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ISOTOPIC ZONING OF LEAD AND SULFUR IN SOUTHEAST MISSOURI

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Reprinted from ECONOMIC GEOLOGY MONOGRAPH 3, 1967

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Printed in U. S. A.

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ABSTRACT

The Upper Cambrian Bonneterre formation (400 feet) is widely mineralized, predominantly with galena. The Bonneterre, dolomite or limestone, is underlain generally by highly porous Lamotte sandstone (0–500+ feet) resting on a Precambrian basement that rises in many places into the carbonate series. Above the Bonneterre is the Davis shaly limestone (150 feet), succeeded, where not eroded, by several hundred feet of dolomites which contain extensive barite deposits with accessory galena.

Isotopic studies show conclusively that all ore lead in the Paleozoic beds is anomalous, of J-type, varying considerably within deposits. In general, any vertical section of Bonneterre ore lead, as in a drill hole, is distinctly more radiogenic at the base of the formation, less so upward. Furthermore, any large mineralized area is generally more radiogenic centrally, along guiding faults or controlling basement highs (knobs), and less toward perimeters. Finally, in all clear-cut cases noted, the earlier deposited galena is least radiogenic.

Note, however, that the trace galena in overlying barite deposits is notably more radiogenic than in the Bonneterre ore bodies, apparently due to association with large deep-seated faults.

Traces of post-Precambrian lead in the basement are excessively radiogenic. However, minor veinlets of typically Precambrian galena also are known.

Sulfur isotopes are virtually identical with sea water sulfate (21.80) in the less radiogenic lead but in more radiogenic galena are lighter (22.00). Sulfur variations also show definite stratigraphic relations to horizons of high fossil content (reef rock) in the Bonneterre.

The conclusion is that radiogenic lead from the Precambrian basement mingled with normal lead in the connate fluids of the sediments to yield the anomalous hybrids. The relative proportion of the basement contribution possibly was on the order of one-third of total lead.

INTRODUCTION

THE Southeast Missouri lead district, situated 75 to 100 miles southerly from Saint Louis, Missouri, occupies, in patchy fashion, a zone several miles wide forming a semi-circle on the northerly margin of a small area of Precambrian outcrop that forms the apex of the Ozark dome. (Consult the geological map of the United States or, better, that of Missouri by the Missouri Geological Survey.) Only the eastern half of this area, called the "Lead Belt," was known prior to 1950, but recent exploration has more than doubled its extent to the west and south (14). The present paper is concerned chiefly with the old "Lead Belt," and mainly with its three principal producing areas, the Bonne Terre, Leadwood-Desloge, and Federal (or Flat River) mines, but includes sketchy data from the newer areas that were just being developed while the investigation was in progress in 1954–55. The geography of the area discussed is shown in Figure 1 (See also Snyder, this volume, Fig. 1).

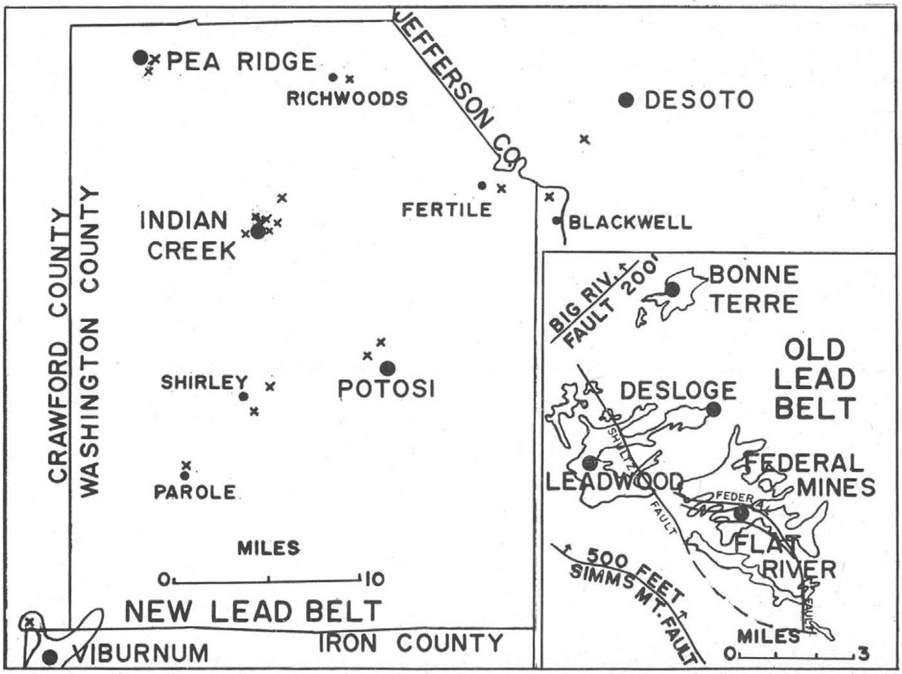

FIG. 1. Geography of Southeast Missouri Lead Belt and related mineralization in Washington county area. Leadwood shown in approximately correct position relative to Washington county. Sample localities indicated for Washington county; mine outlines only in Lead Belt.

A study of the isotopic variations of lead and sulfur as related to geological features in the ores of the old Lead Belt was conducted by Lamont Geological Laboratory of Columbia University in cooperation with the Saint Joseph Lead Company and the Geological Society of America. The Lamont program was directed by J. L. Kulp with F. D. Eckelmann as field man. The writer, as Chief Geologist for Saint Joseph Lead Company, supplied the geological direction and staff assistance. A total of 172 samples was analyzed isotopically for lead, and many of these also for sulfur.

GEOLOGY

Geological details of lead occurrence in this district have been described at length in many papers, most pertinently, for present purposes, by James (7), Ohle (9), Ohle and Brown (10), Snyder and Emery (12), Snyder and Odell (13), and Brown (3, 5). Commercial lead ores occur only in the Upper Cambrian Bonneterre formation, a limestone unit 300 to 400 feet thick, and only where this formation has been thoroughly dolomitized. This is generally in a circle five to thirty miles wide surrounding the Precambrian outcrop, but dolomitization is erratic both laterally and vertically.

The Bonneterre is overlain directly by the Davis formation, a shaly dolomitic limestone about 150 feet thick, succeeded by some hundreds of feet of dolomitic limestone beds which comprise several distinctive formations. Beneath the Bonneterre, normally, lies the Upper Cambrian Lamotte sandstone. However, the Precambrian basement was very uneven topographically and at many places rises above the Lamotte-Bonneterre contact and even through the higher formations. The Paleozoic beds are essentially flat-lying but considerably faulted.

Lead ores occur mainly in two structural settings:

1. Axially guided by fault zones from which ore runs spread laterally along depositional ridges of sandy dolomite, or into algal reefs that grew upon such ridges or other sea-floor elevations, and
2. Around and above small buried hills (knobs) of Precambrian that just pierced the Lamotte-Bonneterre contact thus localizing many sandy dolomite ridges and algal reefs.

Fault zones and knobs, therefore, constituted focal points for the dispersion of mineralizing solutions upward and outward into the more porous parts of the Bonneterre formation.

In the Lead Belt the Bonneterre has been subdivided into numerous lithologic zones numbered one to nineteen from top to bottom, but with various units missing or inconsequential. Normally unit 12 underlies unit eleven, etc., but the seven zone, an algal reef rock, transgresses these units and may be equivalent, laterally, to any from nine to twelve. Smaller reef zones also occur at higher and lower levels.

ISOTOPIC ZONING IN THE (OLD) LEAD BELT

Isotopic data are segregated logically into three main bodies corresponding to the three principal mining areas of Figure 1, the Bonne Terre, Leadwood-Desloge, and Federal (or Flat River) mines. The relative magnitude of these deposits is roughly 1:2:6. However, the Bonne Terre mine, though smallest, has produced about thirty-five million tons of ore, containing one million tons of lead. The district is noted for its low content of zinc, not exceeding one to two percent of the amount of lead.

The basic isotopic data for the principal mineralized horizons of these three areas are presented (as averages) in Table 1. Also included is a reconnaisance sampling of the Indian Creek mine, opened in 1953, situated 30

TABLE I

VERTICAL ISOTOPIC VARIATIONS IN THE LEAD BELT

Horizon	204 Per Cent	Ratios to 204: 206	207	208	No. Pb. Samples	S32/S34	No. S. Samples
			Bonne Terre Mine				
1, 3	1.295	20.43	15.94	39.87	6	21.79	6
5 Zone	1.286	20.75	15.97	40.02	8	21.85	4
7 Zone	1.276	20.99	16.05	40.35	5	21.96	5
12, 15	1.278	20.96	16.02	40.24	9	21.78	8
15/19	1.272	21.16	16.04	40.38	5	21.81	5
			Leadwood-Desloge Mines				
7 Zone	1.285	20.84	15.96	40.02	6	21.96	6
12, 15	1.285	20.80	15.96	40.03	13	21.90	13
15/19, 19, 20	1.282	20.94	15.95	40.09	17	22.04	17
			Federal (Flat River) Mines				
5 Zone	1.294	20.57	15.91	39.81	10	21.80	6
7 Zone	1.284	20.80	15.98	40.09	17	21.92	13
12, 15	1.288	20.69	15.95	39.98	5	21.84	3
15/19, 19	1.280	20.90	16.00	40.23	24	21.94	17
			Indian Creek Mine				
7 Zone	1.285	20.79	16.00	40.04	5	22.00	5
19/20	1.264	21.46	16.08	40.57	1	21.98	1

miles northwest of Bonne Terre. Indian Creek resembles most nearly the Bonne Terre mine in size and setting and, in some degree, ties together the old and newly discovered Lead Belts.

