Fall 1983

Lead-zinc metallotects of the Ozark dome

Linda Leigh Mallery

LEAD-ZINC METALLOTECTS OF THE OZARK DOME

BY

LINDA LEIGH MALLERY, 1957-

A THESIS

Presented to the Faculty of the Graduate School of the

UNIVERSITY OF MISSOURI-ROLLA

In Partial Fulfillment of the Requirements for the Degree

MASTER OF SCIENCE IN GEOLOGY/GEOPHYSICS

1983

Approved by

______________ (ADVISOR) ______________

____

ABSTRACT

This is a regional study of the relationship between Mississippi Valley-type mineral deposits and structural features of the Ozark dome which resulted in the description and classification of lead-zinc "metallotects". A more accurate delineation of the Ozark dome was accomplished by examining the gradient and structural contour lines of its Precambrian basement. A general background on the geology, structure, and evaluation of the Ozark dome was discussed along with the stratigraphy, structure, and ore deposits of the major lead-zinc districts of the Ozark dome in order to develop the background data for the application of the "metallotect" concept. The major lead-zinc districts studied in this research are the Southeast Missouri District, the Tri-State District of Missouri, Kansas, and Oklahoma, the Central Missouri District, and the Northern and Northeastern Arkansas Districts. Many more small occurrences were also plotted and their distribution studied. Lineament terminology and lineament studies were also discussed as further background data. The "metallotect" concept as it was developed and applied in this study consists of the relationship between the Precambrian highs, faults and fractures, lineaments, and mineral deposits of the Ozark dome. Thus, previously the "metallotect" concept was poorly defined but this study developed and defined the concept as it is applied to dome-hosted Mississippi Valley-type deposits in a platform region and based on spatial (geometric) relationships. Furthermore this concept, as it is purely descriptive, will serve as an example for further studies performed by economic and structural geologists. The multifacted structural relationships between the whole dome, secondary Precambrian highs and districts, major and local faults, and mineral deposits are described. It was found that the structural features of the region had at least as much if not a larger role than the lithofacies or "ore solution chemistry" in localizing mineral deposits on a regional and local scale.

ACKNOWLEDGEMENTS

The writer would like to thank her academic advisor, Dr. Geza Kisvarsanyi, for suggesting the study and for his valuable guidance during the research of her thesis. She would also wish to thank other members of her committee, Dr. Alfred Spreng and Dr. David Barr, both of the University of Missouri-Rolla. Also she would like to thank Dr. Paul Dean Proctor of the University of Missouri-Rolla for his assistance during the research of her thesis.

The writer wishes to express special thanks to James Martin and Heyward Wharton of the Missouri Geological Survey for their valuable assistance in obtaining information and data for her research.

Finally the writer wishes to thank her parents for their confidence and support in helping to complete this study.

TABLE OF CONTENTS

LIST OF ILLUSTRATIONS

I. INTRODUCTION

A. LOCATION OF THE OZARK DOME AND STUDY AREA

The study area includes the Ozark dome and adjacent areas in the states of Missouri, Arkansas, Kansas, and Oklahoma (Figure 1). The Ozark dome is a deformed ellipsoidal-shaped structure located within the North American Platform of the Midcontinent. Topographically it is ill defined having a steeper boundary on the east than on the west and north and breaking off rather abruptly on the south. It covers an estimated 53,400 square miles (136,704 km) occupying parts of the states of Missouri, Arkansas, Kansas, and Oklahoma. The general area of the Ozark dome can be seen in Figure 2. The boundary of this geotectonic unit could be better defined by structural contour lines and gradients of its Precambrian basement than by topography. Defined in such a way that the northern boundary is just north of the Missouri River, this also being near the limit of glacial drift and the Dissected Till Plains of the Central Lowlands. The eastern boundary is west of the Mississippi River. The Arkansas River Valley (foreland basin of the Ouachita orogeny) and the Mississippi Embayment make up the southern boundary. The western boundary is not quite as distinct but is roughly 50 miles east of the Nemaha uplift. The dome is a slightly elongated and biaxial structure. Its long axis trending northeast-southwest through the St. Francois Mountains, south central Missouri, and northeastern Oklahoma and its shorter axis run north-south through the middle.

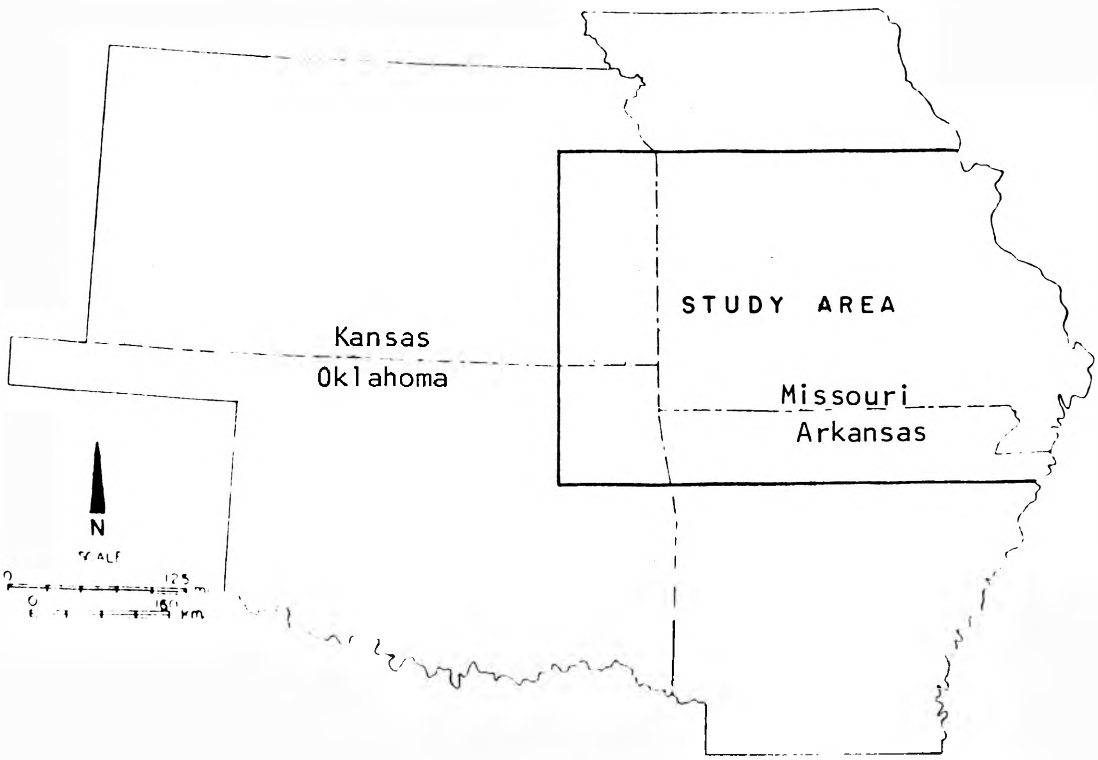


Figure 1. Index map of the study area.

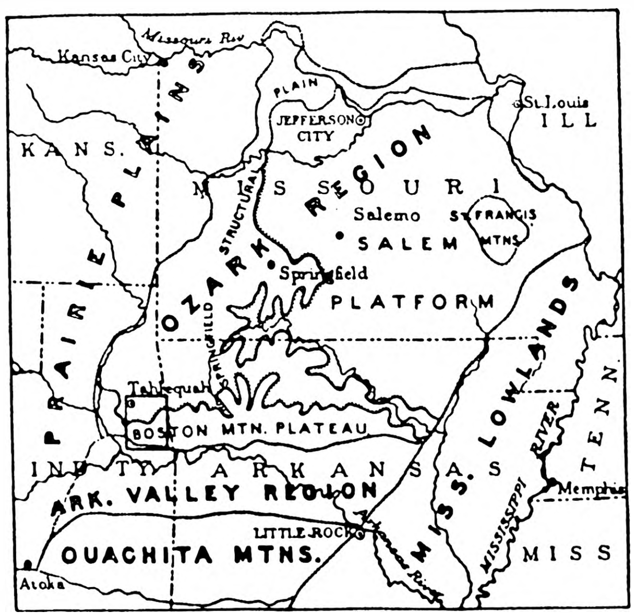


Figure 2. Physiographic map of the thesis area (from Fenneman, 1938).

B. PHYSIOGRAPHY OF THE OZARK DOME

There are two physiographic provinces (Figure 2) occupying the area of the Ozark dome - the Ozark "Plateau" Province and the Central Lowlands Province. The Ozark "Plateau" Province encompasses the states of Missouri, Arkansas, Kansas, and Oklahoma. Although physiographers refer to this area as a plateau, one may actually think of it being more of a platform or uplands area with local rugged topography. The average elevation is a little more than 1000 feet above mean sea level. There are four subprovinces included in the Ozark "Plateau" Province: 1) Salem Platform or "Plateau", 2) St. Francois Mountains, 3) Springfield Platform or "Plateau", and 4) Boston Mountains "Plateau". The Salem Platform is carved on Ordovician and older rocks. The St. Francois Mountains are on the eastern edge of the dome. This is an area of Precambrian igneous rocks which appear as knobs surrounded and/or covered by Cambrian rocks. The Springfield Platform is underlain largely by Mississippian age Boone cherts and limestones. It is often called the Springfield Structural Plain due to the surface of the upland coinciding nearly with the bedding of the Boone chert. The Boston Mountains formed as a result of the general denudation of the Ozark dome. This southern margin of the dome is an extensive remnant of Pennsylvanian shales and interbedded sandstones which probably once covered the province. There appears to have been three successive uplifts and peneplains. The first peneplain being the Boston Mountains followed by the Springfield Platform and then the Salem Platform.

Western Missouri, southeastern Kansas, and northeastern

Oklahoma are located in the Prairie Plains subprovince of the Central Lowlands Province. This area consists of Pennsylvanian age shales, limestones, and sandstones.

C. <u>CLIMATE, VEGETATION, CULTURE</u>

This is an area of moderate climate with four seasons. There are cold winters with occasional blizzards and the summers are hot and humid. During the Spring, there are occasional tornadoes. The average annual precipitation is 40 inches with an average annual temperature of 58 degrees.

The soil of this area consists of red clay and chert fragments from deeply weathered sedimentary, igneous, and volcanic rocks upon which grow forests of oak and pine. Much of the land is too steep for farming and remains in forest. Where the land is not too steep, it has a cherty and rocky soil and is therefore unproductive for the cultivation of crops but suitable for raising livestock. If the land is good for farming, the main crops grown are corn and winter wheat and where these are unproductive, fruit trees are grown.

The Ozark dome is an area of numerous rivers and caves carved through the predominantly limestone terrane. Many of the streams flow outward from the top of the dome. They radiate down the dip on the main late Paleozoic uplift. The surface of the original dome may have been cut down 1000 feet. During this long process, the rivers may have shifted their position and many captures may have occurred in the effort to adjust the line of drainage to the minor folds, domes, and fault blocks which originated with the uplift of the dome. Thus, the valleys are mostly antecedent and mature. The Mississippi and Missouri Rivers are near the eastern and northern boundary of the Ozark dome, while within the dome the following are the dominant rivers: the Osage, Gasconade, St. Francis, Meramec, Current, Black, White, and Neosho.

The main cities in the general area of the Ozark dome include: St. Louis, Jefferson City, Rolla, Kansas City, Springfield, and Joplin.

Active and past major mining areas include the Old Lead Belt and the New Lead Belt (Viburnum Trend) of southeast Missouri; the Tri-State Zinc-Lead District of Missouri, Oklahoma, and Kansas; the Central Missouri Barite and Lead-Zinc District; and the Northern and Northeastern Arkansas Zinc-Lead District.

D. PURPOSE OF INVESTIGATION

The purpose of this study is to examine the relationship between the major structural features and the widely scattered major districts and smaller mineral occurrences and classify them into various orders of "metallotects". This is a regional study - not a detailed or local study. Thus, no concentrated research was devoted to any one specific mineral district. According to the AGI Glossary of Geology metallotect is defined as

> "a term used in metallogenic studies for any geologic feature (tectonic, lithologic, geochemical, etc.) considered to have influenced the concentration of elements to form mineral deposits; an ore control, but without the implication of economic value".

The term metallotect will be used in this study purely as a descriptive geometric term. The first order relationship is between the Ozark dome, that is the dome itself and the regional distribution and setting of all its deposits. The second order relationship is between the major mineral districts and the secondary Precambrian structural highs within the dome. The third order relationship is between faults and fractures, lineaments, and mineral deposits on a district to subdistrict scale. The fourth order relationship is between single ore bodies, small mineral deposits or mines and any structural feature.

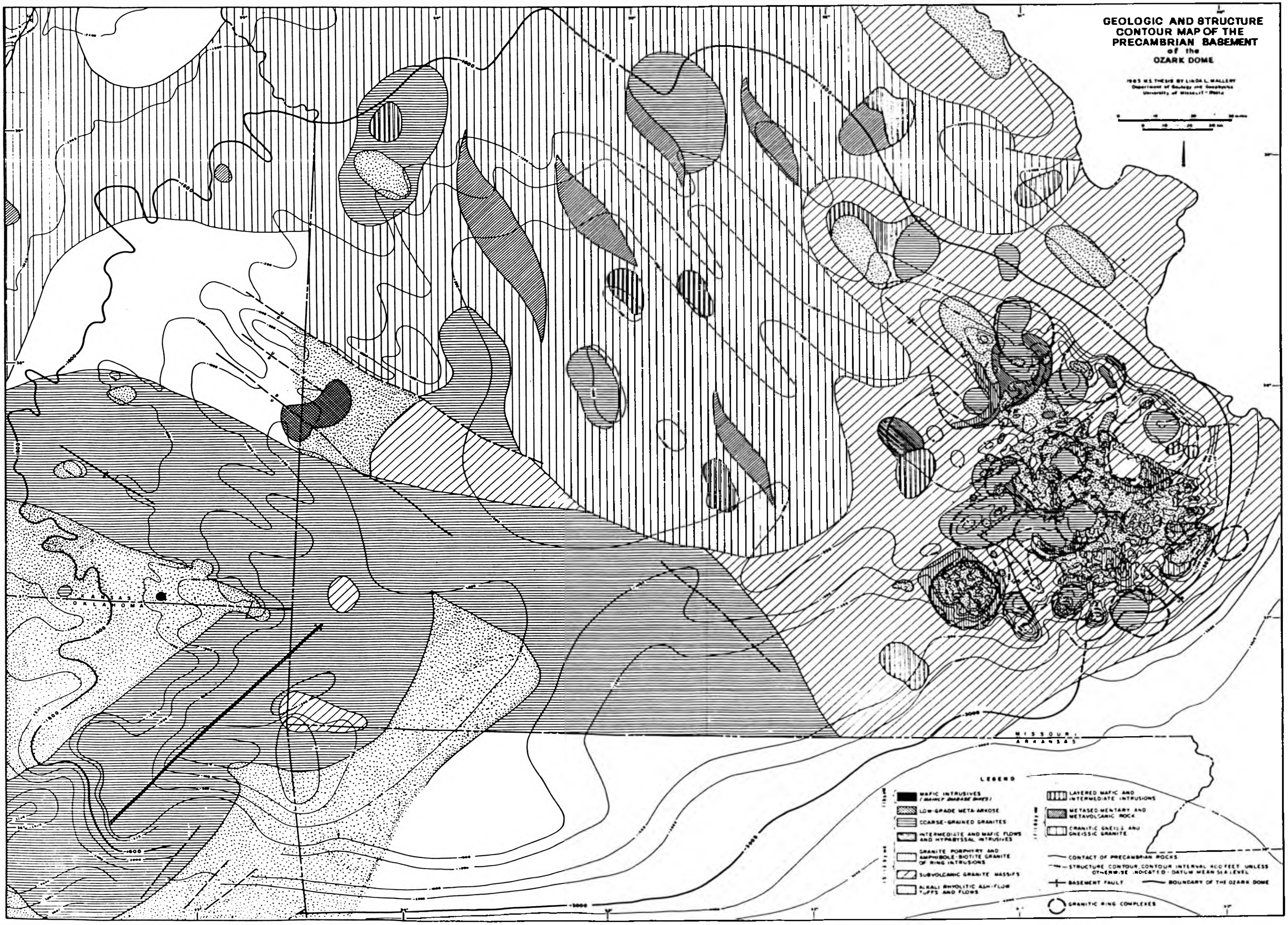
E. GEOLOGIC METHODS AND PHILOSOPHY APPLIED IN THIS STUDY

In this age of highly developed instruments we tend to forget the basic methods of scientific investigation involving observation, empirical study of geologic data, and finally the geologic synthesis of the results. This approach is especially lacking on a regional scale. In this study these methods were utilized as well as instrumental techniques.

In order for this study to be accomplished it was necessary to compile a series of regional maps encompassing the entire Ozark dome- which is not known to have been done or published. Since the Precambrian basement played such a dominant and integral role in the formation of the Ozark dome, the first map (Figure 3) completed was a Precambrian rock type map of the Ozark dome. The data sources included: R.W. Bayley and W.R. Muehlberger (1968), E.B. Kisvarsanyi (1975, 1979, 1980), V.B. Cole (1976), and M.E. Bickford, et.al. (1979,1981). By analyzing the structure contour lines and the gradient of these contours, the boundary of the Ozark dome was

Figure 3. Geologic and Structure Contour Map of the Precambrian Basement of the Ozark Dome.

Complied from: Bayley and Muehlberger, 1968; Cole, 1976; E. Kisvarsanyi, 1975, 1979, 1980; Bickford, *et al.*, 1979, 1981.

