a metamorphic hydrothermal source. (Jensen) or a non-homogeneous source. (Ault, Feely, Kulp)

The wide range of sulfur isotope values is consistent with a meteoric origin of the sulfides. The sulfur was derived from many sources and subject to differentiation before final deposition in Tri-State ore. (Grawe)
THE VALLEY MILLS FAULT ZONE

by

Thomas R. Beveridge*

The Valley Mills fault zone is an east-trending structure at the north edge of Springfield, Missouri. It is slightly over twenty miles long and at the east end, coalesces with the Graydon Springs fault zone. The Graydon Springs fault zone extends nearly 110 miles from central Douglas County northwestward through Mansfield into the Springfield area as shown in Figure 8. From the Springfield area it extends northwestward through southwestern Polk County, central Cedar County and the extreme southwestern part of St. Clair County where the mapped terminus is approximately six miles northwest of Eldorado Springs, as shown on the 1961 Geologic Map of Missouri. The namesake of the Graydon Springs fault zone is the Graydon Springs field station of Drury College in southwestern Polk County. It is appropriate that the major fault system be named after a field camp for the training of geologists and conversely, that the field camp was selected in the area of the fault zone.

Shepard (1898, pp. 155-160) mapped the Graydon Springs fault zone in northern Greene County and southwestern Polk County and also mentioned faulting in the Valley Mills fault zone area but did not portray it on his geologic map of Greene County. E. L. Clark, former State Geologist, referred to faulting in the vicinity of Valley Water Mills reservoir in unpublished field notes and maps made in 1936 and 1937 while he was a summer employee of the Missouri Geological Survey and Professor of Geology at Drury. The writer had complete access to these notes while doing the detailed geology of the Bassville quadrangle in 1953, as well as the benefit of field conferences with Clark. The writer also had access to the 1891-1892 field notes of Shepard which were especially valuable because they contained logs of long-abandoned prospect shafts and other pertinent unpublished data which aided greatly in interpreting the fault system.

Mapping of the Bassville quadrangle in 1953 disclosed the complex system of parallel faults in the vicinity of the Valley Water Mills reservoir, as well as a major fault extending north and thence eastward from this area. In an effort to understand the regional setting of the Valley Mills fault system, this writer did reconnaissance mapping both to the east and west of the Valley Mills fault zone. This reconnaissance work showed that a major fault system extended from the Greene County line southeastward into Webster County to the vicinity of Diggins, and revealed that apparently the Graydon Springs fault, as mapped by Shepard, represented but a segment of a major fault zone. As a result of this reconnaissance, quadrangles included in the faulted area of Webster County were selected for mapping as Survey subsidized theses projects, and the mapping showed the zone of complex faulting which extended southeastward to previously mapped faulting in the Mansfield area. Thesis mapping and reconnaissance mapping done for the 1961 geologic map extended the known Graydon Springs zone northwestward to the Eldorado Springs area.

The Valley Mills fault zone apparently connects the Graydon Springs fault zone with the Chesapeake fault to the west. Subsurface control and exposures do not permit mapping of a continuous east-west zone between these major northwest-trending fault zones, but the mapped faults suggest that there is an east-west trending major zone of weakness along which there has been faulting, although the faulting has not necessarily been of appreciable magnitude along the complete extent of the apparent zone of weakness.

The maximum mapped vertical throw along the Graydon Springs fault zone is 250 feet in the extreme southeastern part in the vicinity of Mansfield (Aid, 1941). The maximum in the Valley Mills zone is 170 feet along the most southerly of the three parallel faults east of Valley Water Mills reservoir. The Valley Mills fault zone is of special significance because it lies in an area which is rapidly becoming urbanized and has been both a bane and a blessing to Greene County. The most northerly of the three parallel faults east of Valley Water Mills follows an east-west road along which many homes, each with a drilled well, have been built. Because the wells are drilled in the fault zone, muddy water and "bad ground" have created problems in drilling and necessitated exceptional amounts of casing. One well required nearly 300 feet of casing to seal out muddy surface waters. The fault system has also created leakage problems in the Valley Water Mills reservoir, especially along the west edge where large amounts of both neat cement and concrete have been used throughout the years in an attempt to stop major leakage.