Since the Bonne Terre mine presents the simplest geological situation, being related to a single igneous knob and uncomplicated by major faulting, it is considered first. The outline of this mine and horizontal plan of sampling are given in Figure 2. The vertical and stratigraphic distribution of samples, together with their lead isotope values, are shown in Figure 3, which also serves as a general stratigraphic column for the district. Samples are projected onto a vertical axial plane extending from southwest to northeast as the mine is elongated. Samples situated far off this plane are rotated into position as indicated. Only at Bonne Terre is the Bonneterre formation mineralized virtually from bottom to top. At other mines ore is confined generally to the lower half, or even the lower fourth, of the formation.

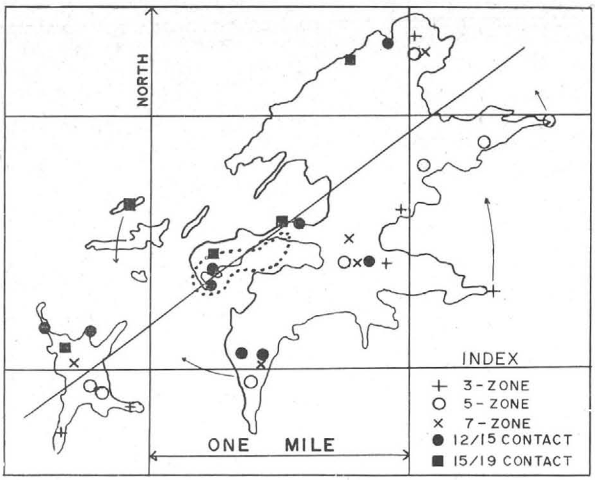

FIG. 2. Outline of Bonne Terre mine and plan of sampling. Central igneous knob shown by dotted line; section, Fig. 3, solid line.

The radial variations in the isotopic indices at Bonne Terre are plain, although a slight irregularity is evident, mainly at the southwestern end which is, in fact, a detached ore body. Lowest 204 content and highest radiogenic ratios are situated directly on top of the knob, with one exception each at either end, suggesting the possible existence of hidden satellite knobs. These indices vary upward along an axis inclined distinctly to the northeast. Highest 204 content and lowest ratios to 204 are concentrated at the top and outer limits. Note that the vertical scale is exaggerated by a factor of roughly twenty.

All lead samples from all these deposits are clearly but variably anomalous. The writer regards the percentage of 204 as the best index of the degree of anomaly, but geochemists usually stress the radiogenic ratios to 204, especially that for lead 206. All three ratios are listed, together with the S32/S34 ratio where determined.

It is obvious from Table 1 and Figure 3 that the percentage of 204 increases from the base of the Bonneterre upward, whereas the 206/204 and other radio-

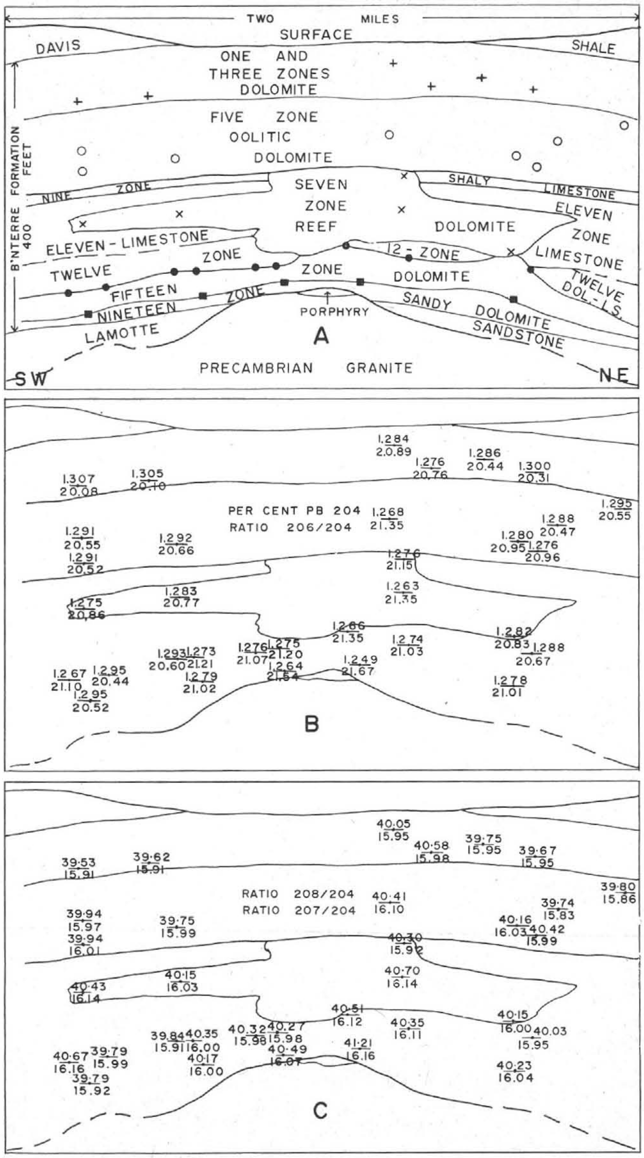

FIG. 3. Vertical section of Bonne Terre mine showing subdivisions of Bonneterre formation with distribution and values of isotope samples. See location of section in Fig. 2.

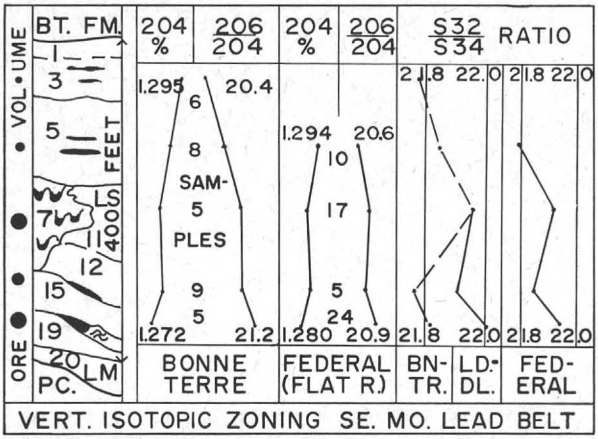

FIG. 4. Vertical isotopic zoning of lead and sulfur in the old Lead Belt, in relation to Bonneterre horizons and ore occurrence.

genic ratios diminish. That is, the degree of anomaly decreases upward. Sulfur ratios show no uniform progression but rather a definite stratigraphic correlation. The lightest sulfur (highest S32/S34 ratios) occurs in the basal horizons except at Bonne Terre, and recurs in the intermediate seven (reef) zone. Strata between and above contain heavier sulfur of nearly uniform values. The essential features of these variations for both lead and sulfur, as related to stratigraphic horizons and ore occurrence in the three mine areas, are illustrated graphically in Figure 4.

The vertical isotopic variations at Leadwood-Desloge and Federal are evident in Table 1 and Figure 4, but the lateral picture is considerably more complex because numerous focal centers evidently were involved. Thus Leadwood-Desloge has perhaps a dozen separate knobs plus a complex of important faults, resulting in considerable internal irregularity. Federal has no knobs whatever, but a strong axial fault pattern with a central graben plus numerous cross faults and some parallel ones (Fig. 1). At both Leadwood-Desloge and Federal, however, the extremities of ore bodies are least anomalous.

AGE RELATIONS OF ISOTOPIC VARIATIONS

The direction of isotopic variation with time is established by certain critical observations, as shown in Figure 5, representing conditions along a central sector of the Shultz fault, the major dislocation of the Leadwood-Desloge area. Typical bedded galena displaced about 30 feet vertically on opposite sides of this fracture exhibits distinct crushing and deformation near the fault in contrast to normal crystallinity elsewhere. Also, some galena within the fault zone, evidently dragged down, or up, from the bedded zone is strongly slickensided and plainly older than the latest fault movement.

A few feet below the slickensided galena the fault plane bulges forming an opening partly filled by calcite and coarse undeformed crystals of galena, the

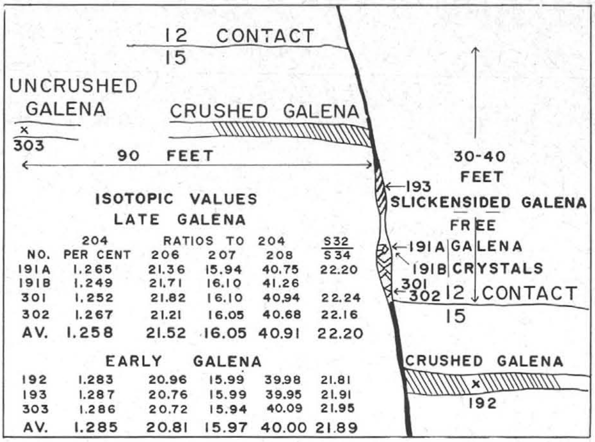

FIG. 5. Geologic relations and isotopic comparison between older, bedded galena and younger galena crystals in fault opening, Leadwood-Desloge area.

largest one collected being a four-inch cube (191). This galena must be later than the bedded and crushed material. Isotopic comparisons are tabulated on Figure 5. The younger crystals show a pronounced increase in anomaly in virtually every index, and a marked increase in the S32/34 ratio as well. Two similar examples were found elsewhere, one in the southern part of the Leadwood-Desloge mine and one in the central part of the Federal area along the Federal fault, though the isotopic differences were not quite as large.