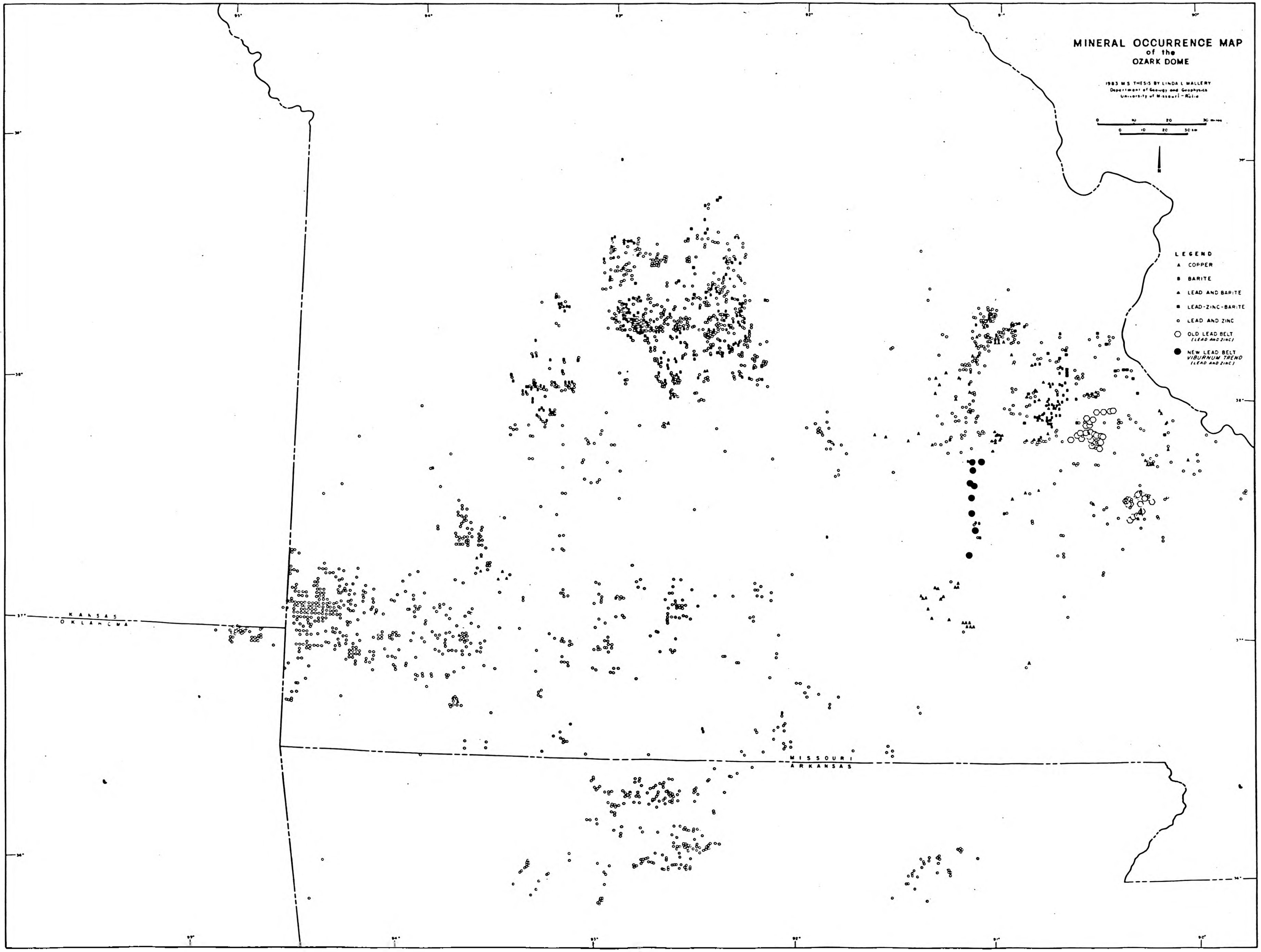

GEOLOGIC AND STRUCTURE CONTOUR MAP OF THE PRECAMBRIAN BASEMENT of the OZARK DOME
MISSOURI
ARKANSAS
LEGEND
MAFIC INTRUSIVES
LOW-GRADE META-ARKOSE
COARSE-GRAINED GRANITES
INTERMEDIATE AND MAFIC FLOWS AND HYPABYSSAL INTRUSIVES
GRANITE PORPHYRY AND AMPHIBOLE-BIOTITE GRANITE OF RING INTRUSIONS
SUBVOLCANIC GRANITE MASSIFS
ALKALI RHYOLITIC ASH-FLOW TUFFS AND FLOWS
LAYERED MAFIC AND INTERMEDIATE INTRUSIONS
METASEDIMENTARY AND METAVOLCANIC ROCK
GRANITIC GNEISS AND GNEISSIC GRANITE
CONTACT OF PRECAMBRIAN ROCKS
BASEMENT FAULT
BOUNDARY OF THE OZARK DOME
GRANITIC RING COMPLEXES

delineated. The -1600 foot contour line was chosen for the boundary of the dome, except in southeast Missouri and northern Arkansas and there the -3000 foot contour line was used. The -1600 foot contour line was chosen because it was continuous and included the Precambrian high of the St. Francois Mountains in southeast Missouri, the central Missouri high, and the southwest Missouri high. Also included within this contour are three of the four major mineral districts of the Ozark dome - the Southeast Missouri Lead-Zinc District, the Central Missouri Barite and Lead-Zinc District, and the Tri-State Zinc-Lead District. The -3000 foot contour line was chosen for the southern boundary of the Ozark dome because in this area the contour gradient changed from a gentle slope at -2000 feet to a more steeper slope at -4000 feet. It is evident that the gradients here express the deformation of the Ozark dome towards the foreland basin (Arkoma) of the Ouachita orogeny. The boundary was also chosen here due to the existence of normal faults on the northern side of the Arkoma basin. Also the final reason for choosing the -3000 foot contour line was because it would include within the boundary of the Ozark dome the Northern Arkansas Zinc-Lead District. The northeastern Arkansas zinc-lead deposits are not included since they lie off the southeast flank of the dome due to major structural development during the Paleozoic in this area and the formation of the Reelfoot rift zone.

The next map (Figure 4) is a map of the mineral occurrences of the Ozark dome. This map was compiled from the Missouri

Figure 4. Mineral Occurrence Map of the Ozark Dome.

Compiled from: Ball and Smith, 1903; Adams, Purdue, Burchard, 1904; Van Horn, 1905; Marbut, 1907; Snider, 1912; Weidman, 1932; McKnight, 1935; Mather, 1946; Leach, Nelson, Williams, 1975; Miller, 1982; Missouri Geological Survey County Mineral Spot Maps.


MINERAL OCCURRENCE MAP
of the
OZARK DOME
1983 M.S. THESIS BY LINDA L. MALLERY
Department of Geology and Geophysics
University of Missouri - Rolla
LEGEND
COPPER
BARITE
LEAD AND BARITE
LEAD-ZINC-BARITE
LEAD AND ZINC
OLD LEAD BELT (LEAD AND ZINC)
NEW LEAD BELT VIBURNUM TREND (LEAD AND ZINC)
KANSAS
OKLAHOMA
MISSOURI
ARKANSAS

Geological Survey County Mineral Spot Maps and other Missouri Geological Survey publications. Other data sources included publications from the Kansas Geological Survey, Oklahoma Geological Survey, the U.S. Geological Survey, and various other sources. It should be noted that the symbols represent mine(s) and prospect(s) and that these mineral occurrence(s) have been enlarged to show their locations better.

The mineral districts map with the location of major lead-zinc deposits and their host rocks (Figure 5) was the next map completed. The lead-zinc deposits taken from Figure 4, in some instances, were grouped together. After the lead-zinc deposits were located, then their host rocks were determined from the published works of the Arkansas Geological Commission, Kansas Geological Survey, Missouri Geological Survey, Oklahoma Geological Survey, U.S. Geological Survey, and various other sources.

The next map completed was the structural features of the Ozark dome (Figure 6). This was compiled from M. McCracken (1971), V. Cole (1976), the Geologic map of Oklahoma (1954), the Geologic map of Arkansas (1976), and the Geologic map of Missouri (1979).

The final map, a lineament map of the Ozark dome (Figure 7) was completed by interpreting LANDSAT imagery. Thirteen LANDSAT scenes, at a scale of 1:1,000,000, of bands 5, 7, and false-color composites were studied. Also studied was the east and west region of the Rolla 1° X 2° Quadrangle (1:250,000) false-color composites that had been geometrically stretched. The lineaments were identified and then plotted on transparent mylar overlays.

Figure 5. Host Rocks of the Major Lead-Zinc Districts and Mineral Occurrences of the Ozark Dome.

Compiled from: Winslow, 1894; Ball and Smith, 1903; Adams, Purdue, Burchard, 1904; Buckley and Buehler, 1905; Van Horn, 1905; Marbut, 1907; Snider, 1912; Weidman, 1932; McKnight, 1935; Mather, 1946; Brockie, et al., 1968; McKnight and Fisher, 1970; Leach, Nelson, Williams, 1975; Miller, 1982; G. Kisvarsanyi, 1982; Geologic Map of Oklahoma, 1954; Geologic Map of Kansas, 1964; Geologic Map of Arkansas, 1976; Geologic Map of Missouri Geological Survey County Mineral Spot Maps.

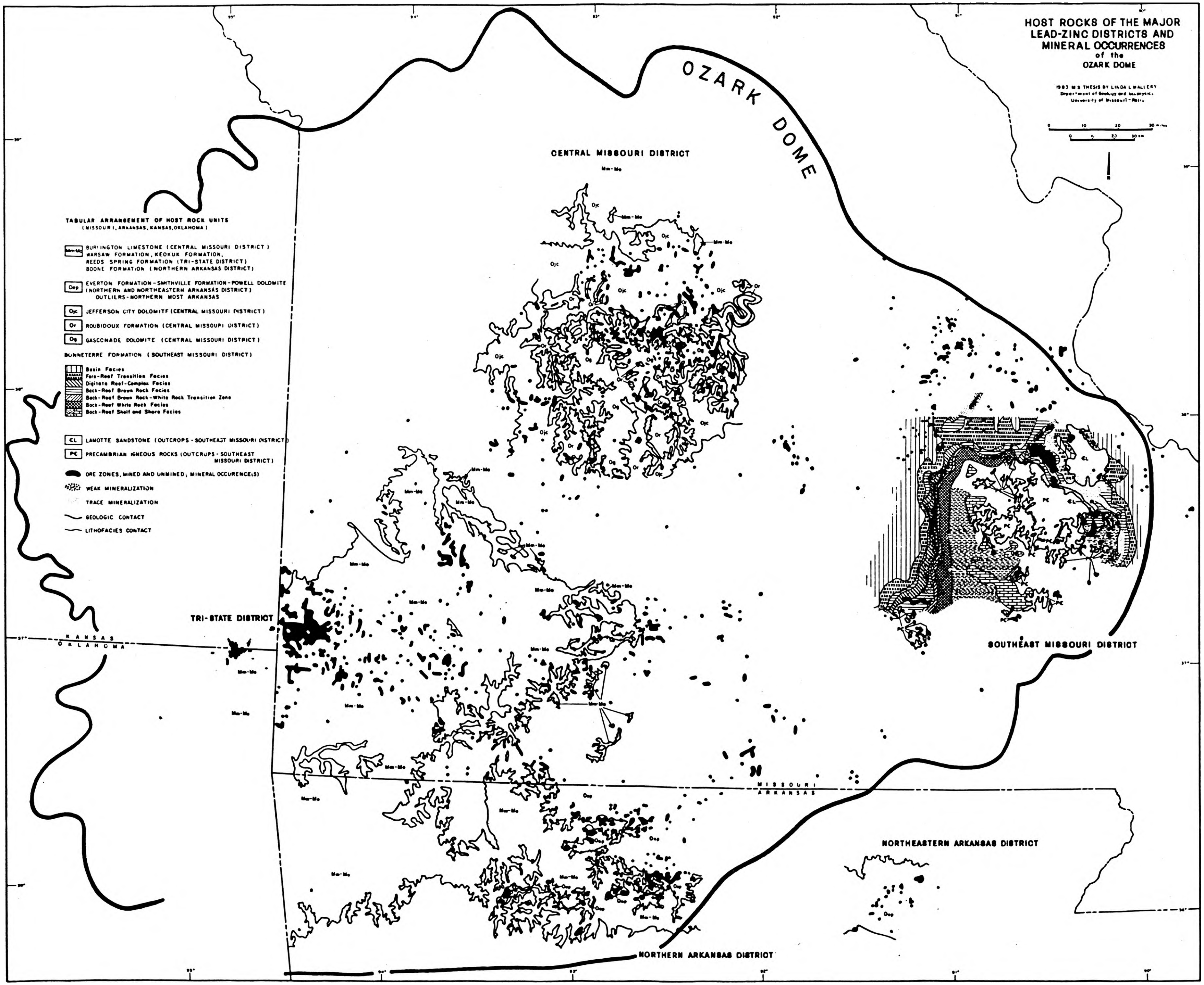

HOST ROCKS OF THE MAJOR
LEAD-ZINC DISTRICTS AND
MINERAL OCCURRENCES
of the
OZARK DOME
1983 M.S. THESIS BY LINDA L. WALLERY
Department of Geology and Geophysics
University of Missouri - Rolla
0 10 20 30 miles
0 10 20 30 km
OZARK DOME
CENTRAL MISSOURI DISTRICT
TRI-STATE DISTRICT
SOUTHEAST MISSOURI DISTRICT
NORTHEASTERN ARKANSAS DISTRICT
NORTHERN ARKANSAS DISTRICT
KANSAS
OKLAHOMA
MISSOURI
ARKANSAS
TABULAR ARRANGEMENT OF HOST ROCK UNITS
(MISSOURI, ARKANSAS, KANSAS, OKLAHOMA)
Mm-Mo BURLINGTON LIMESTONE (CENTRAL MISSOURI DISTRICT)
WARSAW FORMATION, KEOKUK FORMATION,
REEDS SPRING FORMATION (TRI-STATE DISTRICT)
BOONE FORMATION (NORTHERN ARKANSAS DISTRICT)
Oep EVERTON FORMATION - SMITHVILLE FORMATION - POWELL DOLOMITE
(NORTHERN AND NORTHEASTERN ARKANSAS DISTRICT)
OUTLIERS - NORTHERN MOST ARKANSAS
Ojc JEFFERSON CITY DOLOMITF (CENTRAL MISSOURI DISTRICT)
Or ROUBIDOUX FORMATION (CENTRAL MISSOURI DISTRICT)
Og GASCONADE DOLOMITE (CENTRAL MISSOURI DISTRICT)
BONNETERRE FORMATION (SOUTHEAST MISSOURI DISTRICT)
Basin Facies
Fore-Reef Transition Facies
Digitate Reef-Complex Facies
Back-Reef Brown Rock Facies
Back-Reef Brown Rock-White Rock Transition Zone
Back-Reef White Rock Facies
Back-Reef Shelf and Shore Facies
CL LAMOTTE SANDSTONE (OUTCROPS - SOUTHEAST MISSOURI DISTRICT)
PC PRECAMBRIAN IGNEOUS ROCKS (OUTCROPS - SOUTHEAST MISSOURI DISTRICT)
ORE ZONES, MINED AND UNMINED; MINERAL OCCURENCE(S)
WEAK MINERALIZATION
TRACE MINERALIZATION
GEOLOGIC CONTACT
LITHOFACIES CONTACT

Figure 6. Structural Features of the Ozark Dome.

Compiled from: McCracken, 1971; Cole, 1976; Geologic Map of Oklahoma, 1954; Geologic Map of Arkansas, 1976; Geologic Map of Missouri, 1979.

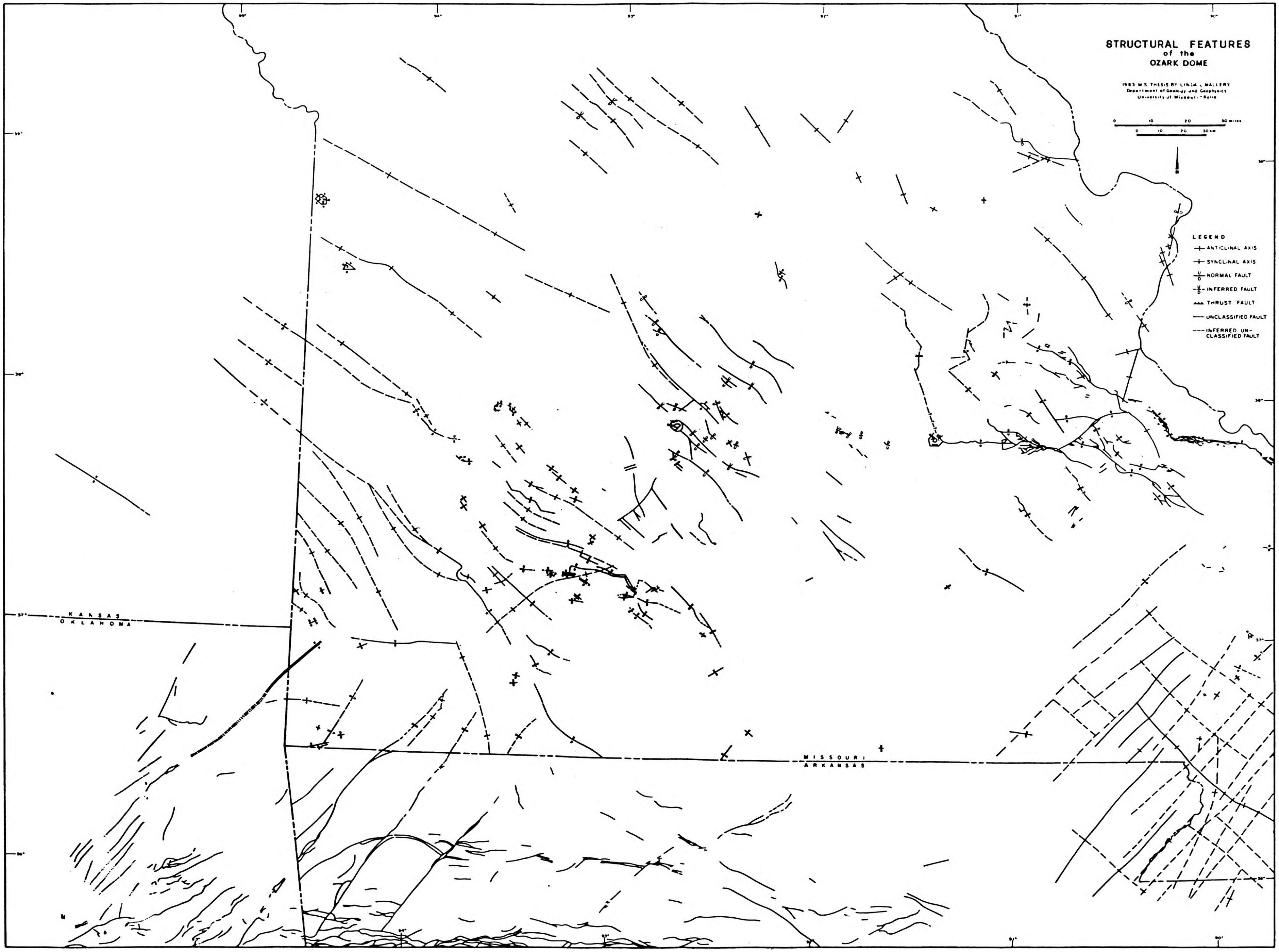
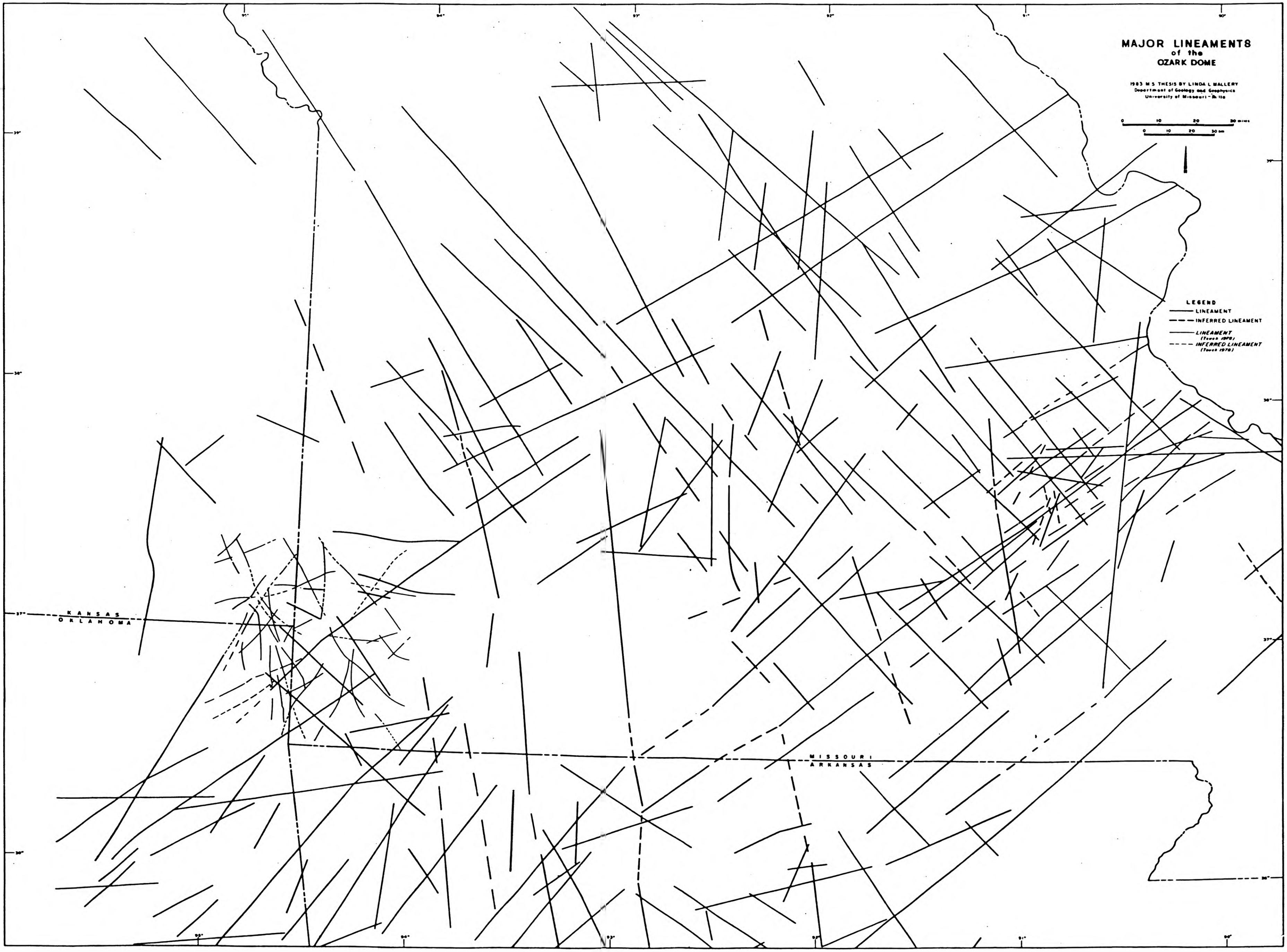