The benefits of the fault zone are both academic and practical. Because Springfield now has three colleges giving courses in geology, with two of the schools granting degrees in this field, the fault zone is an excellent backyard laboratory. Although the actual juxtaposition of indurated rocks is not seen

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THE VALLEY MILLS – GRAYDON SPRINGS
FAULT ZONES

COMPiled FROM DATA BY: T. R. Beveridge, E. L. Clark,
N. W. Jeffries, F. Lock, J. Pulliam, E. M. Shepard, and
R. O. Taylor

LEGEND

Fault
Spring
Town

FIGURE 8
at very many localities in the area, other criteria for mapping faults are exceptionally well developed. These criteria are boulders of brecciated chert which lie on the surface in the immediate vicinity of fault zones, marked contrasts between residual cherts on either side of fault zones, striking topographic unconformities which are so marked that the topographic maps provide some of the best clues for mapping the fault system, fault-line springs, and marked contrast in vegetation types reflecting the contrast in soils developed on either side of fault zones.

The fault system has proved both an aid and a hindrance to the development of the Springfield water supply system. Valley Water Mills reservoir is fed by a large spring at the south end. Water from this reservoir is piped through a ten-inch main into a fissure in the bed of South Dry Sac Creek. Water entering this fissure from the main emerges at Fulbright Spring, three miles to the west, which supplies part of the water to the city water works located at the spring. It had been suspected that not all the flow from Valley Water Mills was emerging at the spring and tracer chemicals were introduced. They showed that part of the water emerged at Ritter Spring, nearly a mile and a half west of Fulbright and four and a half miles west of Valley Water Mills, where there is also a city water supply reservoir.

The Survey was contacted regarding the loss of water in this natural drainage system but, unfortunately, geologists could give no assistance in mapping the extent or bifurcations of the fissure system as a guide for damming the subsurface diversion fissures. If there is any vertical displacement in the area between Valley Water Mills and Fulbright diversion, it is not of sufficient magnitude to map. However, as shown in Figure 8, there is a mappable fault extending from Fulbright to Ritter Springs, and Ritter Spring is definitely a faultline spring system.

The horst, which extends eastward from Valley Water Mills, is a prominent topographic feature and owes its preservation, in part, to a remanent capping of Pennsylvanian sandstones and conglomerates, and to the fact that much of its core is composed of Northfield siltstones and shales. Because solution is such an important factor in the erosional process, siltstones and shales are relatively resistant in the Springfield area, and the horst, of softer yet more resistant material, stands above cherty limestones to the north and south of the horst.

All the faulting shown in Figure 8 demonstrates the complexity of fault zones and that many faults in Missouri are represented by zones rather than by a single fault surface. The single long fault shown in the northwestern part of Figure 8 undoubtedly will prove to be a more complex zone when it is mapped in detail with the aid of modern topographic maps. At the time Shepard mapped it in the early 1890's, he was using a planimetric base and was determining elevations with an altimeter. Modern topographic maps will provide much better control and will also give clues for small faults which are less obvious.

Both the Graydon Springs and Valley Mills faulting have affected beds as young as those of the lower Desmoinesian Krebs subgroup (Pulliam, 1954, pp. 83 and 84; Baker, 1962, pp. 71 and 78). Clark (1937, pp. 5-7 and 13) dates the Chesapeake fault to the west as pre-Pennsylvanian and post-St. Louis. These data show the Graydon Springs and Valley Mills fault zones to be younger, or to have had activity at a later date, than the Chesapeake fault. The geometric relations of all these faults suggest, however, that they have a structural kinship.

In closing, it should be mentioned that the complete Graydon Springs fault zone presents an enigma to the geologist working in Missouri. The vertical displacement is relatively small in many areas of this major fault, being less than 100 feet or even 50 feet in many places. Because the units represented in the zone are thin and fairly easily identified units of the Mississippian, faulting of small vertical displacement may be mapped. Is there similar faulting to the east in the Ozark area where thin, mappable Ordovician units are not so easily recognized? The writer suspects that there is additional faulting to the east and also that Graydon Springs fault zone may extend farther to the southeast. It is impractical to map the continuation unless exceptionally slow, tedious, and detailed studies are made in an attempt to establish thin, mappable units in the Ordovician.
REFERENCES CITED

Aid, Kenneth, geological map, Mansfield area, Wright County: unpublished manuscript map, Missouri Geological Survey and Water Resources, 1941.


Clark, Edward L., unpublished field notes, Greene County reconnaissance, 1936-1937.


Because of the possible interest individuals will have to study surface exposures of Osagean formations after seeing their importance as ore bearers, descriptions of several representative sections of Warsaw and Keokuk formations as exposed near Joplin are given here. These are from R. C. Moore (1928): "Early Mississippian Formations in Missouri", vol. 21, Mo. Bur. of Geol. and Mines. Moore described many other sections which are exposed in the Missouri part of the Tri-State District, and you are referred to his work for these.