A second approach to this problem was found in the study of a series of free-growing crystals from a twelve-inch solution cavity at Indian Creek. Numerous small (one-fourth inch) crystals lining the walls of this cavity were overgrown at one place by a two-inch cube. Table 2 compares the isotopes of the small earlier crystals with the larger, later one.

The "early" sample consisted of several small crystals. The "late" data comprise six determinations on the large crystal, two from corners, two from outside edges and two from interior locations. Differences between these were minor compared to the large difference shown in the table which, again, shows the later galena to be much more anomalous, and with lighter sulfur. The sulfur isotopes of the large crystal have been discussed by Ault and Kulp (1, p. 94) with the conclusion that the lighter sulfur is later.

Galena crystals from the Tri-state (Joplin) district are known to exhibit wide internal isotopic variations with the exteriors more radiogenic (6).

TABLE 2

ISOTOPES OF EARLY VERSUS LATE CRYSTALS AT INDIAN CREEK

Sample	204%	206/204	207/204	208/204	S32/34
Early	1.293	20.71	15.95	39.69	21.99
Late	1.256	21.57	16.04	41.02	22.17

TABLE III

LEAD ISOTOPES LEAD DEPOSITS VERSUS BARITE DEPOSITS

WASHINGTON COUNTY AREA

Locality	Horizon	204 Per Cent	Ratios to 204: 206	207	208	S32/S34
		Lead Ore, Bonneterre Formation				
Viburnum	18/19	1.263	21.44	16.09	40.66	----
Shirley	15	1.276	21.02	16.02	40.34	----
Ind. Creek	7	1.284	20.72	16.03	40.30	22.00
Ind. Creek	19/20	1.264	21.50	16.08	40.57	21.98
Blackwell A	3	1.290	20.53	15.89	40.11	21.81
Blackwell B	7	1.333	19.56	15.67	38.78	----
		Barite Deposits, Potosi-Eminence or Higher				
Parole M.	Eminence	1.246	21.61	16.03	41.61	----
Krueger M. (Shirley) A	Eminence	1.272	20.85	16.07	40.67	
" B	Eminence	1.231	22.06	16.20	41.98	
Potosi Mines A	Potosi	1.218	22.41	16.32	42.37	22.15
" B	Potosi	1.239	21.97	15.99	41.73	----
Richwoods	Pot.-Em.	1.238	21.63	16.31	41.83	----
Lee M. (Fertile)	Pot.-Em.	1.234	21.99	16.13	41.93	----
DeSoto	Jefferson City	1.230	22.20	16.17	41.96	22.32
Average (7)	Krueger A Excluded	1.234	21.98	16.15	41.92	22.23
		Pea Ridge Iron Deposit. Trace Lead in Fractures				
200 Feet Below Lamotte	Precambrian	1.112	26.26	16.38	46.25	---A
In mine shaft	Bonneterre 3 Zone	1.108	26.65	16.45	46.15	21.95B

All single samples except Indian Creek seven zone (6).

However, the reverse situation has been described from New Mexico by Austin and Slawson (2), and Slawson and Austin (11).

The pattern in the old Lead Belt, therefore, is that individual mine variations are confined to similar ranges, averages and stratigraphic and lateral distribution. This holds true, likewise, for several smaller deposits to the southeast, including Doe Run, Mine Lamotte (Fredericktown area) and Annapolis, from which a dozen confirmatory samples were analyzed. Since ore in these localities is almost all found at low levels, in or just above the nineteen zone, most results tend to be higher than Lead Belt averages but similar to the corresponding low-level Lead Belt values. Outer margins of the districts again are less radiogenic than central areas.

ISOTOPIC PATTERNS OF THE NEW LEAD BELT, BARITE FIELDS, AND PEA RIDGE

In the old Lead Belt the Bonneterre or immediately overlying Davis prevail in outcrop with only thin remnants of higher beds. In most of Washington county to the west (Fig. 1), from the new Lead Belt at Viburnum northeastward, considerably higher beds outcrop. The Potosi-Eminence contact zone, roughly 500 feet above the top of the Bonneterre, is mineralized widely

FIG. 6. Comparative sections from Viburnum northeastward across Washington county showing structural and stratigraphic relations of isotopic samples from Bonneterre horizon and overlying barite deposits. Central inset for Pea Ridge samples to northwest.

with barite. This zone carries trace galena, in some places recoverable as a by-product, and in certain areas once mined for lead. Barite has been mined extensively for many years from residual concentrations in the lateritic soil.

The underlying Bonneterre is still mineralized, with galena but not barite, at various places in this area, as at Indian Creek. There is no close vertical concordance between the two types of mineralization but it seemed desirable to establish an isotopic comparison. Furthermore, a significant instance of post-Precambrian trace lead was discovered in the Pea Ridge iron deposit within the Precambrian. An isotopic comparison of these three types of lead is presented in Table 3 and Figure 6.

Excluding Krueger mine sample A, barite lead and Lead Belt lead compare as follows:

TABLE 4

ISOTOPES OF BARITE LEADS AND LEAD BELT LEADS

	204%	206/204	207/204	208/204	S32/34
Barite lead	1.234	21.98	16.15	41.92	22.23
Lead Belt (Old)	1.283	20.84	15.99	40.12	21.92

Krueger sample A serves to relate the types. Samples A and B are from a single four-inch cube within a barite-lead deposit. The one (A) is very similar to average Lead Belt ore whereas B is typical barite lead. Unfortunately there is no recorded evidence as to which is earlier, though presumably the A sample should be. Otherwise, all barite leads, though found at considerably higher horizons, are more radiogenic than the Bonneterre lead, and resemble closely the late-stage crystals from the fault zone of Figure 5. The close association of several of the barite lead samples with major faults, as indicated in Figure 6, suggests that the lead rose at a late stage along these faults and was characteristically more radiogenic, but present in small volume.

The Viburnum sample affords the only analysis from the great new Lead Belt, which was just being explored in 1955. It is normal for low Lead Belt horizons. So also with the Shirley lead, situated about one mile from the Krueger mine. At Blackwell, the three zone is normal for high horizon Bonneterre lead, but the sample from the underlying seven zone, is the least radiogenic encountered in the entire survey. No obvious explanation is available. Both samples represent only trace mineralization.

The Pea Ridge samples are significant, particularly that from the Bonneterre formation, analyzed especially for this study at the author's expense. It is virtually identical with the earlier result on a sample of small, late galena crystals in a calcite veinlet encountered in the Precambrian Pea Ridge iron deposit 200 feet beneath the Lamotte formation. The Bonneterre at Pea Ridge is limestone, not dolomite, and the Lamotte has proved water-bearing only in thin lenses. The Bonneterre lead is in a sheeted zone near the top of the formation. Evidently lead of this extremely radiogenic type circulated unchanged from Precambrian to Paleozoic in minor fractures within these tight wall rocks.

SULFUR ISOTOPES

Sulfur isotopes exhibit two distinct patterns of variation. Lighter sulfur (high ratios) follows more radiogenic lead, especially in fracture zones, but the more important correlation volumetrically is stratigraphic with lighter sulfur ((22.0 ±) concentrated in the two principal ore horizons, at the top of the 19 zone, and again in the seven zone (Fig. 4). The seven zone is largely algal reef rock with irregular minor partings of pyritic black shale along which ore tends to be concentrated. The nineteen horizon (sandy dolomite) typically constitutes ridge structures (10, Figs. 6, 7) on the flanks of which minor reefs enclosing small muddy lagoons, now represented by patchy black shale, tended to develop (Fig. 4). Rich ore commonly occurs just above this shale band. These associations suggest that an original organic content in the shale bands and related reef rocks nurtured a bacterial growth that abstracted sulfur (as H_2S) from sea water, initially to produce pyrite early in diagenesis. It seems doubtful that this situation could have persisted to the time of lead ore formation. However, galena to some extent definitely replaced pyrite and may have derived part of its sulfur in this manner. No free carbon now exists in these ore horizons and free hydrocarbons are extremely uncommon anywhere in Southeast Missouri, in contrast to other Mississippi Valley ore districts. A limited study of sulfur isotopes in galena compared to adjacent iron sulfide (marcasite in this case) in a high-level stope at Bonne Terre showed the sulfur in both galena and marcasite to average close to the 21.80 ratio (1, p. 81). A similar study of the sulfur composition of galena and associated barite in the barite fields (1, p. 97), however, showed barite from six localities to average 21.57 whereas galena averaged 22.09. The two samples of lead from barite deposits in Table III average 22.23. Clearly the lead of barite deposits, presumably late and apparently related to major deep-seated faults, carries sulfur close to the normal crustal average such as is commonly considered to be of magmatic origin (but possibly merely homogenized?). In contrast the sulfur of the great mass of lead in the deposits of the Bonneterre formation is either essentially like that of sea water in composition, or intermediate between the sea water and the supposed magmatic norm, perhaps suggesting a blending of the two types and sources.

GENETIC INTERPRETATIONS

An interpretation of the genesis of these ores has been presented recently (4) elsewhere, and there seems to be no reason to modify this materially. The primary ore fluid is considered to have been the connate water generated in the Paleozoic section, highly concentrated, circulating mainly in the Lamotte formation. The lead, partly originally in solution and in part leached from the rocks permeated, was derived mainly from the sedimentary rocks but the radiogenic contaminant came entirely from the Precambrian. It may have been obtained solely by leaching, but it is possible also that much of it may have been driven out of the basement rocks by crustal heating possibly induced by depression of the land, or otherwise. This probably occurred in Mesozoic time, since the Cretaceous sea once extended inland almost to the Lead Belt. The downward tilting should have produced lateral flowage in the connate waters resulting in upward pressure in the Lead Belt, a situation that, at present, has been reversed by re-elevation.