STRUCTURAL FEATURES
of the
OZARK DOME
1983 M.S. THESIS BY LINDA L. MALLERY
Department of Geology and Geophysics
University of Missouri - Rolla
0 10 20 30 miles
0 10 20 30 km
LEGEND
ANTICLINAL AXIS
SYNCLINAL AXIS
U D NORMAL FAULT
U D INFERRED FAULT
THRUST FAULT
UNCLASSIFIED FAULT
INFERRED UN-CLASSIFIED FAULT
KANSAS
OKLAHOMA
MISSOURI
ARKANSAS

Figure 7. Lineament Map of the Ozark Dome.


MAJOR LINEAMENTS
of the
OZARK DOME
1983 M.S. THESIS BY LINDA L. MALLERY
Department of Geology and Geophysics
University of Missouri - Rolla
LEGEND
LINEAMENT
INFERRED LINEAMENT
LINEAMENT
INFERRED LINEAMENT
KANSAS
OKLAHOMA
MISSOURI
ARKANSAS

The final product of the lineaments mapped went through a filtering process in which only the longer, more pronounced or defined linears were used in the final map.

These maps were then utilized in the study of metallotects, or geometric (structural) relationships described above. These maps were constructed and used as a series of overlays. This series of overlays gives a three-dimensional or "layered - cake" view of the study area by viewing surface maps, mineral deposits and their host rocks, and the Precambrian basement at different layers, stratigraphic horizons and vertical structures.

F. METHOD OF INVESTIGATION USING LANDSAT IMAGERY

Remote sensing methods provide a useful geologic tool as a reconnaissance and/or detailed exploration technique for mineral exploration. LANDSAT images have proven valuable in mapping regional and local fracture systems that controlled the formation of ore deposits. Many mineral provinces occur along linear trends known as mineral belts and many mines have been found by exploring the projections of these trends. Also within these mineralized belts, individual mining districts are commonly localized by intersecting fracture systems. Thus LANDSAT imagery has been proven useful for mapping both the regional structural features and thus providing useful information for mineral exploration.

This study is concerned with the use of remote sensing in the identification and analysis of lineaments in the Ozark dome region and their correlation with the mineral occurrences, known structures, and mineral districts and the large number of lead-zinc occurrences and their host rocks.

The images analyzed for this study were taken by LANDSAT-2. ERTS-1 was launched by the National Aeronautics and Space Administration (NASA) in July 1972. ERTS-B was launched in January of 1975 and when it achieved orbit it was named LANDSAT-2, and acronym for Land Satellite to distinguish it from SEASAT, an oceanographic satellite program, and ERTS-1 was renamed LANDSAT-1. LANDSAT-3 was launched in March of 1978 and LANDSAT-4 was launched in July of 1982 (NASA, 1976).

The satellite payload for LANDSAT-1 and 2 consists of two imaging systems, the Return Beam Vidicon (RBV) and the Multispectral Scanner (MSS). The RBV consists of three cameras that acquire green, red and photographic infrared images. The image is formed on a photosensitive camera tube, instead of film, that is scanned by an electron beam. Then the resulting video signal is transmitted to the Earth. Due to an electrical component failing, only a few RBV images have been acquired from LANDSAT-1. Most images have been acquired with the MSS on both LANDSAT-1 and 2 and it is generally accepted that MSS images are equal or superior in quality to those from the RBV (NASA, 1976).

The MSS is located on the base of the satellite. Its mirror oscillates through a scan angle of 12 degrees. At an altitude of approximately 920 km LANDSAT images are acquired by the mirror as it scans a swath 185 km wide normal to the orbit path. The satellite crosses the Equator at roughly 9:42 am local time. It circles the Earth about 14 times a day and after 18 days the satellite returns to its beginning position. Image data are recorded only on the east bound mirror sweep with the data being transmitted to a ground receiving station for recording on magnetic tape. The processed tapes produce images that cover a 185 km by 185 km area on the ground. The MSS has an instantaneous field of view of 79 m by 79 m which produces a spatial ground resolution cell of 56 m by 79 m - the LANDSAT picture element or pixel (NASA, 1976).

Sunlight reflected from the terrain is separated into the four wavelengths or spectral bands. These bands are - MSS 4, visible green, 0.5-0.6 micrometers; MSS 5, visible red, 0.6-0.7 micrometers; MSS 6, invisible reflected infrared, 0.7-0.8 micrometers; and MSS 7, invisible reflected infrared, 0.8-1.1 micrometers. There are 6 detectors for each spectral band. Thus, for each sweep of the mirror 6 scan lines are simultaneously generated for each of the four spectral bands (NASA, 1976).

Thirteen scenes covering the entire area of the Ozark uplift were analyzed at a scale of 1:1,000,000 of bands 5 and 7 and false-color composites. Also the east and west half of the Rolla 1° X 2° Quadrangle color composites at a scale of 1:250,000 were analyzed. The latter composites had been geometrically stretched. The lineaments were identified and plotted on transparent mylar overlays and then compared with known structures, mineral occurrences, host rocks of the mineral deposits, and Precambrian rock types and structure contour lines.

A light table, magnifying glass, and map enlarger-reducer was utilized for viewing and interpretating the LANDSAT images. The images were observed from different positions and angles so as to recognize lineaments that might not be noticeable in one direction but in another direction. Also some lineaments were more pronounced on certain images than others. Thus, this corroborates the advantage of analyzing more than one LANDSAT band of the same area.

The lineaments in this study are represented as straight line segments. This is because the human eye has a tendency to merge closely spaced line segments into continuous linear features, where in reality they curve and are discontinuous, as are the faults they represent. Lineaments presumably reflect subsurface features such as faults but lineaments are also caused by a variety of landscape elements on the land surface such as topography, drainage, vegetation, and tonal soil changes. Thus, lineament interpretation is to a large degree subjective and the results and interpretations are many times controversial. The writer was conservative in the approach, indentification, and extrapolation of lineaments.

II. REVIEW OF PREVIOUS LITERATURE

A. MAJOR ORE DEPOSITS OF THE OZARK DOME

The Ozark dome is an enormously rich metallogenic province with several major lead-zinc districts. Due to the vase amount and variety of ore deposits, numerous ore deposit studies have been undertaken. The Viburnum Trend issue of Economic Geology (v. 72, May 1977) was the result of papers presented at the symposium on the geology and ore deposits of the Viburnum Trend (Oct. 1975). The proceedings featured mine geology, sedimentology, petrography, ore genesis, mineralogy, and fluid inclusions. Thus, the Viburnum Trend issue is important as a major contributor in the study of the lead-zinc deposits of Southeast Missouri.

Snyder and Gerdemann published several papers on the lead deposits of southeast Missouri, among them include a 1968 paper in the AIME Graton-Sales volume. Their study included stratigraphy, structure, and ore deposits - types and forms of ore bodies, fracture control of mineralization, mineralogy, and ore genesis.

James (1952) described that in southeast Missouri there are three principal structural environments that are responsible for the emplacement of lead ores. These structural environments are associated with distinct types of lead-zinc deposits. The three environments are: 1) fault zone, 2) knob and ridge, and 3) structural block.

Mather (1947) made a study of the barite and associated lead-zinc deposits of the Central Missouri District. He divided the ore deposit types into six classes: 1) fissure, 2) breccia, 3) circle, 4) solution channel, 5) replacement, and 6) residual deposits. Mather believed the origin of the barite and associated sulfides of the Central Missouri District are from relatively cool, hydrothermal solutions.

McKnight (1935) produced a major work on the northern Arkansas zinc-lead deposits. His description of the Ozark dome concurs with more recent descriptions. He discussed the stratigraphy, structure, ore deposits, and selected mines of the Northern and Northeastern Arkansas Zinc-Lead Districts.

Weidman (1932) was among the important early studies of the Tri-State District. His study included ore deposits, structures of the area, mining fields, and an extensive description of the mines. He believed that a strong relationship existed between fracturing and the occurrence of ore and that the ore bodies follow bedding and major fractures. Weidman believed the magmatic theory for the origin of the Tri-State zinc-lead deposits. He noted that the ore deposits have three general shapes: 1) "flat runs", 2) "vertical runs", and 3) "pockets".

Hagni (1962, 1976) divided the ore bodies of the Tri-State into two groups: 1) deposits localized in filled sink structures, and 2) deposits localized in fractured and brecciated Mississippian formations. He stated that the fractured and brecciated Mississippian cherts and limestones can be grouped into two types by their shape: 1) "runs" and 2) "sheet ground" while Weidman (1932) grouped them into three types. Hagni (1962, 1976) and Lyden (1950) concluded that dolomite and jasperoid are closely related to the location of ore bodies. Hagni noted that the dolomite is more abundant in the center of the "runs". Hagni also emphasized earlier recognitions that the Tri-State ore deposits exhibit three outstanding features: 1) close relationship to the surface (less than 475 feet), 2) remarkable areal extent, and 3) no association with igneous rocks.

A valuable study of the Tri-State District was published by Brockie, et al. in the 1968 AIME Graton-Sales volume. Their study included stratigraphy, general structure, extensive work on the economic geology of the ore deposits, such as stratigraphic relations, mineralogy, mineral zoning, wall rock alteration, mineral paragenesis, and forms of ore bodies.

McKnight and Fisher (1970) discussed the geology and ore deposits of the Picher field in the Tri-State District of Oklahoma and Kansas. They did a comprehensive study on the stratigraphy, structure, and origin and paragenesis of the zinc deposits.

B. STRUCTURES OF THE OZARK DOME

Many scientists have recognized and described a structural pattern existent in the rocks of North America and other continents of the world. Sonder (1947) recognized this pattern and established the "regmatic shear pattern" terminology. He observed four major trends: 1) northwesterly, 2) northeasterly, 3) northerly (meridional), and 4) easterly (equatorial). The dominating trends are the diagonal sets - northwesterly and northeasterly. This structural pattern is found world-wide and is probably due to tidal effects on the Earth's surface.

Although Sonder (1947) was the first to coin the terminology "regmatic shear pattern" he was not the first to observe and describe this pattern. Among the first was Hobbs (1911) who noticed a controlled fracture pattern of NE-SE, NW-SE, N-S, and E-W across North America. Graves (1938) was one of the first to discover a regional structural pattern across Missouri. He studied the Precambrian rocks in southeast Missouri and determined the dominant structural trend was N50°W. The Precambrian faults, joints, bedding planes in the pyroclastics, and flow lines in the felsites strike in that direction. Fisk (1944) also recognized the pattern in the lower Mississippi Valley and Great Coastal Plain. McCracken (1971) compiled a summary of the structural features and structural history of Missouri. More importantly she produced a map of the known structural features of Missouri. This map included much new data and supported previous works that the dominant structural pattern of Missouri is NW-SE followed by NE-SW, N-S, and E-W. Heyl (1965, 1972) described a nearly continuous east-west trending zone of faults and intrusions. This zone follows the 38th parallel of latitude from northeastern Virginia to south-central Missouri. This zone delineates a wrench-fault zone in the basement. Heyl noted that several mining districts occur along the 38th parallel, two of which occur in Missouri. These are the Southeast Missouri Lead-Zinc District and the Central Missouri Barite and Lead-Zinc Districts.

Tikrity (1968) did the only major work on the tectonic genesis of the Ozark uplift. He recognized three major Paleozoic tectonic elements - St. Francois dome, Ozark arch, and Decaturville dome as reflections of their Precambrian ancestors. Tikrity perceived basement faulting as the chief factor in the delineation of the sedimentary features in the area. It had been thought that these granitic blocks were due to tangential and/or compressional forces but Tikrity interpreted the tectonic forces to be vertical. He did an extensive fault study and concluded that the faults in the area are either normal or high angle reverse. Also the "folds" present in the area are fault-controlled asymmetric "anticlines" that have no equivalent synclines.

A large number of structural studies have been executed in the Tri-State District. This is probably due to the structural influence on ore deposition. Fowler and Lyden (1932), Fowler (1938, 1960) made an analogy of the Picher-Miami fields with an oil field on a smaller scale with domes, basins, anticlines, synclines, and flexures. A thick residual oil occurs locally in small volume in the Pennsylvanian Shale that overlies the ore deposits. Structures such as the Miami and Bendelari troughs are probably reflections of structures in the basement and played a very important role as mineral-bearing solutions. Fowler (1938, 1950) recognized that pre-mineral deformational structures, such as shear zones and flexures were important in localizing the ore bodies and that they probably were the avenues through which ore fluids moved. Fowler (1938) noted that the mine workings in the Tri-State are elongated NE and NW, for example, the Picher field is elongated NE and NW while the Oronogo-Webb City-Duenweg is elongated NW. Among others who studied the Tri-State were Brockie, et al. (1968). They also noted that the regional structure can be seen from the mine workings and that the Picher field is elongated along NE and NW structural trends.

The Miami and Bendelari troughs, the main structures of the Picher field, have been previously discussed by Fowler and Lyden (1932), Weidman (1932), Fowler (1938), and Lyden (1950). Fowler and Lyden (1932) considered the Miami shear trough to be a series of elongated basins while Lyden (1950) referred to it as an elongated graben, all within a chief trough in the surface of the Boone Limestone. Fowler (1938) believed that the Miami and Bendelari structures were a series of graben blocks or troughs while Weidman (1932) believed the Miami structure was a syncline with associated faulting.

Desai (1966) did a regional structural study in the Tri-State District to determine if structures influenced the location of ore mineralization. He determined that mineralization was most closely related to a small number of fault-troughs. Desai noticed that mineralization had more of a preference, in his study, for synclines rather than anticlines and that ore-forming fluids probably moved downward at the time of ore deposition.

C. REMOTE SENSING LINEAMENT STUDIES

The advent of aerial photography and satellite imagery brought a resurgence of lineament studies. In particular, the Ozark dome area was the site of a great deal of studies made for a variety of purposes and goals. El-Etr (1967) did a lineament study in ten counties in southeast Missouri. His study emphasized the importance in the use of drainage and airphoto lineations. He also related the regional geologic setting and discussed the major faults, lineament and linear characteristics and their terminology.

Kirk and Walters (1968) did a lineament study in northern Arkansas and southern Missouri. From Radar imagery they recognized three lineament directions NW-SE, NE-SW, and N-S with the dominant being the diagonal trends. They observed that relationships existed between the lineaments, linear terrain elments, and fracture systems in the rock units.

Gay (1974) did an aeromagnetic lineament study in southeastern Missouri and obtained NW-SE and NE-SW trends, but more importantly demonstrated the presence of a N-S and E-W fracture pair-set in the basement rocks. He found that the aeromagnetic lineament directions parallel the Precambrian diabase dikes. Also some of the lineaments coincide with faults in the Paleozoic sediments and with the boundaries of the Precambrian granitic plutons as defined by aeromagnetics. Thus, Precambrian basement faulting is supported in this study.

Smith et al. (1974) did a lineament study from Kansas to western Indiana using ERTS imagery, gravity, magnetics and seismic data. Their study compared geologic structures, basement, gravity, magnetic, and epicenter maps. From these they determined a general parallelism of the basement structures with the lineaments. Also lineaments coincided with known faults and gravity and magnetic trends.

Saunders and Hicks (1976) used ERTS imagery to map a system of regional lineaments across the United States. They believed lineaments were surface expressions of deep-seated zones of weakness and blocks in the Precambrian. Saunders and Hicks noted the same general pattern as have been previously discussed. They concluded that these lineaments are important in controlling tectonics, sedimentation, and mineralization.

Toweh (1978) did a lineament study using LANDSAT imagery in the Tri-State District of Oklahoma, Missouri, and Kansas. He recognized the dominant lineament trend in his area as NE, followed by NW, N-S, and E-W. The major trends were spatially related to trends of mined areas. In the Picher field both NE and NW lineations generally parallel mined areas. While some were fault-related, for example the Seneca graben. The Boone Formation was found to have the most numerous lineaments. He concluded that these lineaments and faults probably acted as passageways for mineralizing solutions. Kisvarsanyi and Martin (1977) performed a structural lineament and pattern analysis study of Missouri using LANDSAT imagery. They determined that the two dominant structural directions in their area was NW and NE followed by N-S and E-W. Thus, they supported previous evidence of this same regional structural pattern across Missouri. They also compiled an extensive description of lineaments. They illustrated the different lineament directions by plotting them separately and showed a close relationship between the major faults, other structural features, mineral deposits, and mafic intrusives and iron mineralization.

G. Kisvarsanyi and E. Kisvarsanyi (1974, 1976) did lineament studies in southeastern Missouri where they noted that the dominant structural direction was a diagonal system of faults and joints trending N45°E and N45°W. This pattern can be seen in the up- and down-dropped blocks related to igneous ring complexes that are bounded by tangential faults. Examples of these are the down-dropped Belleview and Sabula basins and the uplifted Eminence block.

G. Kisvarsanyi (1978) described the tectonic and metallogenic significance of major structural lineaments in the Midcontinent. From his study, several new concepts have emerged regarding lineaments, ore deposits, and Precambrian basement structures.