### SECTION DESCRIPTION—4

**Warsaw Limestone on Spring River**  
Near Bridge on Waco-Lawton Road  
SE 1/4 SW 1/4 Sec. 23, T. 29 N., R. 34 W., Jasper County, Missouri  
(Moore, 1928, p. 234)

<table>
<thead>
<tr>
<th>Thickness</th>
<th>Feet</th>
<th>Inches</th>
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**Osage Group**  
**Boone Formation**  
**Warsaw limestone**

1. Limestone, dark gray to buff, alternating layers of medium and fine-grained compact limestone, contains thin layers of flinty chert. Exposed  

2. Limestone, bluish, medium-grained, slightly crinoidal, rather thin-bedded, contains thin bands and nodules of dense flinty chert, upper part more massive, contains fossils, especially *Productus magnus*  

3. Limestone, buff, fine-grained, compact, hard, thin-bedded, wavy stratification gives beds nodular appearance, non-fossiliferous  

4. Chert and limestone, the chert greatly predominating, limestone bluish, compact, no fossils observed  

### SECTION DESCRIPTION—5

**Warsaw Limestone at Gill & Son Quarry, Northwest**  
of Carthage, Jasper County, Missouri  
(Moore, 1928, p. 245)

**Osage Group**  
**Boone Formation**  
**Warsaw limestone member**

5. Chert and limestone like 7  

6. Limestone like 8 but showing a distinct interbanding of coarser and finer texture, stylolites common. In quarry face two massive beds appear 2-3 ft. above and 4-5 ft. below, a horizon of chert nodules occurring between the beds  

7. Chert with interbedded fine- to medium-grained blue limestone. The chert is marked by an uneven distribution of bluish flinty material through siliceous limestone; beds thin, general appearance unlike typical Burlington chert  

8. Limestone, light gray to bluish, medium-grained, crystalline, in beds 1-2 ft. thick; chert, very irregularly distributed in nodules and thin bands; stylolites present  

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4. Limestone, light bluish to bluish gray, medium-grained, very massive, stylolites common, fossiliferous, containing especially large-stemmed crinoids, Pustula sp., Rhipidomella dubia and Archimedes owenanus ............................... 5

3. Chert and limestone like 7 ........................................ 1

2. Limestone, bluish gray, medium-grained, hard, uniform, massive, stylolites common, non-cherty; this is the chief building stone; contains Archimedes owenanus, Pustula alternata, Rhipidomella dubia, Reticularia pseudolineata, Spirifer lateralis and other characteristic Warsaw fossils ........................................ 25

1. Chert and limestone interbedded similar to 7. Exposed .......... 4

SECTION DESCRIPTION--6

Boone Formation in old Quarry in O'Possum Hollow
SE 1/4 NE 1/4 Sec. 33, T. 28 N., R. 33 W., Jasper County, Missouri
(Moore, 1928, pp. 215-216)

12. Soil, red clay and residual chert

Osage Group
Boone Formation
Warsaw limestone member

11. Chert, hard, irregularly nodular ............................... 6

Short Creek oolite member

10. Limestone, dark gray weathering white, oolitic, the oolites being embedded in a rather argillaceous hard limestone; contains a few fossils including Orthetes sp. and Rhipidomella dubia ........................................ 4

Keokuk limestone member

9. Limestone, light gray, medium-grained, subcrystalline, contains little crinoidal material ............................... 2

8. Limestone and chert in thin alternating bands, the limestone light bluish gray, fine to moderately coarse-grained and crinoidal; the chert bluish, flinty, grades into dense siliceous limestone ........................................ 9

7. Limestone, bluish gray, medium to coarse-grained, massive, contains chert in nodules and bands at intervals of 1-2 feet ........ 9

6. Chert and limestone in rather thin alternating bands, the chert predominating; limestone lithologically resembles bed 7 ........ 2

5. Limestone like 7, contains chert in nodules at zones 2, 3, 5 and 7.5 feet above base; stylolites common; fossiliferous, containing especially Orthetes keokuk ............................... 8

4. Limestone and chert interbedded, beds about 6 inches in average thickness (exposed near old lime kiln) ............................... 6

3. Chert, white, massive, flinty ........................................ 1

2. Limestone, light bluish, medium-grained, crinoidal, a single massive ledge ........................................ 1

1. Chert like 3. Exposed ........................................ 2