The highly radiogenic lead contributed by the basement inevitably should result in a strong upward diffusion gradient reenforced, possibly even dominated, by convection due to heat from below. The laminar flow induced by tilting would modify this substantially, however, as would the development of faults facilitating more rapid upward escape.

Where faulting was minimal, as at Bonne Terre, so that the Davis cover, present before erosion, was not breached, the overall gradation upward and outward, suggestive of diffusion (plus convection?), is plain (Figs. 3, 4). Where major faults severed the Davis cover, permitting the more highly radiogenic lead generated at depth along these fractures in the Precambrian basement to escape into overlying formations, the vertical pattern is reversed and more radiogenic lead occurs at higher levels, in the barite fields. This effect should diminish laterally away from these master faults, but has not been investigated. The source of the barite, and its conspicuous absence in the Bonneterre horizon are unexplained and outside the scope of this discussion.

Pea Ridge samples are suggestive of the nature of lead contributed by the basement. Elsewhere (4), the writer has assumed that lead normal to the upper Cambrian formations should have averaged about 1.380 percent 204 (with 24.80, 21.55 and 52.25 percent 206, 207 and 208, or ratios of 18.00, 15.65 and 38.00). To obtain average Lead Belt ore one would need to add nearly seven percent pure radiogenic lead divided roughly into 12 percent of the 206, 2 percent 207 and 5 percent of the 208. Assuming Pea Ridge lead to represent the actual basement contribution, an admixture of two parts normal sedimentary lead (1.380 percent 204) with one part Pea Ridge lead would yield a hybrid closely matching Lead Belt ore in percent 204, 206 and 207 but high in 208 (52.08). Hence, it appears that Pea Ridge is close to but not exactly representative of the basement contribution. However, a mixture of equal parts Pea Ridge lead and hypothetical normal lead (1.380) would almost exactly match the composition of the small amount of lead present in the barite fields.

The conclusion, therefore, is that the sediments probably supplied two-thirds of Lead Belt lead and the basement the one-third which accounts for all of its anomaly. The relative proportions varied widely, however, from place to place, and the only significance of time variations is that the proportion of basement lead generally increased as deposition progressed, probably because of the progressive elimination by ore deposition of the lead contained in the sediments and their connate fluids.

APPENDIX

With the exception of analyses set forth individually in the preceding tables and illustrations (Bonne Terre, Washington County, etc.), the Appendix presents in detail all available data on which the averages used herein are based. For completeness the scattered samples of outlying mines and prospects are included.

TOWSON, MARYLAND

APPENDIX

DETAILED LEAD ISOTOPES, SOUTHEAST MISSOURI LEAD BELT

LEADWOOD-DESLOGE (AND HAYDEN CREEK) MINES

NO.	MAP COORDINATES, FEET		LEAD ISOTOPE RATIOS (204 PER CENT)				S32/S34
	NORTH	EAST	204	206	207	208	
			Seven Zone (b = at base)				
212b	61135	46603	1.295	20.53	15.92	39.76	21.95
209	61145	46783	1.292	20.71	15.92	39.78	21.94
207	61060	47162	1.288	20.76	15.95	39.93	21.84
206b	59730	43855	1.280	20.90	16.04	40.18	21.94
23	49228	37679	1.280	20.96	15.99	40.16	22.10
14b	50098	33505	1.274	21.20	15.96	40.34	22.10
		Zones 12 through 15 (a = 12, b = 15, c = 12/15 contact)					
184a	62932	25504	1.312	20.15	15.79	39.28	21.83
277Ac	62165	38100	1.300	20.34	15.87	39.72	21.63
(277B	Cerussite in PbS of A)		1.298	20.41	15.92	39.71	-
189c	65285	29287	1.289	20.82	15.93	39.84	21.91
180c	56102	25485	1.288	20.81	15.91	39.93	22.01
193*	60737	30915	1.287	20.76	15.99	39.95	21.91
200c	58540	38925	1.287	20.79	15.97	39.95	21.86
303c*	60080	31358	1.286	20.72	15.94	40.09	21.95
196a	54170	28035	1.284	20.87	15.96	40.05	21.93
192	59927	31422	1.283	20.96	15.99	39.98	21.81
195c	54170	28035	1.281	20.80	15.96	40.30	21.91
1a	52075	35715	1.281	20.90	15.96	40.20	21.85
202c	59790	40940	1.274	21.08	16.07	40.35	21.91
10c	49865	32815	1.264	21.33	16.06	40.74	21.97

* See Figure 5 for details.

NO.	NORTH	EAST	204	206	207	208	S32/S34
		Zones 15/19, 18 (conglomerate), 19, 20 (Lamotte) c = 15/19 contact; n = 19; s = Lamotte sandstone					
182c	62989	24979	1.307	20.23	15.87	39.42	21.83
225h	50280	17890	1.299	20.62	15.77	39.60	21.95
201n	64680	40340	1.295	20.54	15.97	39.72	21.85
22c	49480	34212	1.286	20.96	15.84	39.97	21.82
181c	59809	21075	1.285	20.88	15.92	40.02	22.13
7(18)	49185	31090	1.284	21.18	16.02	39.69	22.16
214c	60985	46355	1.282	20.94	15.94	40.12	21.88
198n	58215	38060	1.282	20.96	15.95	40.10	21.94
305n	52260	35860	1.281	21.07	15.93	40.09	22.61
8n	50420	32730	1.281	21.05	15.78	40.23	22.16
172c	48370	25580	1.280	20.95	15.93	40.25	22.00
185s	57420	29548	1.278	21.12	15.88	40.24	22.05
226h	50200	17575	1.277	20.95	16.02	40.34	21.95
174n	50515	28180	1.276	21.07	16.03	40.27	22.23
194n	51730	27340	1.271	21.28	16.08	40.32	22.27
232(18)	52910	36250	1.270	21.14	16.00	40.60	22.02
197c	56490	55955	1.268	21.11	16.19	40.57	21.85

225h is from upper, 226h from lower 18 zone, Hayden Creek

FEDERAL (FLAT RIVER) MINES

NO.	MAP COORDINATES, FEET NORTH	EAST	LEAD ISOTOPE RATIOS (204 PER CENT) 204	206	207	208	S32/S34
Five Zone. b = base							
241b	55800	53300	1.317	20.20	15.65	39.10	-
275b	47100	56500	1.314	19.99	15.85	39.27	21.60
245b	45900	62200	1.304	20.02	15.90	39.63	-
261	45900	54800	1.297	20.50	15.88	39.72	21.84
94	43968	59253	1.292	20.84	15.86	39.71	21.81
95	43968	59253	1.291	20.65	15.92	39.89	21.81
93	43968	59253	1.289	20.71	15.92	39.95	21.89
96b	42573	57540	1.280	20.88	16.00	40.23	21.83
242b	40200	55450	1.278	20.91	16.10	40.24	-
274b	54200	49700	1.277	20.97	16.01	40.33	-
Seven Zone. b = base							
91b	45948	62191	1.321	19.77	15.79	39.14	21.90
97b	42633	57527	1.307	20.07	15.94	39.51	21.84
81b	55810	53310	1.305	20.17	15.96	39.49	21.85
246b	47800	63000	1.293	20.46	15.96	39.92	-
39	34785	55340	1.293	20.66	15.91	39.78	21.84
113b	24000±	59000±	1.290	20.76	15.83	39.94	-
76b	54223	49700	1.284	20.79	15.97	40.17	22.02
103	40200	55450	1.284	20.90	16.10	39.88	21.79
83b	51033	47718	1.283	20.88	15.97	40.10	21.96
38	34760	55375	1.278	20.91	15.97	40.37	21.85
36b	30745	61225	1.278	20.85	16.06	40.34	21.80
41b	42835	44575	1.276	21.03	15.98	40.36	22.02
49b	37900	51800	1.276	21.00	16.07	40.31	21.90
32b	46718	39600	1.275	20.98	16.05	40.41	22.07
27b	50260	41836	1.274	21.05	16.01	40.42	22.08
268b	43100	47000	1.264	21.50	15.97	40.64	-
271b	41800	48200	1.255	21.84	16.09	40.76	-
Zones 12 and 15. a = 12; b = 15; c = 12/15 contact							
37b	35415	56020	1.299	20.17	15.97	39.83	21.84
272c	41700	48500	1.292	20.77	15.78	39.85	-
265c	45800	52100	1.289	20.74	15.90	39.95	21.74
260c	47300	57000	1.285	20.77	15.94	40.10	-
306a	48090	50200	1.276	20.98	16.15	40.26	21.93
Fifteen-nineteen contact (c), and nineteen zone (n)							
244c	45900	62200	1.313	19.96	15.86	39.34	22.23
89c	47850	62987	1.305	20.24	15.87	39.52	21.80
247c	47800	63000	1.304	20.17	15.92	39.60	21.74
266c	43600	49200	1.295	20.72	15.83	39.68	21.85
280c	39605	53730	1.289	20.78	15.83	39.98	-
252c	35400	56000	1.288	20.65	15.94	40.05	22.01
273c	46810	56095	1.287	20.78	15.98	39.96	-
79c	54380	49650	1.286	20.78	15.95	40.04	21.85
263c	45800	52000	1.285	20.70	16.04	40.10	21.85
243c	40200	55450	1.284	20.83	15.90	40.15	-
99c	42464	57641	1.280	20.88	16.02	40.23	21.98
238c	50360	41800	1.278	21.01	15.86	40.38	-
251c	38000	51750	1.278	21.00	15.98	40.27	-
77c	55855	53170	1.275	20.88	16.09	40.46	21.80
40c	43200	44805	1.273	21.07	16.08	40.39	21.98
35c	30620	62175	1.272	21.08	16.11	40.49	22.04
262c	45900	54800	1.271	21.12	16.04	40.52	21.84
239c	51000	47700	1.270	21.15	16.04	40.56	-
47c	38138	51698	1.269	21.10	16.14	40.57	21.92
112c	24000±	59000±	1.268	21.33	16.01	40.53	22.13
250c	43200	44800	1.265	21.21	16.14	40.71	21.91
82c	51076	47649	1.265	21.26	16.06	40.73	21.96
253c	30700	61200	1.264	21.42	16.06	40.64	-
25n	50535	42817	1.259	21.53	16.16	40.76	22.02