The above papers are some of the more important studies involving ore deposits, structures, and lineaments of the Ozark dome. These studies provided increasing recognition that the Midcontinent Mississippi Valley-type deposits are strongly related to faults and other structural features and that a genetic link exists between structure and ore deposits. Thus, the knowledge gained from these studies, especially the structural features, lead to further exploration of the lead-zinc deposits of the Ozark dome region.

III. GEOLOGY OF THE OZARK DOME

A. REGIONAL SETTING AND EVOLUTION OF THE OZARK DOME

The Ozark dome lies within the North American Platform of the Midcontinent. For more than half a billion years, erosion has reduced this area to an undulated platform upon which a veneer of slightly dipping Paleozoic sediments was deposited. The Paleozoic seas were relatively shallow so the sediments tended to thin over the local Precambrian highs and thicken outward and downward from the highs.

The Ozark dome is comprised of a complex Precambrian metamorphic and igneous core, which is overlain by Paleozoic marine sediments composed of sandstones, shales, and carbonate rocks. The Precambrian metamorphic rocks are determined to be Churchillian age. But the granitic rocks and silicic ash-flow tuffs are a segment of the 1.5 b.y. old St. Francois province (E. Kisvarsanyi, 1979). During the Late Precambrian this area remained a high. The igneous activity in the region commenced 1.5 b.y. ago with the formation of the St. Francois province and thereafter has been greatly reduced except for intermittent emplacement of ultramafic pipes in Late Devonian and is continuing to the present in the area of the Reelfoot rift zone. The Paleozoic marine sediments surround and dip away from the igneous outcrops. The Cambrian, Ordovician, and Mississippian sediments are relatively flat-lying, but broken up by faults and gentle folds. These faults tend to develop upthrown and down-thrown blocks with sediments draped across them - thus the term "fold" has been often incorrectly used.

During the Late Cambrian and Early Ordovician, the area slowly subsided and sediments transgressively overlapped the higher Precambrian knobs. Minor disconformities indicate brief interruptions in deposition. The first major unconformity occurred during the Paleozoic on the Jefferson City surface. The Jefferson City - St. Peter unconformity signaled a reversal of tectonic activity. The crustal movements were reversed and the Ozark area started to rise. At the end of the Silurian, uplift and widespread erosion occurred, with the greatest amount around the rising Ozark dome. The Devonian strata lies unconformably on the Silurian and are truncated by post-Devonian erosion. The unconformity indicates that the dome was again uplifted in Late Devonian and considerably eroded. Widespread submergence during the Mississippian again lead to deposition of sediments over the uplift, this probably covered up the highest knobs. Uplift and removal of Mississippian sediments occurred again in Late Mississippian and early Pennsylvanian. During the Pennsylvanian the sea again trangressed producing another period of submergence. This transgression probably almost completely covered the dome and thus left sediments deposited on the Jefferson City karst surface (Snyder, 1968a). There have been no recurrences of uplift, described thus far during the Pennsylvanian or Permian. But the Devonian and Mississippian uplifts left the dome warped with faults and very gentle narrow folds that trend in a northwest direction.

Along with uplift, subsidence, block-faulting, and erosion, the basement of the Ozark dome has also been subjected to tilting. The thickness of the Paleozoic sediments is controlled by the regional dip of the Precambrian basement, but locally it is defined by the basement topography. After the advancement of the Late Cambrian sea, the area slowly subsided with a slight southward tilt and the deposition kept pace with the subsidence. The regional dip, as determined by G. Kisvarsanyi (1977), is 0.35-0.36 degrees to the south-southwest in southeastern Missouri. The Precambrian basement continues to the south and at the southern margin of the Ozark dome the rocks dip less than 10 degrees.

There are four major lead-zinc districts within the Ozark dome (Figure 8). The first major mineral district is in southeastern Missouri. This includes the Mississippi Valley-type lead-zinc deposits in the Paleozoic sediments, the Precambrian iron-copper-manganese deposits, and the Washington County barite and residual iron deposits. The second is the Tri-State Zinc-Lead District of Missouri, Oklahoma, and Kansas which occur in Mississippian age sediments. The third major mineral district is the Central Missouri barite and lead-zinc deposits in Ordovician and Mississippian age sediments. And finally the fourth major district is the zinc-lead deposits of northern and northeastern Arkansas which occur in Ordovician and Mississippian age sediments. The northeastern Arkansas deposits lie outside the boundary of the Ozark dome but they probably did occur within the boundary in the past. Thus, the Ozark dome is a significant mineral-rich province.

In order to discuss the tectonic history of the Ozark dome one must first clarify the term dome. Eardley (1962) defined a dome as

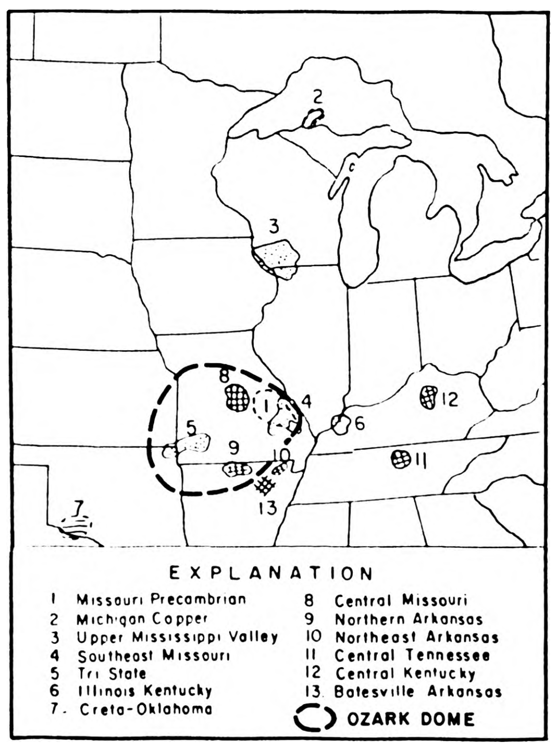


Figure 8. Major mineral districts of the Midcontinent (modified after Snyder, 1968b).

a "gentle, round elliptical uplift of arch proportions". He stated that it generally occurs along an arch and expands the arch locally. He warned that this type of regional dome is not to be confused with an igneous plug or a salt dome. An arch, according to Eardly is a "gentle, broad uplift with a evident width of 25-200 miles and a length conspicuously greater than the width." While the AGI Glossary of Geology defines a dome as "an uplift or anticlinal structure, either circular or elliptical in outline, in which the rocks dip gently away in all directions."

Next it is necessary to define the term platform since the Ozark dome is a part of the North American Platform. According to the AGI Glossary of Geology, the platform is "that part of a continent that is covered by flat-lying or gently tilted strata, mainly sedimentary, which are underlain at varying depths by a basement of rocks that were consolidated during earlier deformations. A platform is a part of the craton." Also the platform has not suffered from orogenies since the late Precambrian time. Thus the terminology, Central Stable Region, is out-dated and is now replaced by the North American Platform.

The writer refers to the Ozark dome as a deformed ellipsoid-shaped structure while Eardley (1962) a broad, nearly circular area, and McKnight (1935) crudely oval in outline. The shape of the Ozark dome, itself, may be judgemental, but everyone generally agrees that it occupies the states of Missouri, Arkansas, Kansas, and Oklahoma - but again its definite boundary is a matter of opinion.

Tikrity (1968) the only one who really studied the genesis of the Ozark uplift, used the term Ozark uplift to include three major Paleozoic tectonic elements - the St. Francois dome, the Ozark arch, and the Decaturville dome (Figure 9). Granitic Precambrian basement underlies these three tectonic elements. The granitic basement was structurally higher than the felsitic, metamorphic, and more basic basements of the surrounding areas in Precambrian time. Thus, the Precambrian history is reflected in these Paleozoic tectonic elements.

Uplift of the St. Francois dome was initiated in early Pennsylvanian time and the other two features were uplifted in late Early Ordovician and late Middle Devonian. Then during the early Pennsylvanian the Ozark arch and Decaturville dome was rejuvenated.

Block-faulting was characteristic of the Precambrian basement and transmitted through the Paleozoic sediments. The lighter granitic blocks moved upwards relative to the heavier blocks through geologic time. Differential movement of these blocks are due to vertical tectonic forces. The faults are predominantly steeply dipping normal faults. Thus, the tectonic evolution of the Ozark dome was fundamentally influenced by the style of deformation of the Precambrian basement.

B. FAULT PATTERNS OF THE OZARK DOME

The Ozark dome is a structurally complex, block-faulted uplift that has been rising gradually and periodically since the Precambrian. The major fault areas are in southeastern and southwestern Missouri, northeastern Oklahoma, and northern Arkansas. These areas are also the

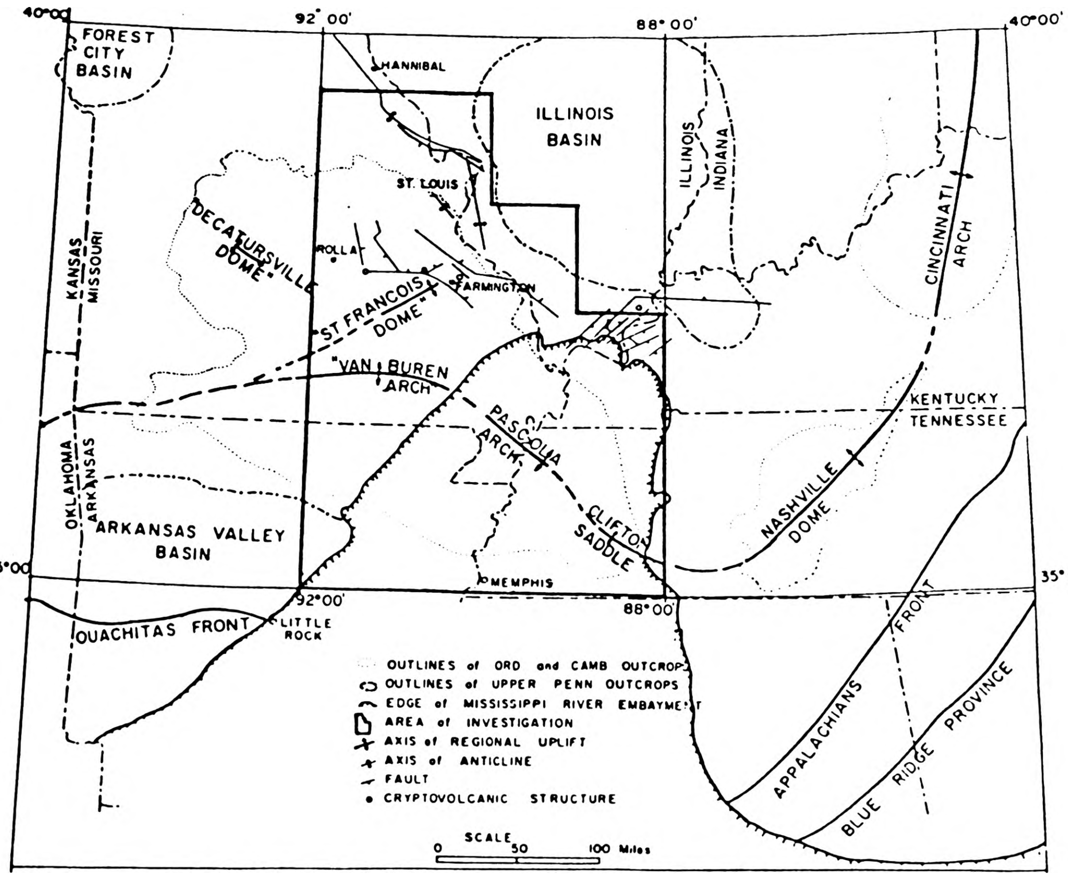


Figure 9. Tectonic setting of the Ozark dome area (from Tikrity, 1968).

major ore-producing districts and will be discussed in more detail under the mineral districts section. The dominant structural features trend NW-SE, NE-SW, N-S, and E-W. The principal trend of the "fold" axes is NW-SW, which is also the dominant trend of the joints, fractures, and lineaments (Graves, 1983, El-Etr, 1967 and McCracken, 1971). The major faults in southeast and southwest Missouri also trend northwest, while in northeast Oklahoma and northern Arkansas they trend northeast.

The Ozark dome is bounded by the Ste. Genevieve fault zone on the east-northeast, the Reelfoot rift zone on the southeast, and the south-dipping normal faults of the Arkoma basin on the southern boundary (Figure 10). There is no bounding fault system on the northern boundary of the Ozark dome. Also, there is no western bounding fault system unless one considers the Nemaha Ridge-Humboldt fault zone in east-central Kansas and Oklahoma.

The orthogonal, block-faulted pattern of the Ozark dome can best be observed in the Precambrian outcrops of the St. Francois Mountains and Eminence areas (G. and E. Kisvarsanyi, 1974). The igneous outcrop area in the St. Francois Mountains exhibits nearly a square shape and is referred to as the St. Francois Mountains block. Tectonic movements developed square-shaped basins and highs within these outcrops. Horst and graben patterns were developed by some of the blocks. While the larger blocks are bounded by steeply dipping faults and fractures. Many structural blocks are the result of tangential faults bounding the granitic ring complexes. This can be exemplified by the down-dropped blocks of the Belleview and Sabula

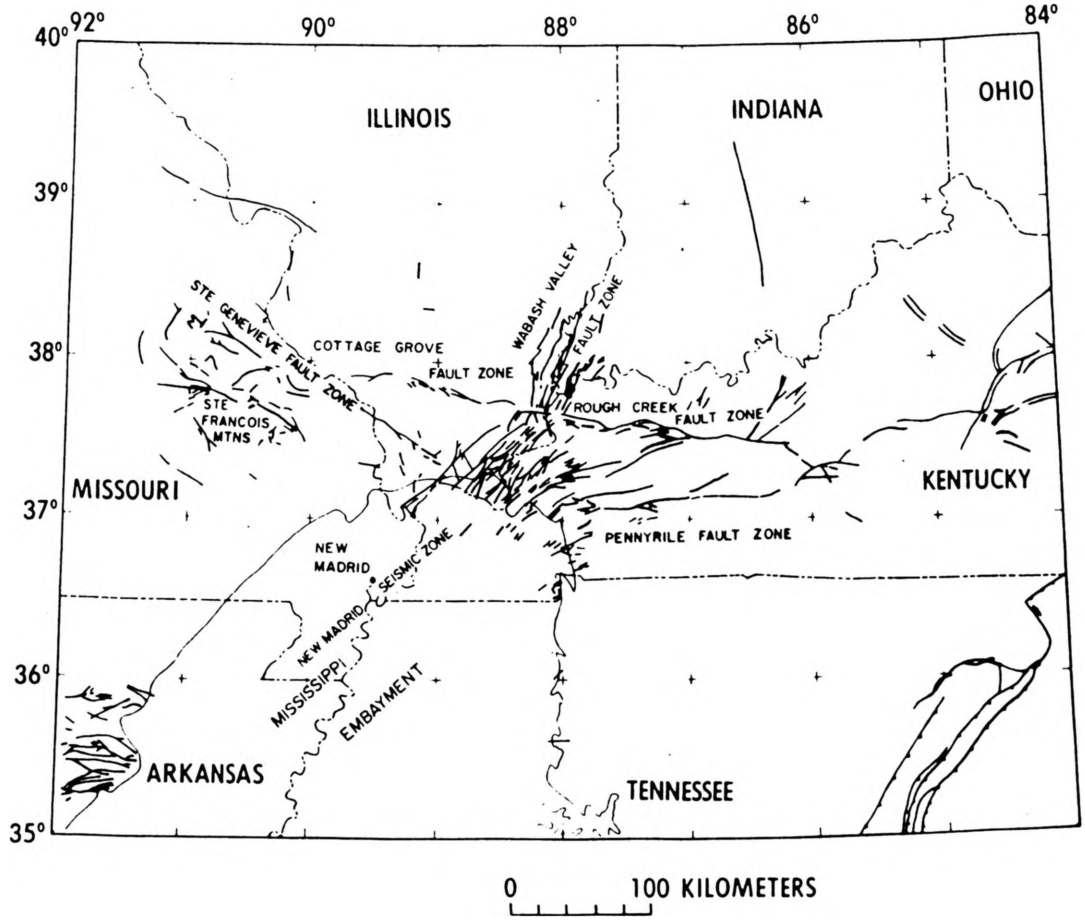


Figure 10. Tectonic features in the New Madrid seismic zone and surrounding area (from McKeown and Pakiser, 1982, generalized from Heyl and McKeown, 1978, and Heyl, 1972). Faults are shown by thick solid lines. Thin solid line is outline of Mississippi Embayment.

"basins" and the uplifted Eminence block (G. and E. Kisvarsanyi, 1974, 1976, E. Kisvarsanyi, 1979) (Figure 11).

As determined from drillhole data the Eminence area also seems to be bounded by steeply dipping faults and fractures that exhibit a rectangular shaped area and is referred to as the Eminence block. The St. Francois Mountains and Eminence blocks (Figure 12) have essentially the same shape and orientation, and their boundary faults strike N35°-45°E and N40°-50°W (G. and E. Kisvarsanyi, 1974) which as above was mentioned are the principal trends of the structural features of the Ozark dome.

The St. Francois Mountains are the structural apex of the Ozark dome. They lie a few miles to the southwest of the complex intersection of the Ste. Genevieve, Palmer, and Cottage Grove fault zones, in the eastern part of the southeast Missouri mineral district. Also fault displacement is another expression of the high uplift of this part of the Ozark dome.