PERIPHERAL MINE AREAS

NO.	MAP COORDINATES, FEET NORTH	EAST	LEAD ISOTOPE RATIOS (204 PER CENT) 204	206	207	208	S32/S34
	Doe Run (South of Federal). Lead Belt coordinates.						
221	13920	57200	1.286	20.79	15.98	39.99	-
219	6810	63545	1.269	21.38	15.97	40.46	22.16
222	16900	54220	1.267	21.33	16.03	40.58	22.17
218	7865	64405	1.251	22.08	16.15	40.72	22.15
	No. 219 is basal conglomerate. Others, 12-zone within a few feet of underlying granite.						
	Mine Lamotte, north of Fredericktown. Independent coordinates.						
118	51725	62520	1.292	20.50	15.94	39.97	-
120	54490	56516	1.285	20.75	16.02	40.05	21.92
121	53230	55055	1.276	20.92	16.10	40.37	21.88
124	52050	50420	1.252	21.78	16.13	40.97	22.14
123	52060	50410	1.252	21.68	16.14	41.01	22.22
	No. 120, 12-zone; 121, 19-zone; others, 19/20 contact. No. 124, fault gouge.						
	Annapolis (25 miles southwest of Mine Lamotte)						
109	1/2 mi.S.E.Annapolis		1.269	21.39	15.94	40.47	-
107	1/2 mi.N.W. Annapolis		1.261	21.54	16.01	40.76	-
	No. 107, 10 feet above 19-zone. No. 109, in 15 zone.						
	Indian Creek. Seven-zone detail.						
53	Within 7-zone.		1.293	20.71	15.95	39.69	21.99
54	"		1.287	20.78	15.93	40.00	22.09
58	"		1.282	20.94	16.02	40.04	21.99
55	"		1.281	20.43	16.06	40.16	22.00
62	"		1.275	21.07	16.04	40.32	21.95
52	Av. 6 Anal., one Xtal.		1.256	21.57	16.04	41.02	22.17
	Precambrian leads						
126	"Silver Mine," 8 mi.		1.405	17.05	15.79	37.27	-
127	W. of Fredericktown		1.441	16.48	15.54	36.38	21.95
170	4 mi. S. Fredericktown		1.441	16.40	15.51	36.49	22.18
	Nos. 126 and 127 from tungsten-bearing quartz pegmatite vein in granite. No. 170, Jackson-Ravelle shaft. Narrow veinlet in porphyry. PbS in gouge-like matrix, crushed appearance.						

REFERENCES

1. Ault, W. L., and Kulp, J. L., 1960, Sulfur isotopes and ore deposits: Econ. Geol., v. 55, p. 73–100. See p. 94.
2. Austin, C. F., and Slawson, W. F., 1961, Isotopic analyses of single galena crystals: Am. Min., v. 46, p. 1132–1140.
3. Brown, J. S., 1950, Sedimentary rocks as hosts for ore deposits: p. 524–536 in Trask, F. D., Editor, Applied Sedimentation: John Wiley and Sons, New York.
4. ——, 1965, Oceanic lead isotopes and ore genesis: Econ. Geol., v. 60, p. 47–68. See p. 61–64.
5. ——, 1958, Field trip number one, Southeast Missouri Lead Belt: Geol. Soc. Am. Guidebook, Saint Louis meeting, p. 1–17.
6. Cannon, R. S., Jr., Pierce, A. F., Antweiler, J. C., and Buck, C. L., 1961, The data of lead isotope geology related to problems of ore genesis: Econ. Geol., v. 56, p. 1–38. See Figure 14.
7. James, J. A., 1952, Structural environments of the lead deposits in the southeastern Missouri mining district: Econ. Geol., v. 47, p. 650–660.
8. Jensen, M. L., Editor, 1962, Biogeochemistry of sulfur isotopes: Proc. Nat. Sc. Fd., Yale Univ. Press.
9. Ohle, E. L., 1952, Geology of the Hayden Creek mine, Southeast Missouri: Trans. A. I. M. E., v. 193, p. 477–483.
10. ——, and Brown, J. S., 1954, Geologic problems in the Southeast Misouri lead district: Geol. Soc. Am. Bull., v. 65, p. 201–222. Also Suppl. p. 935–936.

11. Slawson, W. F., and Austin, C. F., 1962, A lead isotope study defines a geological structure: Econ. Geol., v. 57, p. 21–29.
12. Snyder, F. G., and Emery, J. A., 1956, Geology in development and mining, Southeast Missouri Belt: Trans. A. I. M. E., v. 205, p. 1216–1224.
13. ——, and Odell, J. A., 1958. Sedimentary breccias in the Southeast Missouri lead district: Geol. Soc. Am. Bull., v. 69, p. 889–925.
14. Weigel, W. W., Nov. 1965, The inside story of Missouri's exploration boom: Eng. & Min. Jour., v. 166, p. 77–86, 170–172.

DISCUSSION

H. Pelissonnier: At the beginning of your talk you showed us a good zonality pattern. You told us that these curves suggest diffusion beginning from the Precambrian source of radiogenetic lead which feeds a reservoir located under the normal lead deposits. Couldn't you explain this variation in zonality by a variation in the time of the deposits, the lower deposits being more recent? This would correspond with the facts which you showed thereafter to the effect that the outside edges of the crystals were more radiogenetic.

Brown: I am not sure if I clearly understand the implications of this question. As I indicated, all our evidence here was that the more radiogenic lead tended to come in somewhat later than the less radiogenic when we had definite time relations, but that within the Bonneterre formation there was a diffusion gradient beneath the Davis shale. Now all these major deposits underneath the Davis shale are along minor fault zones that were not large enough to break through the Davis shale.

Where we have larger fault zones that broke the Davis cover and permitted this more radiogenic lead to escape in openings upward, there we had a much more radiogenic lead deposited above and, since this was deposited as those faults had grown larger, I think we can fairly assume that it was later.

GSA Bull. v. 70, 1959, p. 1595

LEAD ISOTOPES AND ORE DEPOSITION IN THE SOUTHEAST MISSOURI LEAD DISTRICT

L

F. D. Eckelmann and J. L. Kulp

Department of Geology, Brown University, Providence, R. I.; Lamont Geochemical Laboratory, Columbia University, Palisades, N. Y.

[redacted]

GSA Bull. vol. 69, 1958, p. 1551

DISTRIBUTION OF COPPER, ZINC, AND MINOR METALS IN THE SOUTHEAST MISSOURI LEAD DISTRICT

James H. Davis

[redacted]

BULLETIN OF THE GEOLOGICAL SOCIETY OF AMERICA
VOL. 65, PP. 201-222, 4 PLS. 11 FIGS, MARCH 1954

GEOLOGIC PROBLEMS IN THE SOUTHEAST MISSOURI LEAD DISTRICT

BY E. L. OHLE AND J. S. BROWN, *Editors*[1]

ABSTRACT

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TEXT

ILLUSTRATIONS

[1] Principal contributions by J. S. Brown, W. S. Detrick, J. A. Emery, J. E. Jewell, J. E. Kiser, E. L. Ohle, F. G. Snyder, R. E. Wagner, W. W. Weigel, and F. B. Whiting. Written and edited by E. L. Ohle and J. S. Brown.

BULLETIN OF THE GEOLOGICAL SOCIETY OF AMERICA
VOL. 65, PP. 935-936 SEPTEMBER 1954

Short Notes

GEOLOGIC PROBLEMS IN THE SOUTHEAST MISSOURI LEAD DISTRICT: SUPPLEMENT

BY E. L. OHLE AND JOHN S. BROWN, *Editors*

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STATE OF MISSOURI

DIVISION OF

GEOLOGICAL SURVEY AND WATER RESOURCES

DEPARTMENT OF BUSINESS AND ADMINISTRATION

January 25, 1952

Dr. Edward Wisser
Division of Mineral Technology
University of California
Berkeley 4, California

Dear Dr. Wisser:

I appreciate your advising me that any comments you may wish to make in regard to the fundamental and basic interpretations of large scale structures in the southeastern Missouri mining district will be delayed until you have had ample opportunity to dig deeper into the problem.

I hope that your forthcoming trip to the Philippines is both enjoyable and successful.

With best wishes I am,

Yours very truly,

Jack A. James

Jack A. James
Ass't State Geologist

JAJ:eb

January 19, 1952

Mr. Jack A. James,
Ass't.State Geologist
Missouri Geolgical Survey
Buehler Bldg.
Rolla,Mo.

Dear James:

Your manuscript sent me so long ago has been very much on my conscience. After looking it over I realized that if my comments were to be worth anything I should have to get down and dig for a number of days. I can't pull a rabbit out of hat,and I have been so bogged down with 10001 things all fall and winter I just have not had the time to do it.