The Ste. Genevieve, Palmer, Cottage Grove, and Rough Creek fault zones are a part of a east-west fault system that lies along the 38th parallel of latitude-lineament (Heyl, 1972) (Figures 13 and 14). The Southeast Missouri District is at the intersection of this lineament with the Ste. Genevieve fault system and the crest of the Ozark dome, while the Central Missouri District is adjacent to the intersection of the lineament with the Proctor anticline and faults. The Ste. Genevieve fault zone and the Reelfoot rift zone imposes the northwest and northeast orthogonal fault pattern while the east-west strike-slip pattern is a structural component of many faults in the

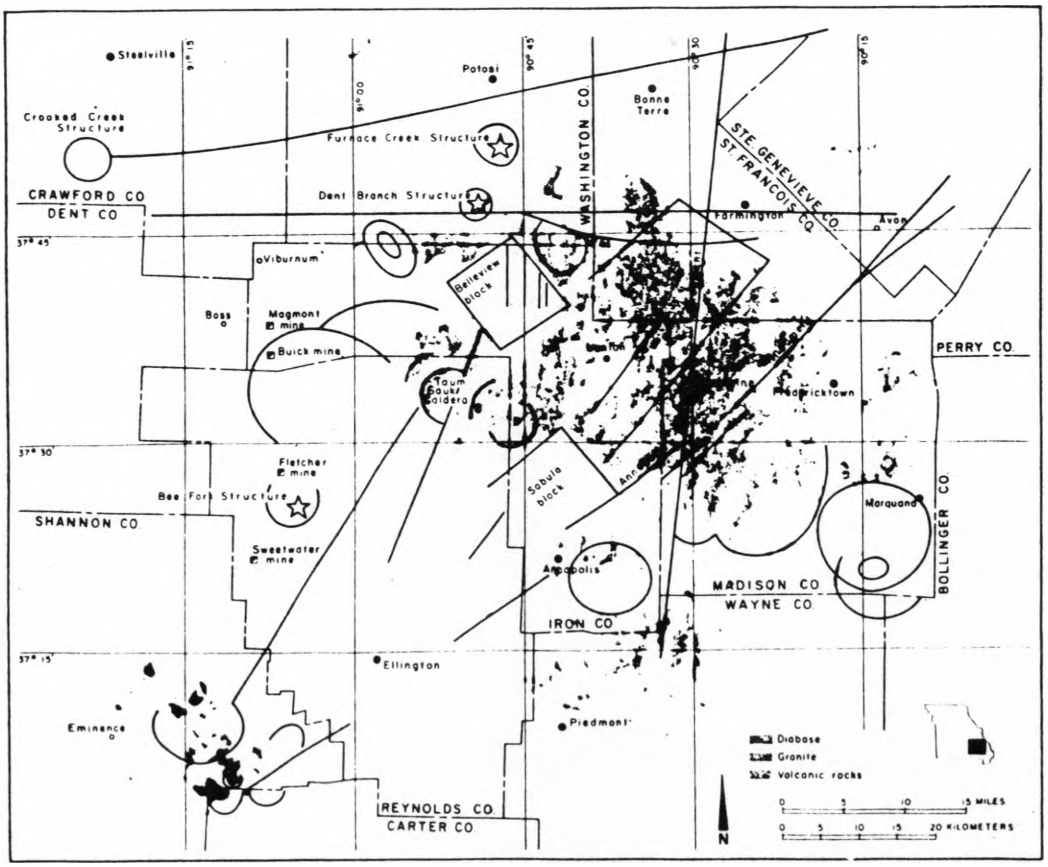


Figure 11. Lineaments and circular features defined from ERTS-1 imagery of Southeast Missouri, note location of the Belleview and Sabula down-dropped blocks and the Eminence uplifted block (from G. Kisvarsanyi and E. Kisvarsanyi, 1974).

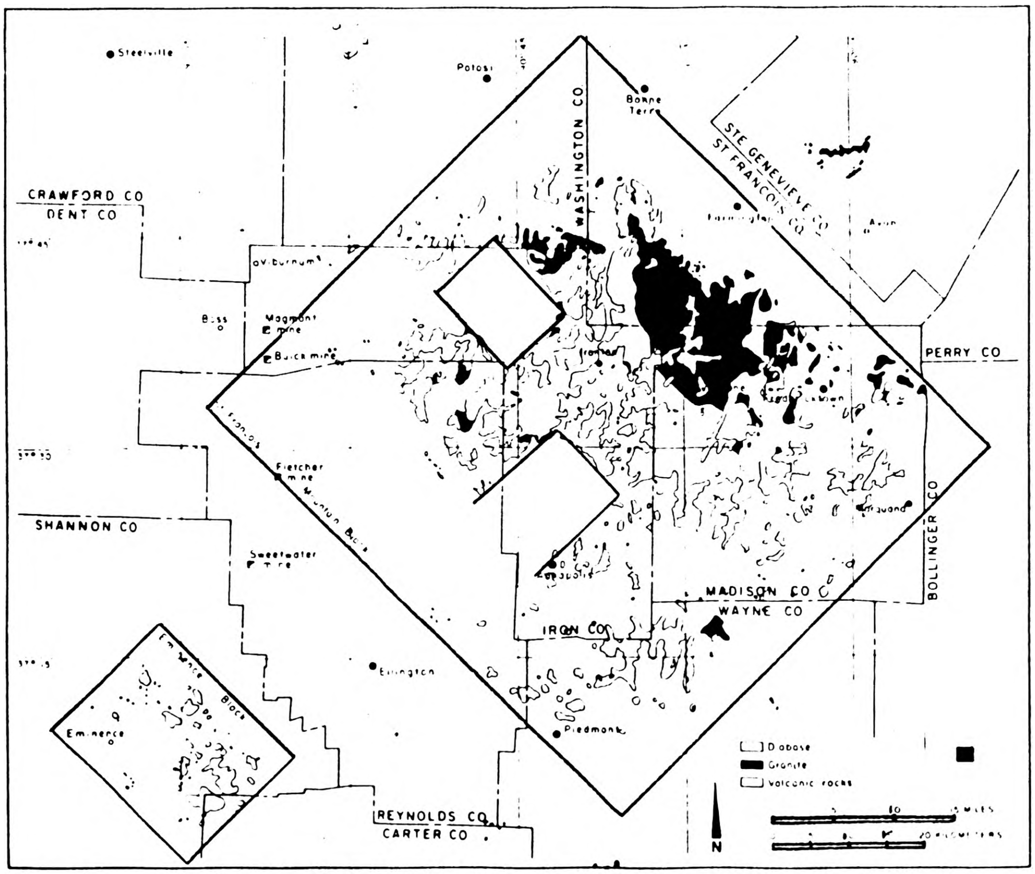


Figure 12. Generalized geologic map of exposed Precmabrian rocks in Southeast Missouri, note St. Francois Mountain Block and Eminence Block (modified from G. Kisvarsanyi and E. Kisvarsanyi, 1974, adapted from Tolman and Robertson, 1969).

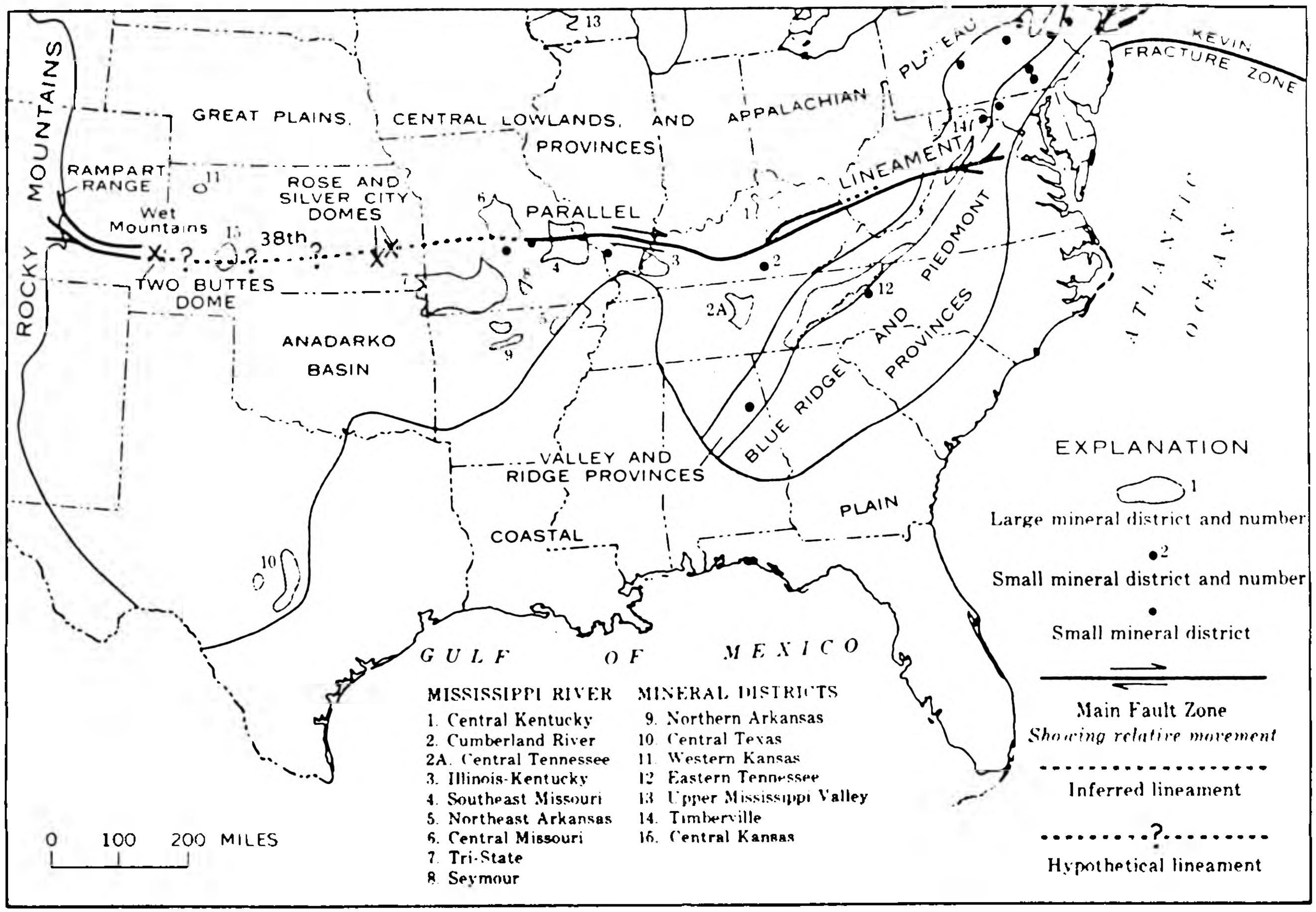


Figure 13. Location of the 38th parallel lineament (from Heyl, 1972).

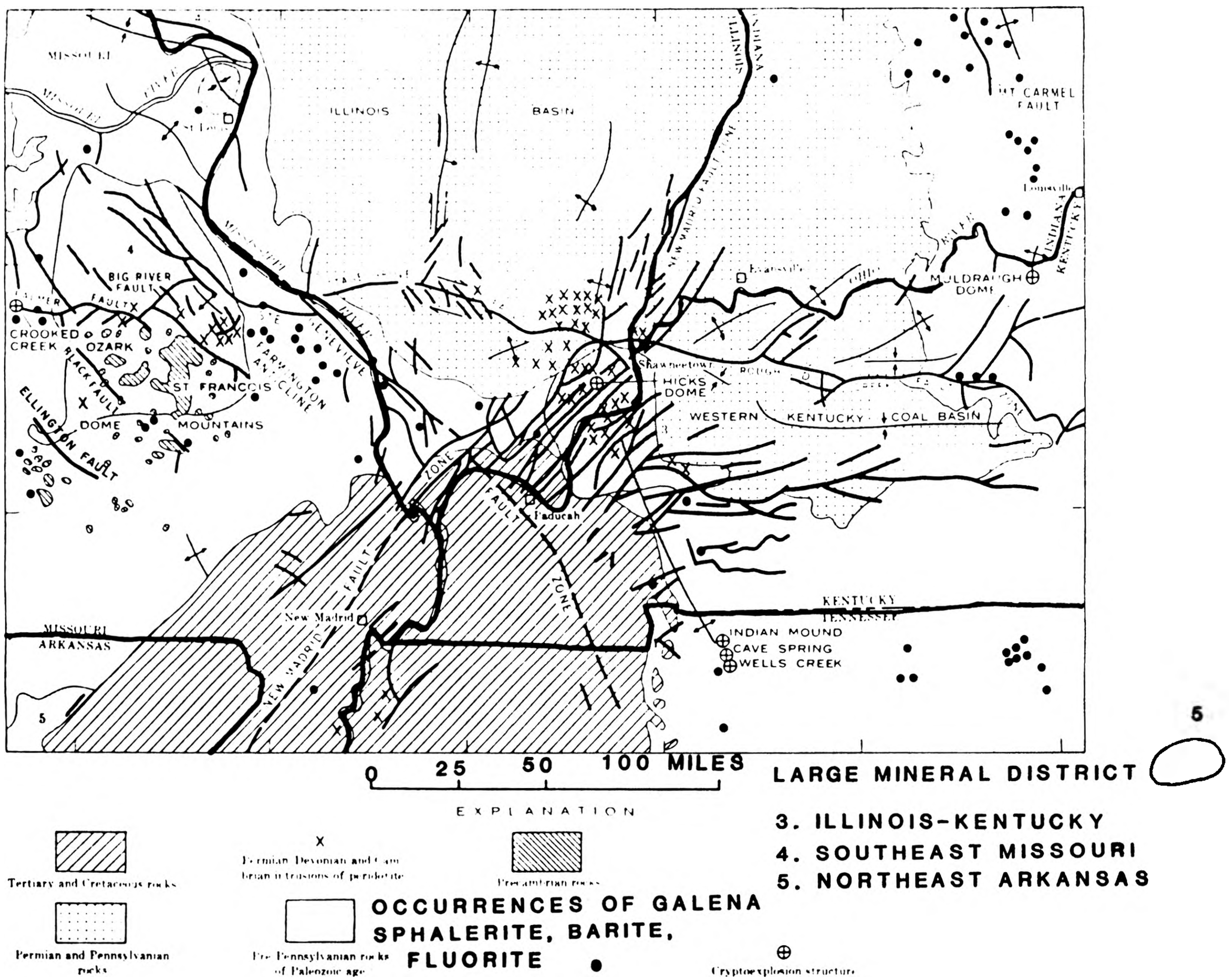


Figure 14. Fault zones, associated structures, and mineral deposits in Southeast Missouri and surrounding areas (modified from Heyl, 1972).

Ozark dome area.

The Cottage Grove fault zone, a segment of the 38th parallel lineament, extends 100 miles across southern Illinois into southeastern Missouri. In southeast Missouri it intersects the northwest trending Ste. Genevieve fault zone and its branches. The Big River and Palmer faults, the westward continuation of the 38th parallel lineament, cuts across the Southeast Missouri District and continues westward to the Crooked Creek crypto- explosive structure (Heyl, 1972).

Near the center of the intersection of the Ste. Genevieve, Palmer, and Cottage Grove fault zones is the northwest trending Farmington anticline. The Farmington anticline is a broad, asymmetric trending N30°W and almost perpendicular to the axis of the St. Francois dome. Also in this area diatremes and dikes occur ranging in composition from kimberlite to alkalic peridotite (Heyl, 1972).

The Old Lead Belt of southeast Missouri is along the northeastern flank of the St. Francois Mountains and the Ozark dome. This large tilted block of Bonneterre Dolomite of Cambrian age contains most of the lead mines of the Old Lead Belt. This block is bounded by the Ste. Genevieve and Big River fault zones to the north and the Simms Mountain fault to the southeast (Figure 15). The northeast dipping mineralized sedimentary rocks, in the Old Lead Belt, had their dip reversed by later southward tilting of the block between the two fault zones. Also within the tilted block are several other northwesterly trending minor faults (Heyl, 1972).

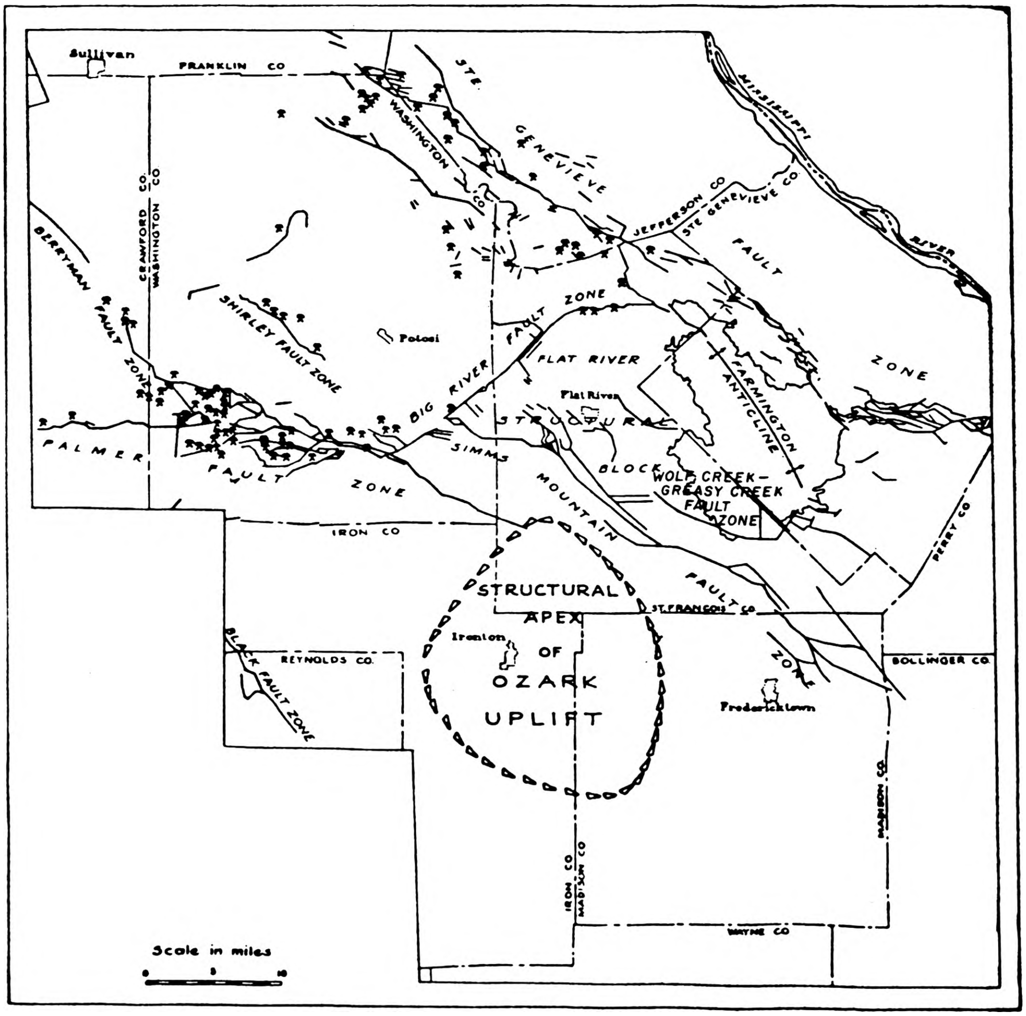


Figure 15. Structural block with fault zones and mineral deposits, Southeast Missouri (modified from James, 1952).

The Big River fault branches westward from the Ste. Genevieve fault zone and curves to the north around the northern edge of the Farmington anticline and around the Old Lead Belt. West of the Old Lead Belt, the Big River fault intersects the Simms Mountain and Palmer faults. The southern boundary of the Old Lead Belt structural block consists of the Palmer fault, which trends east-west and is nearly parallel to the central part of the Ste. Genevieve fault zone (Heyl, 1972).

The Ste. Genevieve fault zone is a complex system of approximately 150-200 miles long. The northwestern 50 miles has a general strike of N50°W, whereas the middle segment strikes east-west for 30 miles.

The Simms Mountain fault zone trends northwest and designates the east and northeast perimeters of the main Precambrian outcrop of the St. Francois Mountains. This fault zone is nearly parallel to the northwest trending segments of the Ste. Genevieve fault zone.

Prominent northwest trending features in western Missouri include the Bolivar fault and the Bolivar-Mansfield fault system. The Bolivar fault is actually an anticlinal structure with displacement of the beds caused by folding rather than faulting. This "fault" is a part of the larger Bolivar-Mansfield fault system (McCracken, 1971). The Bolivar-Mansfield fault system consists of a series of nearly parallel faults and in some areas grabens developed between the faults. This is a zone of discontinuous fractures and high-angle normal faults that may extend into northern Arkansas.

The Seneca graben or fault and the Miami trough are the two main structural features in northeast Oklahoma. The Seneca graben trends N40°E while the Miami trough trends N15°E through the Picher mining area and north of the Picher field it trends N35°E to N40°E. These are complex structures with bounding faults that locally narrow to synclinal sags. Minor structures in this area include the Bendelari "trough" and Picher anticline. They both trend approximately N30°W and are especially evident in the Picher mining area (Brockie et al., 1968) (Figure 16).