I face a further delay because I am taking off for the Philippines on professional work next week. On my return I shall do my very best to assist you with ideas on your problem,which is fundamental and basic,precisely the reason I have not tried to fob off any casual comments on you.

With best regards

Sincerely

Edward Wisser

EDWARD L. CLARK
STATE GEOLOGIST

BUEHLER BUILDING
ROLLA, MISSOURI

STATE OF MISSOURI

DIVISION OF
GEOLOGICAL SURVEY AND WATER RESOURCES
DEPARTMENT OF BUSINESS AND ADMINISTRATION

September 13th, 1951

Dr. Edward H. Wisser,
1986 Yosemite Road,
Berkely, California

Dear Dr. Wisser;

You will recall our discussion of last spring, at the A.I.M.E. convention concerning the relationship between the time of metallization and dynamic movement alont mineralized fractures. In connection with this subject, I mentioned a study of the regional geology in the southeastern mining district. You very kindly expressed an interest in the structural picture of the district and possible interpretation. I am taking advantage of your interest by sending you under separate cover, a print of the geological map, structure sections, major structural features, and a diagramatic cross section of the Ste. Genevieve fault zone.

Also under separate cover are two exerpts from the preliminary manuscript. One exerpt deals with the age of the deformation, and the general summary of the factors involved in the development of the structure in the mining district. The other is a paragraph that emphasizes the different nature of the Ste. Genevieve fault zone in the vicinity of the line of the cross section from its nature elsewhere, in the mining district.

I have become interested in the possibility that collapse may have played an important part in the structural picture. If it can be visualized that the faulting west of the Farmington anticline is the near surface vertical planes of deep seated structures that may curve eastward at depth, similar to gravity faults, and that the Ste. Genevieve fault zone contains the "keystone" and curves westward at depth, the pattern in cross section is similar to the pattern obtained experimentally by Cloos. The expression of this pattern does not include antithetic faults, but the sympathetic synthetic faults are very much in evidence at the surface.

It does not seem unreasonable that antithetic faults similar to those Cloos obtained, would have been removed from this district with the younger formations.

I am very interested in your comments about the structure pattern in the southeastern Missouri mining district. You have applied Cloos' experimental data very sucessfully to the Pachuca Silver District. I presume you would be interested in other possible applications of this experimental data.

I will welcome any comments you wish to make. I am particularly anxious for your reaction to the hypothetical pattern at depth, and its possible correlation to Cloos' experimental data.

If you so desire, please feel free to retain the maps and sections for your files, or to dispose of them as you wish.

Yours very truly,

Jack A. James

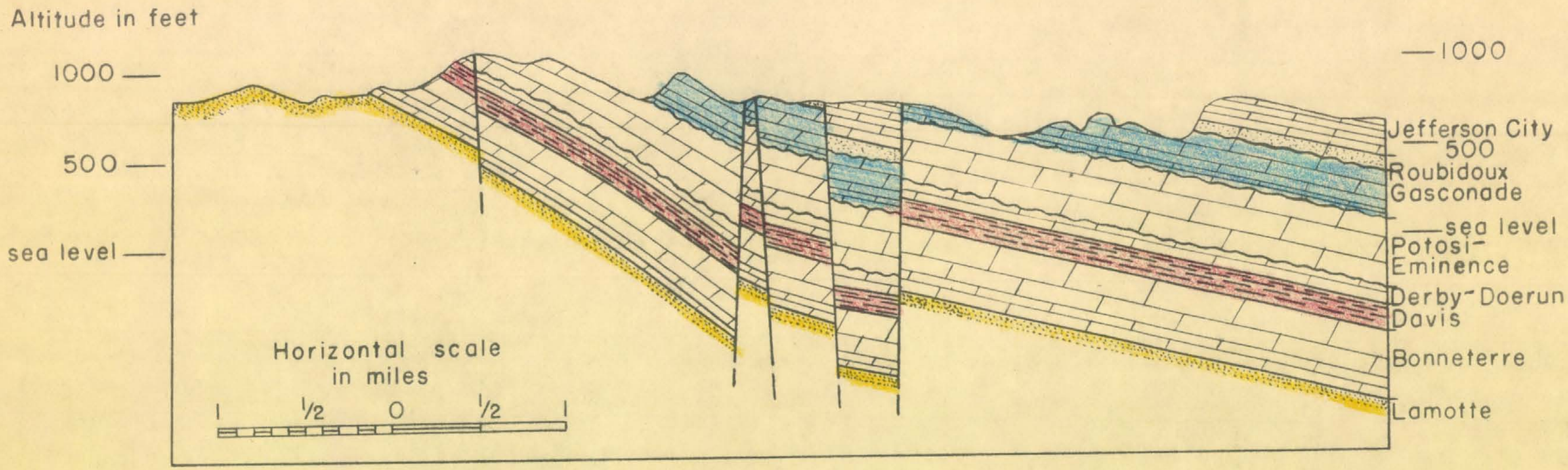
Jack A. James
Ass't. State Geologist

JAJ:jrb

SOUTHEASTERN MISSOURI

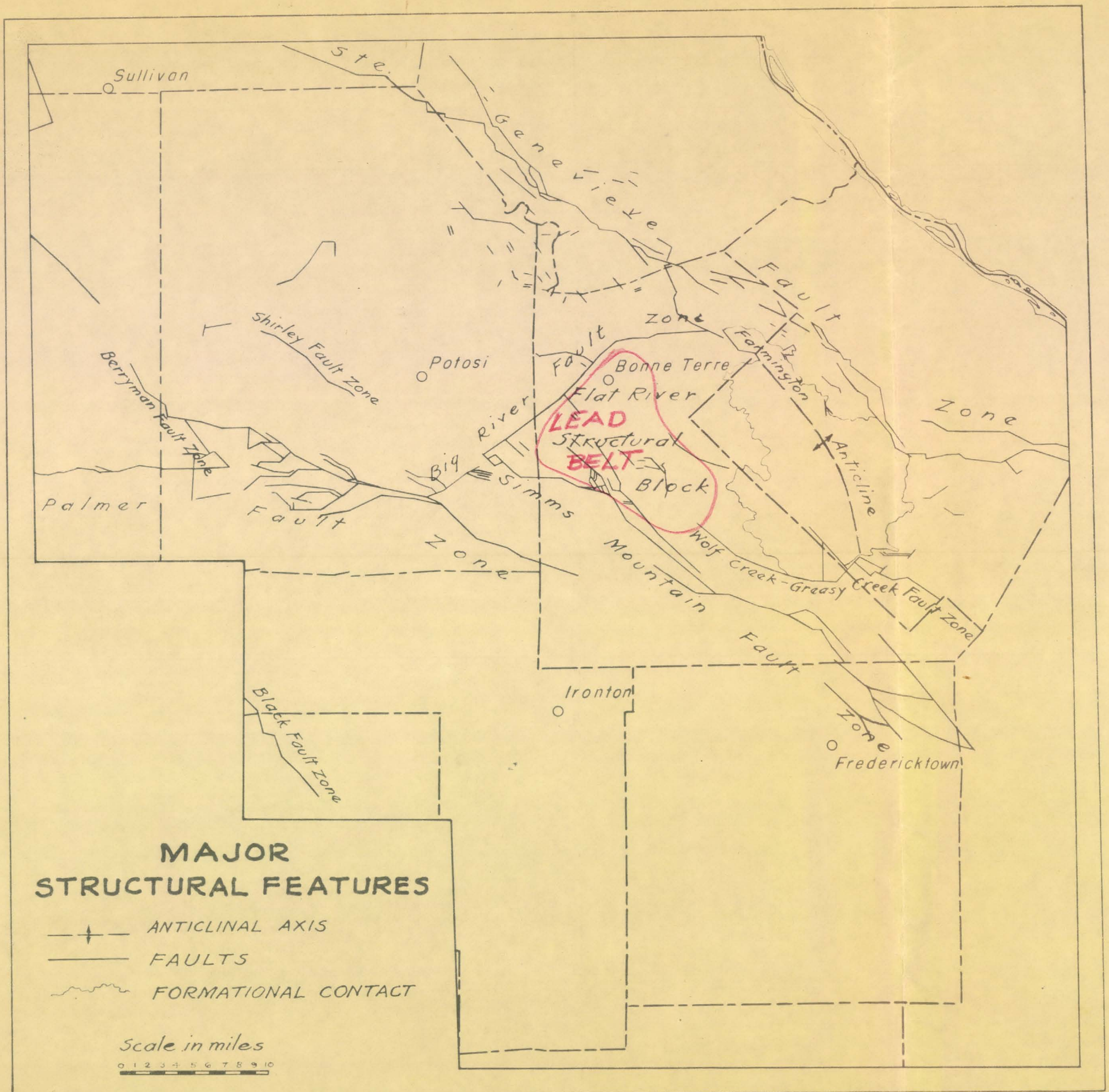
The Ste. Genevieve Fault Zone

The fault zone has a northwest trend from the eastern edge of T. 36 N., R. 7 E., to where it apparently dies out in Franklin County. Northwestward to the St. Francois County line, it is composed of faults belonging to the two periods of movement; the two fault systems coincide in position and it is difficult to differentiate one from the other. Also the character of the structure is different from that elsewhere along the fault zone. A cross-section illustrates this character. The fault zone consists of a series of downfaulted blocks. The aggregate displacement, downthrown to the east, is nearly matched by the displacement along the east boundary fault which is downthrown to the west. If the regional dip of the sediments to the east is projected westward, a total stratigraphic displacement across the fault zone in the magnitude of 200 feet is indicated, but a displacement of as much as 500 feet is present along a single fault plane. The small displacement across the fault zone and the larger displacements within it are in contrast to the character of this zone of faulting elsewhere along its extent.



Diagrammatic cross-section of Ste. Genevieve fault zone
T.37N., R.7E.
Looking north

Southeastern Missouri
By Jack A. James



Southeastern Missouri
By Jack A. James

SOUTHEASTERN MISSOURI

AGE OF THE DEFORMATION

The age of only some of the structural features can be determined accurately. The relation of a few structures to each other indicates the sequence of development, although their specific age is unknown.

Weller and St. Clair[144] recognized two distinct periods of movement in the Ste. Genevieve fault zone. The earlier period is post-Middle Devonian and the later period is post-Pennsylvanian. Some of the other zones of faulting cannot be dated more accurately than as post-Upper Cambrian, post-Lower Ordovician, etc., because only lower Paleozoic formations are present over a large portion of the mining district.

The relative age of the Berryman, the Palmer, the Big River, and the Simms Mountain fault zones can be ascertained. The Berryman fault zone and the faulting to the northwest (Leasburg fault zone) probably are correlative. The relative movement, the amount of displacement, and their trends indicate that they may be one continous zone of faulting. Pennsylvanian beds, in the northwest corner of the mining district, involved in this faulting indicate that the Leasburg fault zone was active in post-Cherokee time. If the Berryman fault is a continuation of the Leasburg fault, then it also had a post-Cherokee movement.

The age relationship of the Berryman and Palmer fault zones is indicated by that segment in sec. 30, T. 37 N., R. 1 W., which was involved in the movements along both the fault zones. The strata

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144 S. Weller and St. St. Clair, Geology of Ste. Genevieve County, Missouri, Missouri Bureau of Geology and Mines, 2d. ser., 22:256-266, 1928.

on the north side were upthrown 200 feet by movement along the Berryman fault and were later downthrown 300 feet by movement along the Palmer fault. The difference in the magnitude of the two movements is 100 feet which is equal to the amount of vertical displacement along this segment of the fault. The Palmer fault zone exhibits 300 feet of stratigraphic displacement east of this segment, but there is no indication of folding along a westward projection of its strike. The abrupt termination of the Palmer fault zone where it exhibits 300 feet of vertical displacement and the absence of folding along its projected strike, suggest that the Berryman fault zone was pre-existant.

The Big River fault zone terminates abruptly at the Palmer fault zone in sec. 26, T. 36 N., R. 2 E., suggesting that the Palmer fault zone is older. Similarly, the Simms Mountain fault zone terminates at the Big River fault zone in sec. 9, T. 36N., R. 3 E. Its abrupt termination indicates that the Big River fault is older.

The actual time of faulting cannot be determined, but the sequence of their development is evident. The Berryman fault zone is the oldest of the four and it may have been active in post-Cherokee time. The Palmer fault zone is the next oldest, and it is followed in order of development by the Big River and the Simms Mountain fault zones.

Fossiliferous rocks in the diatremes prove that the igneous activity is not older than Middle Devonian, because it must have occurred in post-Middle Devonian time to have involved these strata. Regional stratigraphic relations indicate that these rocks were removed from the area of the diatremes prior to Mississippian deposition. Thus, they could not have been involved in igneous activity occurring after the beginning of Mississippian time. Therefore, the igneous activity which produced the diatremes took place in the interval of time between the Middle Devonian and the Mississippian. The same line of reasoning narrows the time interval still more: the diatremes are younger than Middle Devonian and older than the erosional period that removed these strata.

High angle tensional faulting was prevalent in the Ste. Genevieve fault zone during the early period of movement which is post-Middle Devonian and pre-Mississippian in age. The corresponding age of faulting and the igneous activity suggests that they are directly related. The diatremes on the south nose of the Farmington anticline and its increase in width southward suggest that the Farmington anticline originated during the period of igneous activity.

The Geological Map of Missouri, 1939, indicates that the dir ction of some of the regional structural features was determined in pre-Mississippian time. South of Boonville, in Cooper County and in Moniteau County, strata of Mississippian age rest directly on Ordovician rocks. To the east and west, Devonian rocks lie between the Ordovician and Mississippian strata.

Rubey[145] stated that the uplift responsible for the Cap au

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145 W.W. Rubey, "Structural History of the Cap au Gres Faulted Flexure, Illinois," Bulletin of the Geological Society of America, Abstract, 41:52-53, 1930/

Gres faulted flexure (Linclon Fold in Missouri):

> ....began with gentle warping in Silurian time, continued intermittently through the Devonian and Mississippian, culminated in sharp folding before Pennsylvanian, and waned with minor faulting or folding after Pennsylvanian, again after late Tertiary, and possibly continuing into historic time.

According to McQueen, Hinchey, and Aid,[146] the geologic record

146 McQueen, Hinchey, and Aid, op. cit. pp. 100-110

of the Lincoln Fold gives no evidence of pronounced regional folding prior to Silurian time. Regional movement in the present area of the fold probably occurred at the end of Silurian time, and after Devonian deposition the axis of the fold was rejuvenated. The fold reached its maximum structural development near the close of the Mississippian. Faulting may have occurred between Mississippian and Pennsylvanian time, but the late histor of the fold is obscure due to the absence of the younger Pennsylvanian beds.

Structure maps by Hinds and Greene[147] and McQueen and

147 Henry Hinds and F.C. Greene, The Stratigraphy of the Pennsylvanian Ser es in Missouri, Missouri Bureau of Geology and Mines, 2d ser., 13:Plate 23, 1915.

Greene[148] drawn on datum planes in the Pennsylvanian show the same

148 H.S. McQueen and F.C. Greene, The Geology of Northwestern Missouri, Missouri Geological Survey and Water Resources, 2d ser., 25:Plate 1, 1938.

regional structural grain as that indicated in pre-Mississippian time. All the regional structural features cannot be dated as pre-Mississippian although the directional pattern of later features may have been established at an earlier time.

SUMMARY

The voluminous literature concerning the Southeastern Missouri mining district contains little information about the processes which contributed to the deformation. Broadhead thought that the Ozark

Mountain building may have resulted from "...forces acting at different places upon a broad or flat surface forming a massive anticlinal, breaking off into a monoclinal around the margin." [149]

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149 G.C. Broadhead, "Geologic History of the Ozark Uplift," American Journal of Science, 42:6-13, 1889.

Haworth[150] visualized the Ozark uplift as a monoclinal type of

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150 Erasmus Haworth, "Relations between the Ozark Uplift and Ore Deposits, " Bulletin of the Geological Society of America, 11: 231-240, 1900.

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structure, and he believed that the forces acted radially rather than tangentially, stretching the strata rather than crumpling them.

Giles[151] used the term geanticline in describing the Ozark

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151 A.W. Giles, "Structural Features of the Mississippi Valley Region and Their Relation to Mineralization," Edson S. Bastin editor, Contributions to a knowledge of the Lead and Zinc Deposits of the Mississippi Valley Region, Geological Society of America, Special Paper No. 24, 1939. P.44.

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uplift.

Spurr explains the deformation in the mining district, particularly the Ste. Genevieve fault zone, thus:

> Such a crustal sinking as shown by this southeastern Missouri fault graben or ditch, signifying a collapse of a section of the crust due to local sinking of the foundation support, can hardly be explained except by failure of competency of an underlying fluid foundation--that is to say, an underlying supporting magma on which the crust floats or floated;...[152]

152 J.E. Spurr, "The Southeast Missouri Ore-Magmatic District," Engineering and Mining Journal, 122:968-975, 1926.

An attempt to reconstruct the structural history is hampered by the incomplete geologic record. The effect of gentle warping during and at the close of Silurian time is not recognizable in the mining district because of the absence of Silurian strata, except in areas structurally favorable for their preservation. The geologic record does not reveal noteworthy diastrophism prior to post-Middle Devonian time.

After Middle Devonian, but before Mississippian time, magmatic pressure caused explosive blowouts thgough perhaps 4000 feet of sediments.[153] Upfolding and tensional faulting attended this period of deformation. The Farmington anticline originated and was broken axially at the north end by high angle tensional faulting. Silurian and Devonian strata were downfaulted in the Ste. Genevieve fault zone. Spurr's idea of failure of competency of an underlying fluid foundation which permitted the crustal sinking shown by the downfaulted blocks in the Ste. Genevieve fault zone, gains strength now that an incompetency is indicated for this region at the time the crustal sinking occurred.

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153 A.L. Kidwell, Post-Devonian Igneous Activity in Southeastern Missouri, Missouri Geological Survey and Water Resources, Report of Investigations No. 4, 1947, P. 30.

If collapse was a factor in this individual structural feature, it also may have been a factor on a larger scale. Magmatic pressure could have caused the arching that formed the Farmington anticline, and, in addition, it could have raised the Ozark region. The specific age of most of the tensional faults in not known and they may have originated during the period of igneous activity.

The cross section in figure 30 is drawn on a line nearly normal to the regional structural trends. If the regional dip is projected and the faulting is eliminated, the sediments in the vicinity of the Farmington anticline would be essentially 2100 feet above their present position. The projection of the regional dip on the eastern and western flanks of the Ozark uplift indicates that the maximum difference in present and restored positions of the sediments is slightly west of the crest of the Farmington anticline. The different character of the Ste. Genevieve fault zone where it borders the Farmington anticline possible could be explained by hinge action which occurred as the sediments to the west were dropped.

If the mechanics of upthrust as explained by Willis [154] produced the tensional faulting pattern, the relative movement along the fault zones indicates that the intensity of the upthrust at the Farmington anticline was less than that to the west. However, the explosive blowouts on the southern nose of the anticline indicate high magmatic pressure.