Throughout the area of the Ozark dome there are many similar structures. Only the larger structural features were discussed due to the enormous area involved. Many similar structures of smaller magnitude also exist. Thus, to obtain more information on these smaller structures one has to consult the proper references for that particular area.

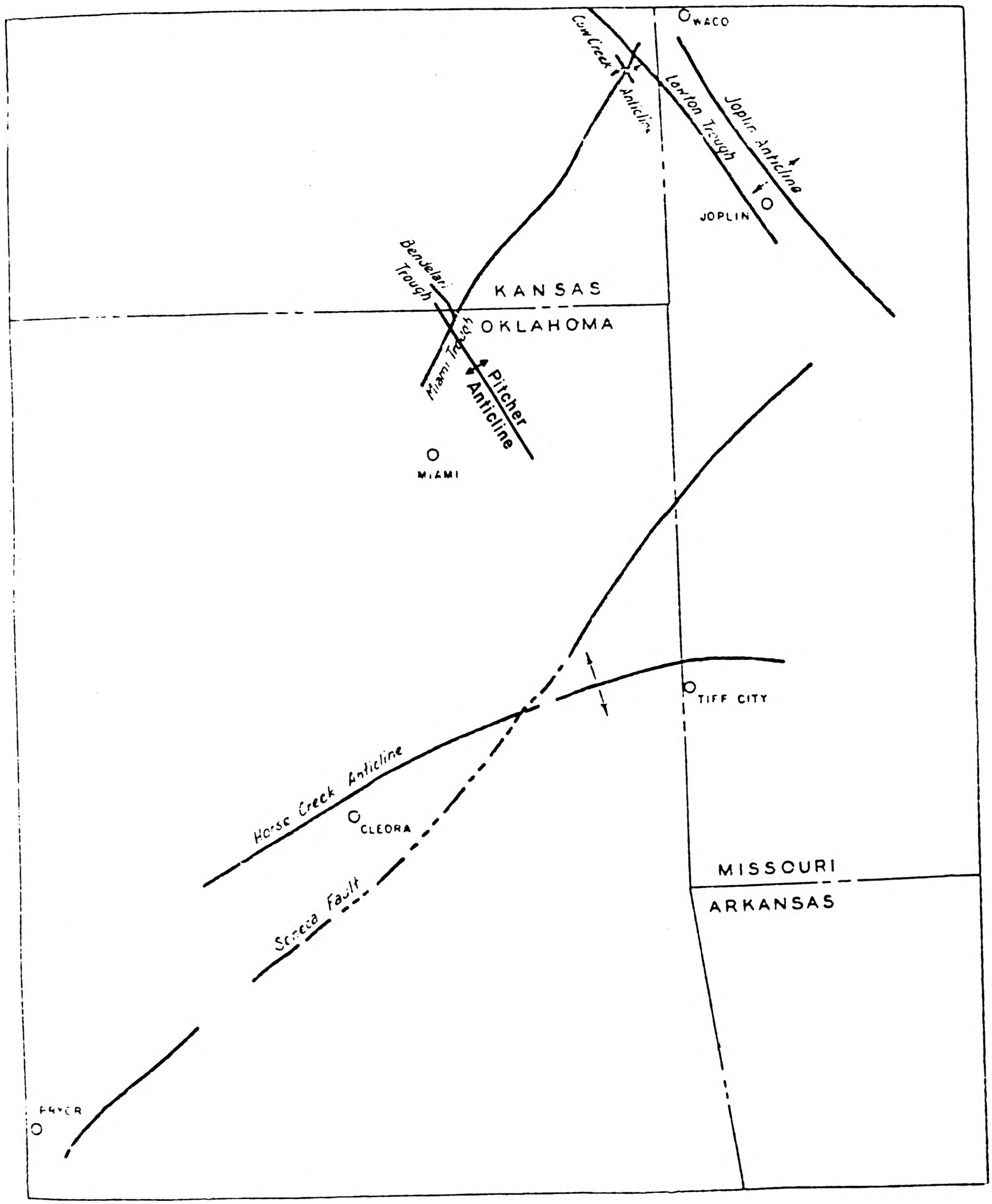


Figure 16. Major structural features of the Tri-State District (modified from Hagni, 1962).

SCALE 0 5 10 MILES

IV. MINERAL DISTRICTS OF THE OZARK DOME

A. SOUTHEAST MISSOURI DISTRICT

1. Stratigraphy. The Southeast Missouri Lead-Zinc District is one of the world's largest lead mining districts. The lead-zinc deposits are classified as Mississippi Valley-type. There are very few Mississippi Valley-type districts in the world which are located in such a classical structural position as is the Southeast Missouri District. The Southeast Missouri District is on the flank of the St. Francois Mountains along the east- northeastern margin of the Ozark dome (Figures 5 and 8).

The only location where the Precambrian igneous rocks, of the Ozark dome, outcrop are in the St. Francois Mountains of southeast Missouri. The Precambrian rocks are part of the St. Francois Mountains Terrane, which consists of 1.3-1.5 b.y. old unmetamorphosed volcanic and plutonic rocks (E. Kisvarsanyi, 1978). These Precambrian igneous rocks appear as a major structural high and are composed mainly of rhyolitic rocks intruded by granites and diabase dikes. The Precambrian rocks form the core of the St. Francois Mountains while the Cambrian and Ordovician marine sediments surround and partially cover the erosional igneous highs. The Cambrian formations include from the oldest upward - the Lamotte Sandstone, Bonneterre Formation, Davis Shale, Derby-Doerun Dolomite, Potosi Dolomite, and Eminence Dolomite. The Ordovician formations include the Gasconade Dolomite, Roubidoux Formation, and Jefferson City Dolomite (Figure 17).

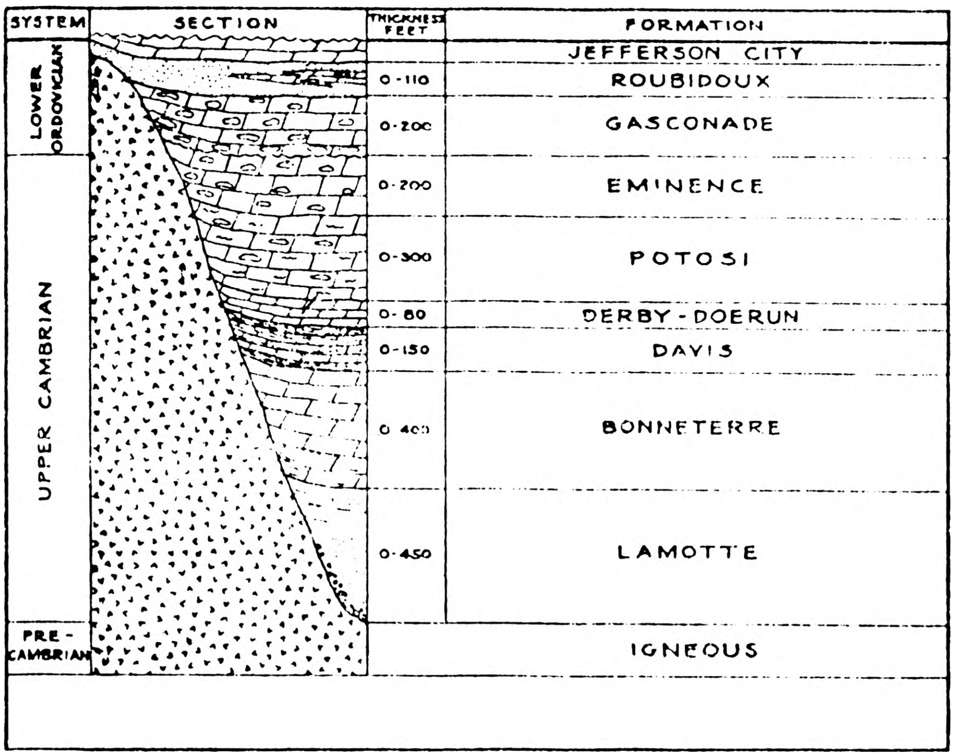


Figure 17. Partial columnar section in the Southeast Missouri District (from James, 1952).

The Lamotte Sandstone is a pure orthoquartzite with occasional siltstone section or dolomitic beds in the upper section, while typically the lowest section is largely arkosic. The Lamotte is usually fine-grained, friable, cross-bedded, and often porous and permeable with a maximum thickness of 450 feet (Snyder and Gerdemann, 1968). Near the igneous knobs a blanket of conglomerate, as much as 300 feet thick, lies on the erosional surface of the Precambrian basement. The conglomerate beds are composed mostly of rhyolite fragments. This lithologic unit, not formally named, underlies the Lamotte Sandstone. An unconformity exists at the base of the Lamotte.

The Bonneterre Formation which is the host rock of the lead-zinc ores is made up almost entirely of dolomite adjacent and over the Precambrian igneous highs but grades into limestone in the local basins away from the highs. The Bonneterre contains shallow water depositional features and various vertical and lateral facies changes. The Bonneterre Formation consists predominantly of tan crystalline calcerenite, lime sand, alternating with gray or brown shaly carbonate (Snyder and Gerdeman, 1968). Its thickness ranges from 300-400 feet.

The Bonneterre in the area of the Viburnum Trend can be divided into a fore reef, reef complex, back reef, and shore facies. These categories are petrographic units that represent different paleo-environments developed due to sea level fluctuations of the Cambrian sea in the area of the Precambrian highs (Lyle, 1977). No other formation exhibits such a contrast in original and superimposed porosity and permeability near the shore as that of the Bonneterre. The physical properties of the Bonneterre are unique among the formations and reflects the configuration of the Precambrian basement as well as deformation and solution movements.

The Davis Shale lies conformably over the Bonneterre Formation. It is comprised of interbedded shales, carbonates, fine-grained glauconitic sandstone, and glauconitic siltstone. Characteristic of this formation are flat-pebble and edge-wise conglomerates. The Davis Shale averages 170 feet thick (Snyder and Gerdemann, 1968).

Two major units make up the Derby-Doerun Dolomite. The lower unit consists of thin-bedded argillaceous, dolomite and the upper unit of massive oolitic dolomite or algal reef dolomite (Snyder and Gerdemann, 1968).

The Potosi is composed of brown, massive-bedded, siliceous dolomite consisting of algal reef and recrystallized oolitic dolomite. Also characteristic of this formation is chert and drusy quartz (Snyder and Gerdemann, 1968).

Both the Eminence and Gasconade Formations consist of clean, light gray, medium to coarsely crystalline, cherty dolomites with widespread masses of silicified cryptozoon beds also present. The Roubidoux is composed primarily of sandstone, dolomitic sandstone, and cherty dolomite. The Jefferson City Formation is comprised principally of tan and gray, medium to finely crystalline, cherty and argillaceous dolomite. A pronounced erosional unconformity exists at the top of the Jefferson City (Snyder and Gerdeman, 1968).

The Bonneterre Formation and to a minor extent the upper Lamotte Sandstone are the host rocks for the lead-zinc stratabound deposits. The upper Potosi Formation and lower Eminence Formation are the host rocks for the Washington and Jefferson Counties barite and lead-zinc deposits. While the Precambrian rocks are the host for the iron-copper-manganese deposits.

2. Structure. The Paleozoic sediments of southeast Missouri dip gently to the southeast. The major structural features include faults and one major fold. The major structural trends are northwest-southeast and northeast-southwest with less prominent trends north-south and east-west (Graves, 1938, El-Etr, 1967, McCracken, 1971, Kisvarsanyi and Martin, 1977). The major northwest trending fault zones include the Ste. Genevieve, Simms Mountains, Wolf-Creek-Greasy Creek, Shirley, Black, Ellington, Berryman, and Cuba with the northeast trending Big River and east-west trending Palmer fault (Figures 14, 15 and 23). Generally the faults are less than 60 miles long with the exception being the Ste. Genevieve which is approximately 200 miles long. The Farmington anticline, the major "fold", trends N30°W for about 20 miles. The term "fold" here refers to fold-like sediments draped over the Precambrian surface. The "folds" are not compressional but are a response of the horst and graben tectonism of these vertical blocks.

3. Ore Deposits. The Southeast Missouri Lead-Zinc District contains stratabound deposits in the Bonneterre Formation and some in the upper Lamotte Sandstone. These deposits occur in Madison, St. Francois, Washington, Crawford, Iron, Reynolds, and Shannon

Counties. Although the Washington and Jefferson County barite and lead-zinc deposits lie in the same geographic area, they are not a part of the district proper.

James (1952) outlined three principal structural environments that were responsible for the emplacement of the lead-zinc deposits. These environments are: 1) fault zone, 2) knob and ridge, and 3) structural block. Each of these environments are associated with distinct types of lead-zinc deposits. The fault environment (Figure 15) is comprised of individual faults that form parallel, sub-parallel, and branching patterns. Ore deposits associated with this environment are found along the Ste. Genevieve, Big River, Palmer, Berryman, Shirley, and Simms Mountain fault zones. The knob and ridge environment (Figure 18) are directly related to the configuration of the Precambrian basement's erosional surface. In this environment sediments were deposited around the knobs and ridges creating pinchout structures in the Lamotte Sandstone. The Precambrian knobs and pinchouts are closely related to the lead-zinc deposits. The structural block environment (Figure 15), which is bounded by folds and faults, is the host for most of the lead-zinc deposits of the Old Lead Belt. The Flat River structural block is bounded by the Farmington anticline on the east, the Big River fault zone on the north and northwest, and the Simms Mountain fault zone on the southwest and south.

These stratabound lead-zinc deposits are localized in a series of neritic facies which includes narrow carbonate bars in an algal reef environment of the Bonneterre Formation. The deposits often occur near the Precambrian igneous highs that in most places, cut out the underlying Lamotte Sandstone. Close to the igneous highs the ore may occur in the upper 100 feet of the Lamotte Sandstone (Snyder, 1968b).

Ore structures developed in a variety of primary depositional features such as pinchout zones, disconformities, ridge structures, reefs, and also related to secondary superimposed structures such as submarine breccias, solution breccias, breccia zones, and faults. The geometry of the ore bodies in the district take many different forms usually controlled by the above sedimentary features and structures so that the sedimentary structure or the deformational structure is essentially what is mined (Snyder and Gerdemann, 1968).

The pinchout-type ore bodies (Figure 18) occur in the area of the Precambrian highs where the Lamotte Sandstone is drastically thinned and/or eliminated. Locally, knobs pinchout part of the Bonneterre. Mineralization could be in any part of the Bonneterre, often it is in the lower Bonneterre above the Lamotte pinchout line. The ore body partially encircles or covers the buried knob being up to 40 feet near the knob and thins away. The mineralization is in the form of disseminated and bedding plane ore (Snyder and Gerdemann, 1968).

The ridge structure ore bodies are bars of coarse-grained sediment that generally take on an anticlinal form. Most of the ore is mined from the lower Bonneterre and occurs on the flanks and crests of the ridge. These ridges generally have an north-east trend (Snyder and Gerdemann, 1968).

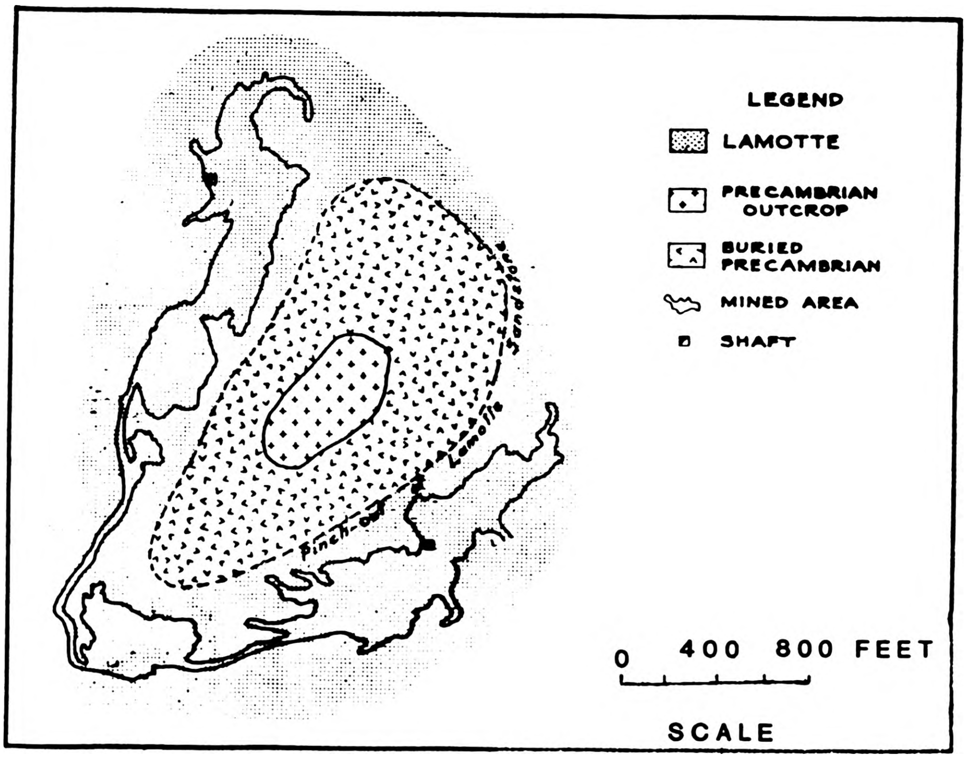


Figure 18. The Precambrian Knobs and Lamotte Sandstone Pinchouts are closely related to the lead-zinc deposits (from James, 1952).

The bar-reef complex ore bodies are very large compound ridges that represent the main ore structures of the district. These compound ridges have lengths up to 15,000 feet and widths of 1,000 feet and are generally found in the lower 200 feet of the Bonneterre. The bar-reef complex is comprised of arch structures at one or more horizons. These arch-shaped structures are due to local abundances of carbonate sand that grades into and intertongues with gray, shaly carbonates. Sites of mineralization are found disseminated throughout any of the Bonneterre or along any of the major bedding plane contacts (Snyder and Gerdemann, 1968).

Algal reef ore bodies refer to a major mass showing organic structures that contain entrapped and interbedded sediment. They are comb-shaped in plan-view. The contact between the superimposed colonial algal structures and clastic carbonates represent the major ore-controlling structure within the reef. The ore minerals are found along bedding-plane and growthline contacts, in fracture zones, and disseminated in the organic carbonates (Snyder and Gerdemann, 1968).

Disconformity-type ore bodies also occur within the Bonneterre. These minor disconformities are the place for blanket-type mineralization and also provided the channelways for extensive lateral migration of ore solutions (Snyder and Gerdemann, 1968).

The submarine breccia-type ore bodies are breccia bodies that formed by submarine gravity sliding along the flanks of calcarenite (lime sand) bars. Ore zones have been mined up to 6,000 feet long and 160 feet high. The ore bodies are long and narrow shaped and usually parallel a calcarenite bar (Snyder and Gerdemann, 1968).

The solution-induced collapse breccia-types consist of breccias occurring in dolomitized shelf-facies, calcarenite in the upper Bonneterre Formation. Digitate algal stromatolites underlies the shelf-facies while the Davis Shale overlies the shelf-facies, for example, at the Buick mine. In plan-view the breccia bodies are sinuous, subparallel, and generally continuous north-south. The individual breccia bodies may be up to 300 feet wide and 85 feet thick (Buick mine) with outward-dipping and bounding fractures on the sides. Some may have well-mineralized slump breccias along the bounding fractures (Rogers and Davis, 1977).

The primary ore minerals of the district are galena and sphalerite. It is believed that mineralizing solutions were concentrated in brines that moved outward from adjacent basins during faulting, uplift, and erosion of the St. Francois Mountains. Numerous investigations show the primary and secondary structural influence on the emplacement of ore, this topic will be discussed later.

B. TRI-STATE DISTRICT

1. Stratigraphy. The Tri-State Zinc-Lead District is one of the largest zinc districts in the world. The district is located on the western margin of the Ozark dome in the states of Missouri, Oklahoma, and Kansas (Figures 5 and 19). The Paleozoic rocks consist of gently dipping rocks to the northwest that range in age from Upper Cambrian to Pennsylvanian (Figure 20). The mineralization is limited to the Mississippian rocks, with no commercial

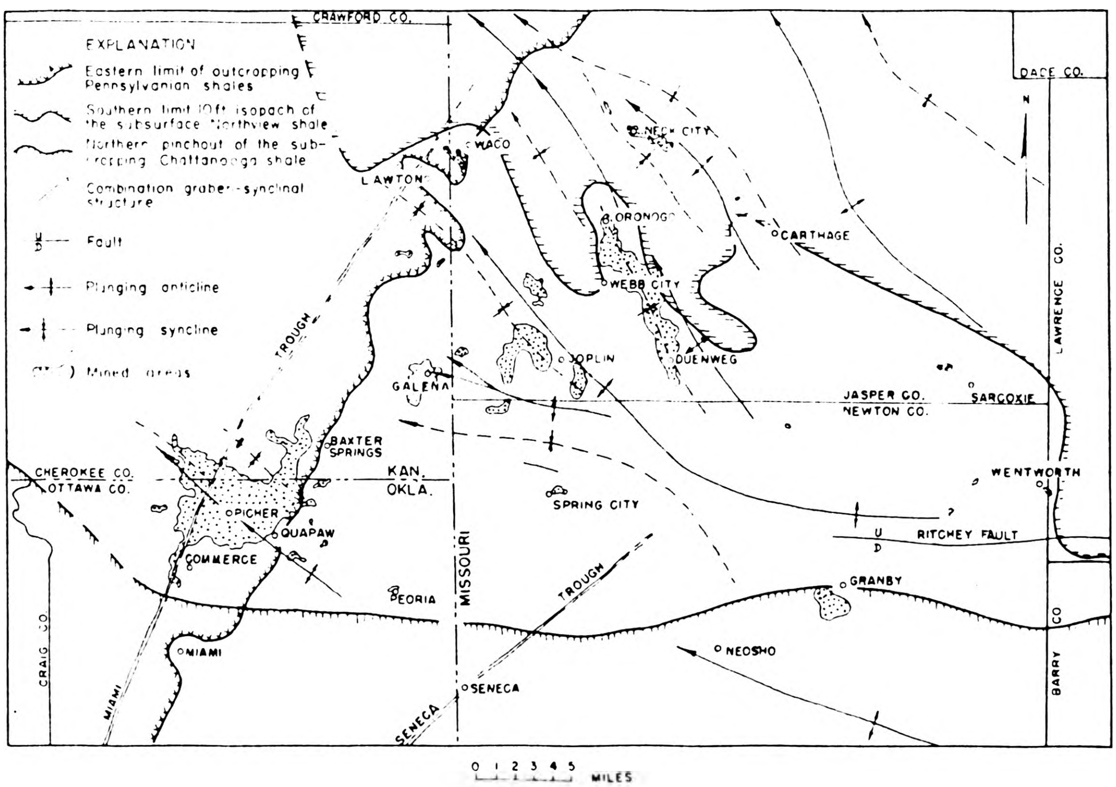


Figure 19. Map of the Tri-State District showing the major structural and geological features (from Brockie, et al., 1968).

SYSTEM	SERIES	FORMATION	REMARKS	
PENNSYLVANIAN	Des Moines	Cherokee Group	Cherokee Group is the surface formation in the Picher Field	
MISSISSIPPIAN	Chester	Fayetteville Shale Batesville Sandstone Hindsville Limestone	The Chester Series is referred to as the Moyes Formation in older literature. The Carterville Formation in the Joplin area is faunally related to the Fayetteville and the Batesville Formations.	
MISSISSIPPIAN	Meramec	Warsaw	B-J bed = Warsaw Formation J bed is equivalent to Cowley Formation of southeastern Kan.	All Meramec and Osage sediments are referred to in some literature as the Boone Formation
MISSISSIPPIAN	Osage	Keokuk	K-Q beds (N, O, P & Q = Grand Falls Chert)	
MISSISSIPPIAN	Osage	Reeds Spring	R bed	
MISSISSIPPIAN	Osage	Fern Glen (St. Joe Group)	Corresponds to Pierson Formation in recent literature	
MISSISSIPPIAN	Kinderhook	Northview Shale (St. Joe Group; Chouteau)	Thin to absent in Picher Field	
MISSISSIPPIAN	Kinderhook	Compton Limestone (St. Joe Group; Chouteau)		
MISSISSIPPIAN DEVONIAN		Chattanooga Shale	Absent except as local patches in Picher Field Subcrop edge is located a few miles south of district	
ORDOVICIAN	Beekmantown	Cotter Dolomite Jefferson City Dolomite Roubidoux Gasconade Dolomite Gunter Member		
CAMBRIAN	Ozark	Eminence Dolomite		
CAMBRIAN	Ozark	Potosi		
CAMBRIAN	Ozark	Derby-Doe Run Davis (Elvins Group)		
CAMBRIAN	Ozark	Bonneterre(?) Lamotte Sandstone		
		Precambrian Complex		

Figure 20. Stratigraphic section, Tri-State District (from Brockie, et al., 1968).

ore bodies thus far having been found in the Cambrian and Ordovician. The Bonneterre Dolomite, of Cambrian age, appears to represent a transition zone between the Lamotte Sandstone and the Davis Shale. A facies change in the Bonneterre Dolomite occurs west of the Bolivar-Mansfield fault system of Missouri. The rocks that represent the Bonneterre in the Tri-State consist of fine-grained silty dolomites, dolomitic siltstones, and dolomitic sandstones. In the Tri-State the lack of mineralization in the Bonneterre is due to it being an unfavorable facies, whereas in southeast Missouri it is the principal host rock for the large lead-zinc deposits. An unconformity occurs after the Ordovician eliminating the Silurian and most of the Devonian. The Chattanooga Shale, classified as unassigned Devonian through Mississippian, is a black to dark-brown, fissile, carbonaceous and slightly arenaceous shale. The Chattanooga is largely absent in the district except for a few small, thin, isolated patches.

Practically all the zinc-lead ore production in the district was from the Boone Formation. Past literature has designated the Boone Formation as a collective term involving some or all of the Warsaw, Keokuk, and Reeds Spring Formation and the St. Joe Group which are included in the Meramec, Osage, and Kinderhook Series (Figure 20), whereas some literature simply refers to the Boone Formation as being the Meramecian and Osagean Series. Therefore, the Boone Formation is an obsolete term which may be replaced by one of the above series combinations.

The Warsaw and Keokuk Formations are the major ore producing beds while the Reeds Spring Formation is of minor importance (Figure 21). The Keokuk is the most important ore producing formation in the district, the second most important being the Warsaw Formation. The upper Keokuk consists predominantly of gray and brown, medium-to coarse-crystalline limestone. It also contains considerable amounts of light-gray to white dense chert to cottonrock (a soft white calcareous chert or siliceous limestone) in the form of layers and nodules. The lower Keokuk consists of white to light-brown and gray bedded chert and brown to gray fine-grained dense limestone. The M bed, found in the upper Keokuk Formation is the principal ore horizon. It consists of white and light-gray chert nodules in gray and pale-brown crystalline and fossiliferous limestone and dolomite. The Warsaw Formation chiefly consists of a light gray and light brown to brown abundantly cherty, fine- to some coarse-grained limestone and dolomite (Brockie *et al.*, 1968).

2. *Structure*. A characteristic feature of the Tri-State District is its intersecting structural features. The principal structures are folds and normal faults which trend northeast and northwest (Figures 16 and 19). These structures probably reflect faults and other structural features in the Precambrian basement.

Three major faults occur within this district. They are the Ritchey, Seneca, and Miami faults. The Ritchey (Figure 19) is a normal fault that trends nearly east-west for 25 miles in Lawrence and Newton Counties, Missouri. So far, no relationship between ore mineralization and the Ritchey fault have been found (Brockie *et al.*, 1968).

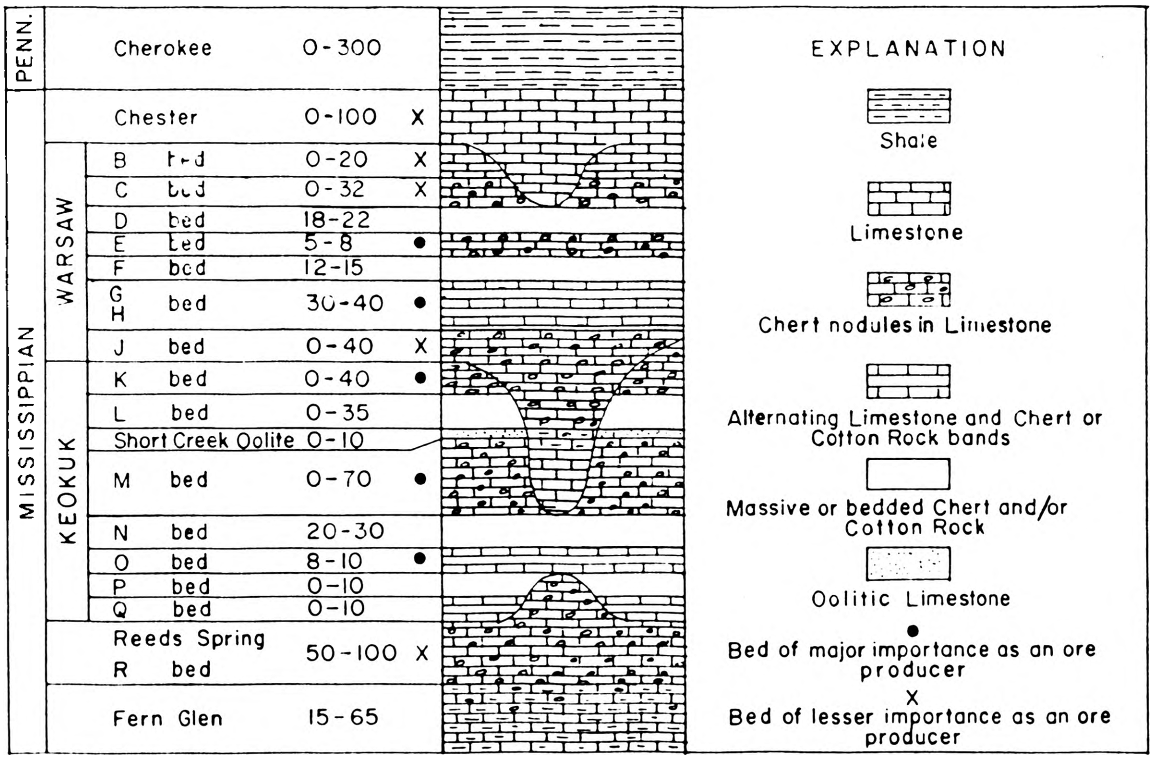


Figure 21. Geologic section of Mississippian Formations, Picher Field of the Tri-State District (from Brockie, et al., 1968, modified after Lyden, 1950).

The Seneca fault or graben (Figures 16 and 19) is a linear and nearly continuous structure that trends N40°E for approximately 70 miles (Brockie _et al._, 1968). The Seneca graben is a complex structure in which the bounding faults are not continuous but are in many places replaced, first on one side and then on the other, or on both, by sharply dipping strata. Thus, the graben grades locally to a narrow synclinal sag.

The Miami trough or fault (Figures 16 and 19) is a linear combination of syncline and graben, except that the synclinal sag, with or without accompanying faults, prevails over the true graben block faulting. The trough trends N15°E through the intensely mineralized Picher mining field area of the Tri-State District and then trends N40°E just north of the Picher field to the Missouri-Kansas state line (Brockie _et al._, 1968). The Bendelari "trough" and the Picher anticline are the principal "folds" of the Picher field (Figures 16 and 19). The Bendelari "trough", as it is locally known, is a monoclinal fold that trends N30°W across the Miami trough in the Picher field. Thus, the Picher field's location seems to be determined by the intersection of the Miami and Bendelari troughs. The northwest side of the Miami trough is where it is particularly well defined. This northwest mineralized extension of the Picher field is along the Bendelari "trough" (Brockie _et al._, 1968).

The Picher anticline, in northeastern Oklahoma, extends in a northwesterly direction through the Picher field, and finally loses its identity just west of the Picher field (Figures 16 and 19). The

Miami trough crosses the Picher anticline (Brockie _et al._, 1968).

The Joplin anticline and Horse Creek anticline are the principal folds in southwestern Missouri (Figure 16). The Joplin anticline first becomes evident on the north side of the Ritchey fault in Newton County, Missouri. It has a northwesterly trend and may possibly break into a fault between Joplin and Smithfield. This is an asymmetric fold with the steeper side on the western limb than on the eastern limb (Brockie _et al._, 1968).

The Horse Creek anticline or monocline trends east-west through western McDonald County, Missouri and just into southeastern Ottawa County, Okalhoma. It also is an asymmetric fold with a steeper dip on its northwest flank than on its southeast flank (McKnight and Fisher, 1970).

3. _Ore Deposits_. The ore deposits of the Tri-State District are restricted almost entirely to favorable stratigraphic horizons in the Mississippian sediments, principally the Keokuk and Warsaw Formations. The Mississippian limestone are overlain unconformably by the Pennsylvanian Cherokee Shale. The Cherokee Shale formed an impermable barrier to the rising mineralized solutions and thus assisted in trapping the ore solutions within the Mississippian Formations.

The principal ore horizon, the M bed, of the Keokuk Formation is near an unconformity at the base of the Warsaw. Where the beds are unmineralized, they consist principally of limestone with some cottonrock or chert as nodules or beds.

Sphalerite and galena are the two primary ore minerals of the

Tri-State District. Other minor minerals include chalcopyrite, pyrite, and marcasite. The main gangue minerals are dolomite and jasperoid which according to Lyden (1950) and Hagni (1962, 1976) are closely related to the location of the ore bodies.

There are three basic forms of ore bodies in the Tri-State District: 1) irregular, relatively narrow, long "runs" of varying heights; 2) circular "runs"; and 3) flat-lying more or less tabular bodies of considerable areal extent (Weidman, 1932, and Brockie et al., 1968).

The elongated "run"-type ore bodies are the most important in the district. This type of ore body is found in all the important ore horizons with the exception of the "sheet ground" (primarily O bed). These "runs" follow curved fracture patterns adjacent to dolomitic core zones. "Runs" are commonly present on either side, and randomly extend up into overlying beds and over the top, of the dolomitic core. The "run"-type ore bodies range in size from 10 feet to as much as 500 feet in width. Infrequently the mineralization is sufficiently rich to permit the dolomitic core to be mined with the "runs". If this happens the "runs" range in size from 5 to over 100 feet in height and from a few hundred to several thousand feet in length. Hagni (1962, 1976) observed that the dolomite is more abundant in the center of the "run" while jasperoid is more prominent on the margins of the "run". Circular "runs" according to Smith and Siebenthal (1907) consist of circular deposits grading into country rock on the outside, with dolomite forming a ring inside the ore zone itself and as more or less completely filling the central mass or core of the circle.

Tabular ore bodies in the Grand Falls Chert (O bed horizon) are flat-lying, low-grade blanket deposits, and are thus known as "sheet ground". These deposits are of uniform thickness ranging from 12-15 feet and an areal extent of 40-200 acres.

Chert is very important in the formation of these ore deposits. The ore-rich horizons in the Warsaw and Keokuk Series consist of chert and limestone. The chert produces a brittle character to the beds which is expressed in widespread shattering in response to slight pre-ore structural stress. The limestone furnished a medium which is easily replaced by ore and gangue minerals. Thus, the shattering of the rock created an increase of permeability in the voids. The M and K beds have yielded some of the richest ore in the district this is probably due to the fact that both have massive chert beds under them, while the M bed lies between these two cherts.

C. CENTRAL MISSOURI DISTRICT

1. Stratigraphy. The Central Missouri District is located on the northern margin of the Ozark dome (Figure 5). Structurally this district is favorably located on what so happens to be a Precambrian high. The Precambrian rocks consist of granitic gneisses and mica schists of 1.7-1.6 b.y. old Churchill Province (E. Kisvarsanyi, 1979). The Pre-Roubidoux outcrop area is an expression of the Precambrian high (McCracken, 1971). Although no Precambrian rocks crop out here, their existence has been determined by drillhole and magnetic data (E. Kisvarsanyi, 1975, 1979, 1980).

The dominant mineralization in the Central Missouri District is barite, commonly accompanied by galena and sphalerite. The host rocks of these deposits consist of Paleozoic formations ranging in age from Late Cambrian through Pennsylvanian. The barite and lead-zinc deposits occur in the Gasconade, Roubidoux, and Jefferson City Formations in the Ordovician and Burlington Formation in the Mississippian (Figure 22). Although, all the formations in the Central District are mineralized, including the Pennsylvanian coal, the dominant host rock is the Jefferson City Dolomite.

The Gasconade Formation is predominantly a light brownish-gray, cherty dolomite. The Roubidoux Formation is a sandstone composed of fine- to medium-grained quartz sand which characteristically is subrounded and frosted. The Jefferson City Formation, which is the most widely mineralized, is composed principally of light brown to brown, medium to finely crystalline dolomite and argillaceous dolomite. "Cotton rock" which is characteristic of the formation is a finely crystalline, argillaceous dolomite. Locally present in the formation are lenses of orthoquartzite, conglomerate and shale. The Burlington Formation consists of white to light buff, very coarsely crystalline, fossiliferous, crinoidal limestone with layers of chert nodules especially common in the upper part.

The principal barite deposits occur in the counties of Cole, Moniteau, Morgan, and Miller. There are hundreds of barite and lead-zinc deposits in the Central Missouri District but they typically tend to be small and often high grade. The Washington County Barite District, in southeastern Missouri, is also accompanied

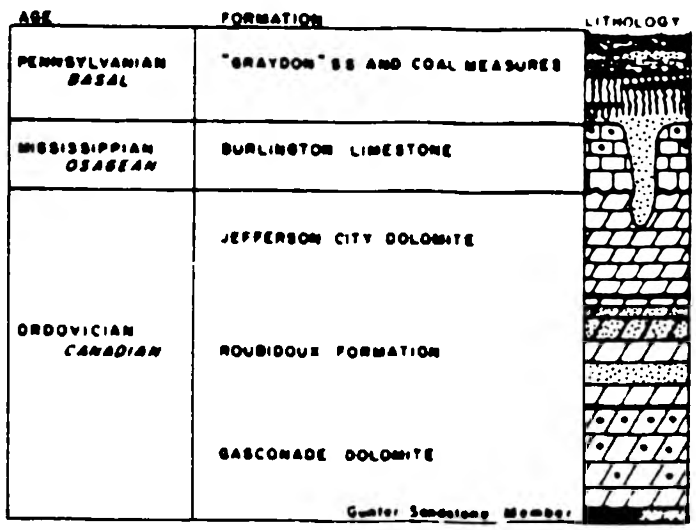


Figure 22. Principal host rocks of lead, zinc and barite deposits in the Central Missouri District (from Wharton, 1973).

by minor lead-zinc but the deposits are located in the upper Cambrian - the Potosi and the Eminence Dolomites. In the Southeast Missouri Lead-Zinc District, barite is totally absent in the Bonneterre Dolomite. The barite is also absent from the Keokuk Formation of the Tri-State Zinc-Lead District. This is puzzling since the Keokuk Limestone of the Tri-State and Burlington Limestone of the Central Missouri District, both host rocks, are almost identical in lithology and age (Mississippian).