Collapse as a factor influencing the pattern of deformation cannot be ruled out, although its influence can be only speculative. A downward settling of the crust following pressure release does not seem to be an unreasonable hypothesis. A possible sequence of events

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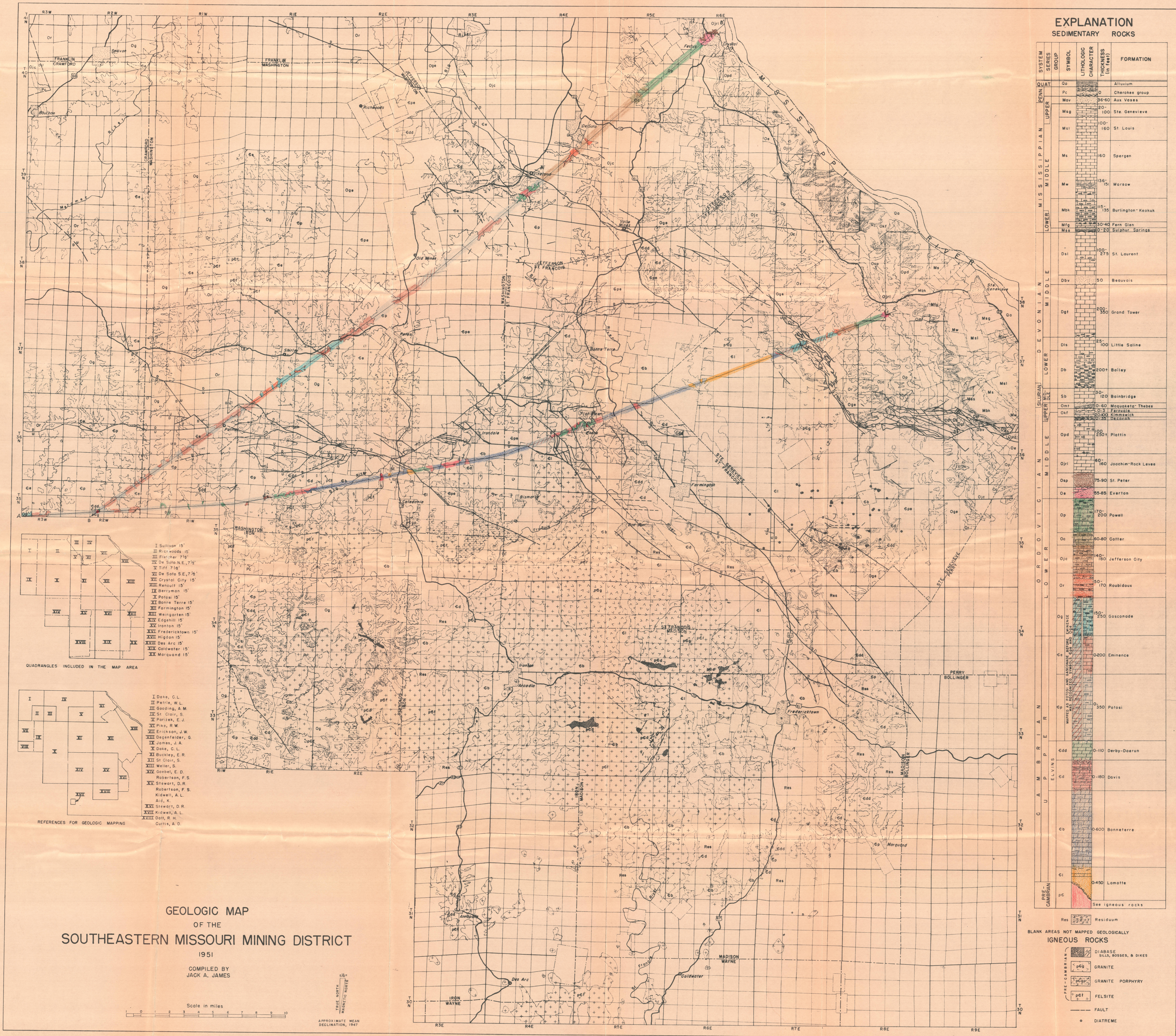
154 Bailey Willis, Geologic Structures, (New York: McGraw Hill Book Company, 1923). P. 45.

may have originated with the build up of magmatic pressure producing uplift of the Ozark region and local upfolding at the position of the Farmington anticline. The explosive blowouts occurred probably near the time of maximum pressure exerted by the magma. Subsequent release of support produced a low pressure chamber and a downward adjustment of the crust followed. Tensional faulting may have taken place either at the time of the uplift, or at the time of the downward adjustment, or possibly at both times.

The mining district in either late or post-Pennsylvanian time, was subjected to compressive stress which, in part, acted tangentially to the surface. The force was applied over a large area and propagated through the basement rock from a southwest direction. It produced reverse faulting in the Ste. Genevieve fault zone, the en echelon pattern of the Big River fault zone, and movement along the Berryman fault. Folds with their axes perpendicular to the Simms Mountain fault zone may be the result of this stress. The high angle tensional fault that cuts the north end of the Farmington anticline was subjected to movement opposite in direction to that which first produced it. The later movememt was not as great as the earlier, but drag folds which dip toward the fault were developed on the downthrown side. Movement provably occurred at this time along all the zones of faulting in the area.

SOUTHEASTERN MISSOURI
By Jack A. James



GEOLOGIC MAP
OF THE
SOUTHEASTERN MISSOURI MINING DISTRICT
1951
COMPILED BY
JACK A. JAMES
Scale in miles
APPROXIMATE MEAN DECLINATION, 1947
TRUE NORTH
MAGNETIC NORTH
EXPLANATION
SEDIMENTARY ROCKS
SYSTEM
SERIES
GROUP
SYMBOL
LITHOLOGIC CHARACTER
THICKNESS (in feet)
FORMATION
QUAT. Qa Alluvium
PENN. Pc 0 Cherokee group
Mav 36-60 Aux Vases
Msg 20-100 Ste. Genevieve
Msl 100-160 St. Louis
Ms 160 Spergen
Mw 136-151 Warsaw
Mbk 115-135 Burlington-Keokuk
Mfg 30-40 Fern Glen
Mss 0-20 Sulphur Springs
MISSISSIPPIAN
UPPER
MIDDLE
LOWER
Dsl 100-275 St. Laurent
Dbv 50 Beauvais
Dgt 200-350 Grand Tower
Dls 25-100 Little Saline
Db 200+ Bailey
DEVONIAN
SILURIAN
MIDDLE
Sb 30-120 Bainbridge
Omt 0-60 Maquoketa-Thebes
Okf 0-3 Fernvale
20-100 Kimmswick
0-35 Decorah
Opd 100 250+ Plattin
Ojrl 60-160 Joachim-Rock Levee
Osp 75-90 St. Peter
Oe 55-85 Everton
Op 170-200 Powell
Oc 60-80 Cotter
Ojc 140-180 Jefferson City
Or 50-170 Roubidoux
Og 150-250 Gasconade
ORDOVICIAN
MAPPED AS POTOSI AND GASCONADE BEFORE EMINENCE WAS RECOGNIZED SYMBOLS €pe AND Oge
€e 0-200 Eminence
€p 0-350 Potosi
€dd 0-110 Derby-Doerun
€d 0-180 Davis
ELVINS
€b 0-600 Bonneterre
€l 0-450 Lamotte
CAMBRIAN
UPPER
PRE-CAMBRIAN p€ See igneous rocks
Res Residuum
BLANK AREAS NOT MAPPED GEOLOGICALLY
IGNEOUS ROCKS
DIABASE SILLS, BOSSES, & DIKES
GRANITE
GRANITE PORPHYRY
FELSITE
PRE-CAMBRIAN
FAULT
DIATREME
QUADRANGLES INCLUDED IN THE MAP AREA
I Sullivan 15'
II Richwoods 15'
III Fletcher 7½'
IV De Soto N.E., 7½'
V Tiff 7½'
VI De Soto S.E., 7½'
VII Crystal City 15'
VIII Renault 15'
IX Berryman 15'
X Potosi 15'
XI Bonne Terre 15'
XII Farmington 15'
XIII Weingarten 15'
XIV Edgehill 15'
XV Ironton 15'
XVI Fredericktown 15'
XVII Higdon 15'
XVIII Des Arc 15'
XIX Coldwater 15'
XX Marquand 15'
REFERENCES FOR GEOLOGIC MAPPING
I Dake, C.L.
II Petrie, W.L.
III Gooding, A.M.
IV St. Clair, S.
V Parizek, E.J.
VI Pike, R.W.
VII Erickson, J.W.
VIII Degenfelder, G.
IX James, J.A.
X Dake, C.L.
XI Buckley, E.R.
XII St. Clair, S.
XIII Weller, S.
XIV Goebel, E.D.
Robertson, F.S.
XV Stewart, D.R.
Robertson, F.S.
Kidwell, A.L.
Aid, K.
XVI Stewart, D.R.
XVII Kidwell, A.L.
XVIII Dott, R.H.
Curtis, A.D.
MISSISSIPPI RIVER
FRANKLIN
CRAWFORD
WASHINGTON
JEFFERSON
ST. FRANCOIS
STE. GENEVIEVE
PERRY
BOLLINGER
IRON
MADISON
WAYNE
Richwoods
Old Mines
Potosi
Irondale
Caledonia
Bismarck
Bonne Terre
Flat River
Farmington
Ironton
Fredericktown
Marquand
Des Arc
Coldwater
Festus
Ste. Genevieve