2. Structure. The Paleozoic rocks of the Central Missouri District have a gentle dip to the northwest. There are not a lot of structural features in the Central Missouri District as there are in Southeast Missouri and the Tri-State Districts but what features are present trend northwest (Figure 23). The folds and flexures have a general northwest axes and in minor cases, vertical and steeply dipping faults parallel the folds. The main feature in this area is the Proctor anticline which strikes N25°- 30°W.

3. Ore Deposits. Barite and lead-zinc were found mainly localized in fissures, breccia zones, solution channels, and solution collapse structures known as circle deposits. The barite in the Central Missouri District was mined from small, high grade, relatively deep, isolated circle, replacement and residual deposits. Whereas, the barite deposits of Washington County were mined from widespread low grade, relatively shallow residual deposits (Mather, 1947).

Mather (1947) divided the lead-zinc and barite deposits into seven types: 1) fissure, 2) horizontal breccia, 3) circle,

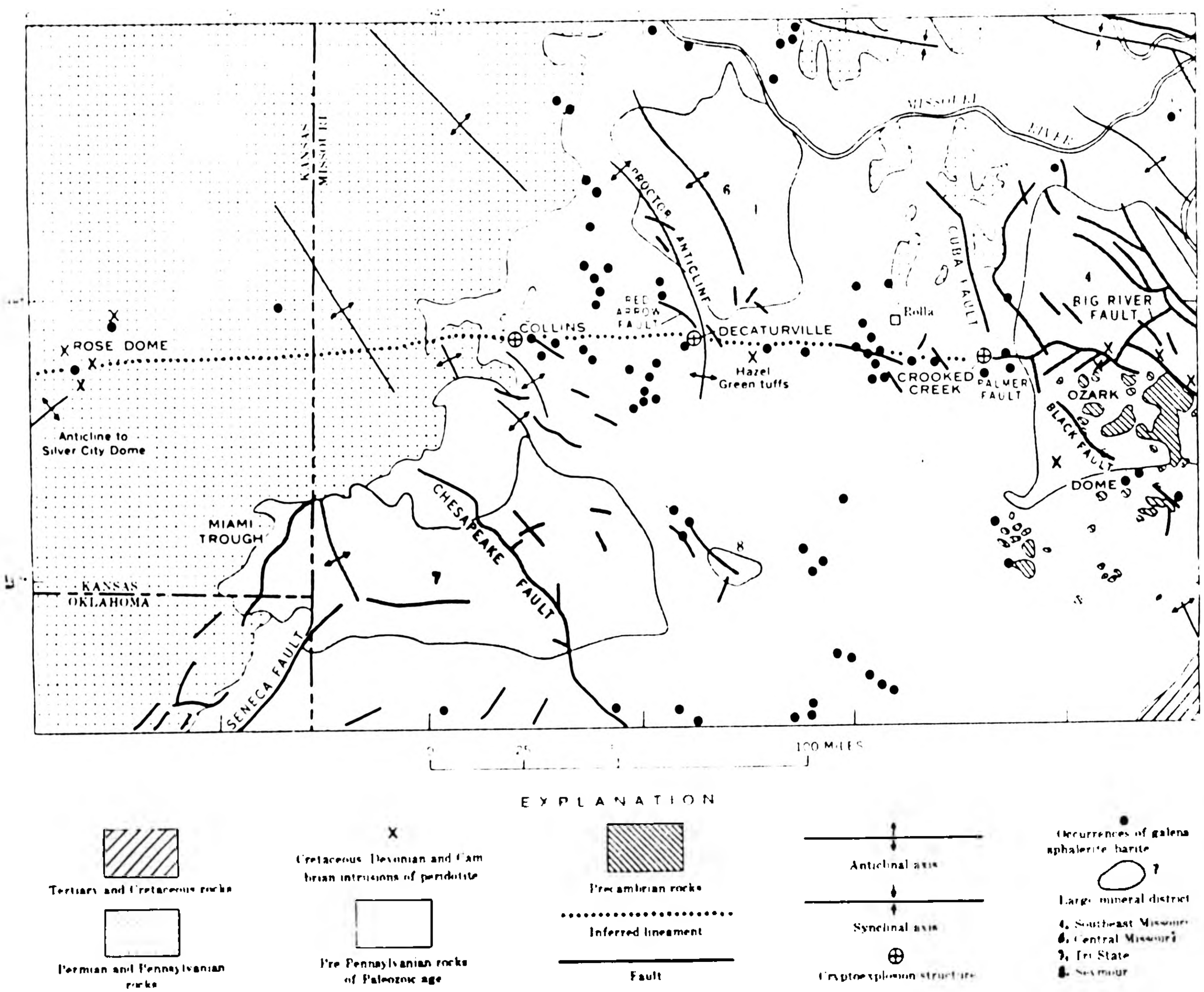


Figure 23. Fault zones, associated structural features, and mineral deposits covering the Southeast Missouri District, Central Missouri District, and the Tri-State District (from Heyl, 1972).

4) solution channel, 5) filled sink, 6) replacement, and 7) residual. Open space filling is characteristic of all the types but replacement and residual deposits. In addition, solution collapse breccias are usually involved in the replacement type deposits.

The fissure and breccia deposits are chiefly important as contributors to residual deposits, while the circle deposits have been very productive for barite and lead-zinc. The largest individual lead-zinc and zinc deposits, of the Central District, are in solution channels near Fortuna in Moniteau and Morgan Counties. These filled-sink type deposits are outliers of Pennsylvanian sandstones, shales, and coal that have been preserved in depressions. Sphalerite and smaller amounts of galena are found in joints, cracks, and rubble zones in the coal and accompanying shales with minor amounts of barite and lead-zinc deposits in the fractured sandstones (Wharton, 1973).

The circle type structure is developed in a karst environment. Due to solution activity, the roof and wall rocks collapsed forming a sinkhole. The peripheral rubble zone that is created, is the site of the richest mineralization. Mather's opinion of the circles was that they would, in time, become sink and filled structures while Bretz (1950) believed that the filled sinks predated the development of the circles.

D. NORTHERN AND NORTHEASTERN ARKANSAS DISTRICTS

1. Stratigraphy. The Northern Arkansas District lies on the southern flank of the Ozark dome. The ore deposits occur in Boone, Marion, Newton, Searcy, and Sharp Counties. While the Northeastern

Arkansas District lies off the southern flank of the Ozark dome to the southeast in Sharp and Lawrence Counties (Figures 5 and 8).

The formations in these districts include a nearly complete Lower Ordovician section overlain by Mississippian and Pennsylvanian units (Figure 24). During the pre-Mississippian erosional period, all of the Devonian and most of the Silurian Formations were removed.

In the Northeastern Arkansas District the ore is found in the Smithville Formation. It consists of a fine- to medium- grained cherty dolomite with interbedded sandstone and limestone. The Smithville Formation occurs approximately in the same stratigraphic position in the geologic column as the Everton Formation. But Ulrich (1911) believes that the Smithville is older. Thus, due to the presence of an unconformity below the Everton the Smithville is included in the Powell Dolomite. The Powell consists dominantly of a fine-grained gray argillaceous dolomite, locally referred to as "cottonrock".

In the Northern Arkansas District the Everton is the most important host rock. It has produced about 70 percent of the ore mined in the district while the remaining production came from the Boone Formation.

The Everton Formation obtained a maximum thickness of 400 feet but is eroded to a feather-edge on the margin of the Ozark dome. It consists of gray, usually fine-grained limestone, gray, fine- to coarse-grained dolomite, and thin lenticular sandstones. The chief ore hosts are the medium- to coarse-grained facies of the dolomite,

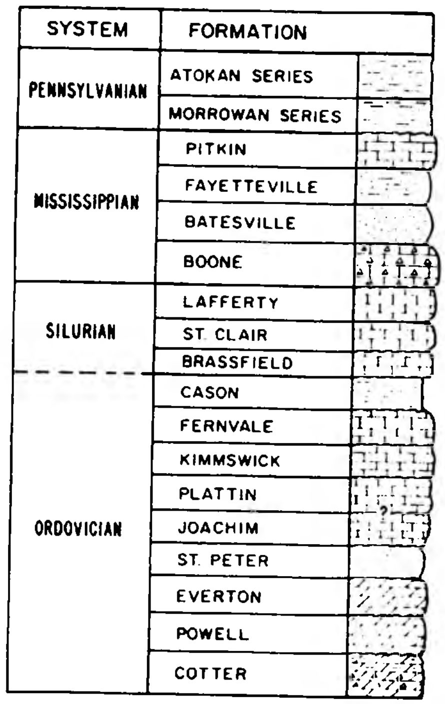


Figure 24. Generalized stratigraphic section for the Northern and Northeastern Arkansas Districts, (from Leach, Nelson, Williams, 1975).

while the fine-grained dolomites and the limestones are less often mineralized (McKnight, 1935).

The term Boone Formation includes the Warsaw, Keokuk, Reeds Spring, and St. Joe Formations. In northern and northeastern Arkansas the Mississippian section includes the thin, basal Sylamore Sandstone, the St. Joe Limestone, and the Keokuk Limestone. While most, if not all, of the Warsaw has been removed by erosion. There is no mineralization present in the Sylamore Sandstone. The St. Joe Limestone includes red and gray thin-bedded limestones containing abundant crinoid remains. From a number of prospects only one mine yielded an appreciable amount of ore. The Keokuk, which is the other principal host rock of the district, comprises of light gray, medium- to coarse-grained limestones with abundant chert.

2. Structure. The Paleozoic sediments of northern and northeastern Arkansas are horizontal but examined over wide areas they show a gentle regional dip to the south. This is more pronounced in the Ordovician beds than in the Carboniferous beds. Faults and gentle folds are quite extensive and classified into two systems, one striking northeast and the other northwest (Figure 6). Along the faults several hundred feet of displacement have been recognized.

Some normal faults with steep dips form narrow grabens with adjacent faults. Most of the faults are post-Pennsylvanian and probably are a part of a late Paleozoic deformation.

The major folds include the St. Joe syncline and the St. Joe and Water Creek monoclines (Figure 25). The axis of the St. Joe syncline trends southwest-northeast along the downthrown side of the St. Joe monocline and associated segments of the St. Joe and Tomahawk Faults. The St. Joe and Water Creek monoclines are parts of a single monoclinal flexure that trends northeast- southwest (McKnight, 1935).

The major faults are the Rush Creek, St. Joe, and Tomahawk faults (Figure 25). The Rush Creek strikes S65°E for a length of 7-8 miles. The St. Joe trends on an average of a few degrees south of east, but the easternmost 2 miles swings into the St. Joe monocline with a total length of the fault of 15 miles. The middle segment of the Tomahawk Fault swings into the general direction of the St. Joe - Water Creek monocline striking N63°E for 2 miles. While the two end segments strike across the direction of the monocline, in accordance with the regional fault trend of southeast-northwest (McKnight, 1935).

Down-faulted areas or grabens are another major structural feature of northern Arkansas (Figure 25). These are narrow down-dropped areas bounded by steeply dipping faults. Some of the main grabens include - Climax graben, Rush Creek graben, Tomahawk graben, and Mill Creek graben (McKnight, 1935).

3. Ore Deposits. The ore deposits of northern and north-eastern Arkansas occur in Paleozoic limestones and dolomites. The ore deposits occur in the Cotter, Powell, Smithville, and Everton Formations in the Ordovician and the Boone and Batesville Sandstone in the Mississippian. The Everton and Boone Formations are the most

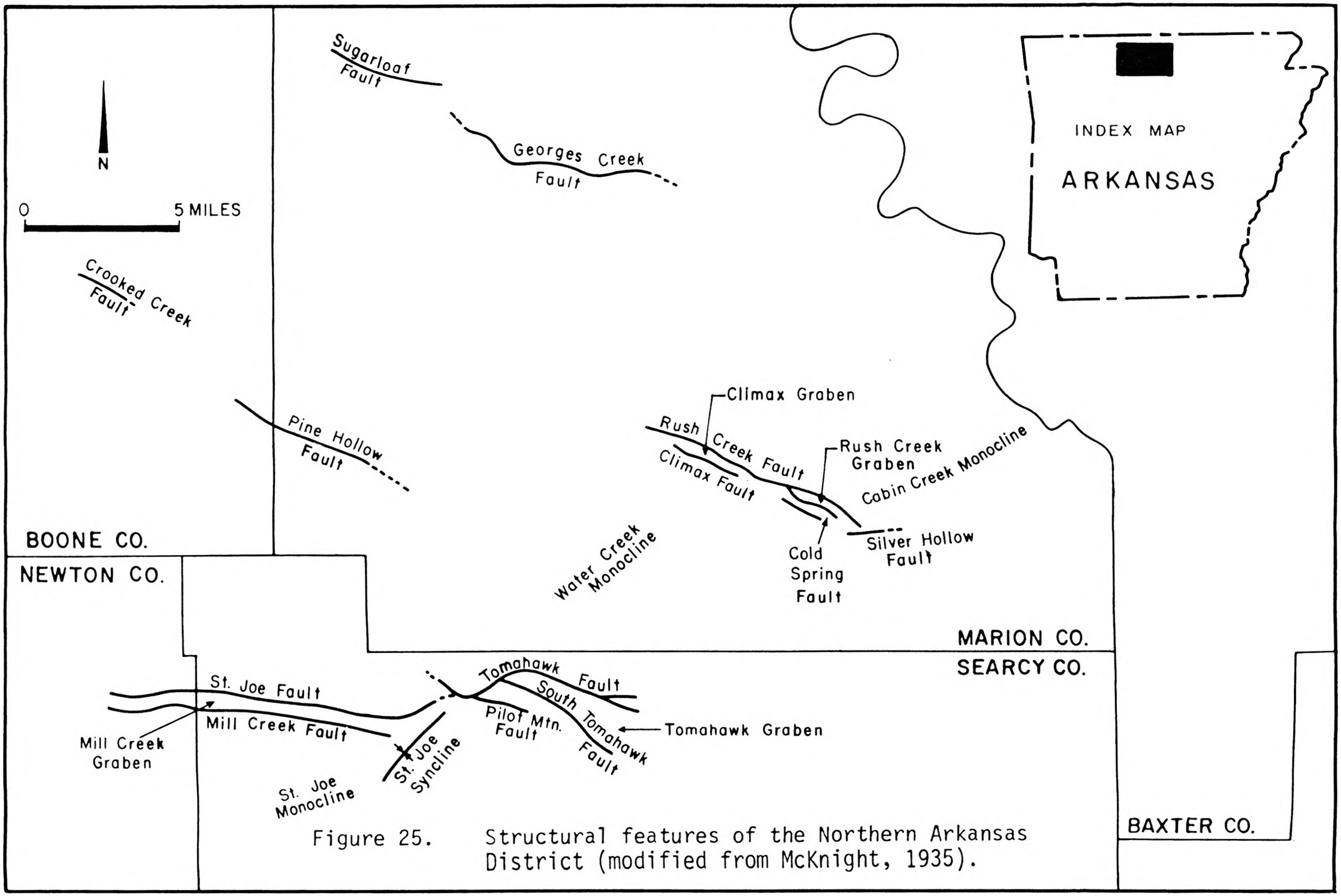


Figure 25. Structural features of the Northern Arkansas District (modified from McKnight, 1935).

favorable host rocks and contain all the mines of commercial value. The Smithville is the dominant host rock of northeastern Arkansas while the Everton and then the Boone are the dominant host rocks of northern Arkansas.

The northern and northeastern Arkansas ore deposits are believed to have a common origin. The mineralizing solutions consisted of a uniform character throughout the districts with local variations due to differences in character and textures of the country rock. The most important factors for the formation of the different types of ore deposits are the structural conditions at the sites of deposition.

McKnight (1935) classified the zinc-lead deposits of northern and northeastern Arkansas entirely on the structure of the deposit and the composition and texture of the country rock. The following divisions are standard types around which the deposits tend to cluster:

- Deposits in faults
- Deposits in runs and blanket veins
    - Deposits in fine-grained dolomites
    - Deposits in medium- and coarse-grained dolomites
    - Deposits in Everton limestones
    - Deposits in St. Joe limestone member
    - Deposits in Boone limestone and chert
    - Deposits in the basal clay of the Batesville sandstone

The deposits in faults are small in number but some are quite productive. They occur where the Boone limestone forms one or both walls.

The largest number of deposits are developed in runs and their associated blanket veins. The runs are confined to certain strata where the mineralization formed along fractures or zones of shattering produced by very slight structural deformation of the rocks. Runs are distinguished from blanket veins by being elongated and the more mineralized portion of the blanket vein. They are formed along the main channels of circulating ore solutions and in the vicinity of faults - where their development is especially favorable.

The Everton limestones carry ore only where they have been silicified early in the period of mineralization. The deposits in the Boone may occur in unaltered limestone. The ore has in part filled pre-existing open spaces and in part replaced the shattered rocks.

The primary ore minerals of northern and northeastern Arkansas are sphalerite and galena. The sphalerite is widely distributed over the region. While the galena is restricted to certain districts. Galena is absent from the sub-districts of southern Marion and Searcy Counties, where most of the zinc is produced. Other minor minerals are chalcopyrite and pyrite and trace amounts of enargite.

V. LINEAMENT INVESTIGATIONS

A. LINEAMENT TERMINOLOGY

Many definitions for lineaments and their associated terms have been proposed over the years. But the first to use the term, best illustrated, and is still highly regarded was Hobbs (1904). He used the term "lineament" to characterize the spatial relationships of landscape features that included:

> 1) crests of ridges or the boundaries of elevated areas, 2) the drainage lines, 3) coast lines, and 4) boundary lines of geologic formations of petrographic types, or of lines of outcrops.

In 1904, he also pointed out that lineaments generally have rectilinear patterns. In 1912, Hobbs expanded the term lineament to include ravines or valleys and visible lines of fracture or zones of fault breccia. Hobbs concluded that any number of these features could be joined end to end to form a lineament. O'Leary et al., (1976) summed up Hobbs' definition of lineaments, stating they:

> 1) have geomorphic expression (in general, topographically negative), 2) are composite (either segmented or complex), 3) characterized by alignment in a single direction (which may or may not conform to regional trend), 4) are straight or slightly curved, 5) are regional in extent, and 6) are scale related.

O'Leary et al., (1976) concluded that Hobbs and others generally agree

> "that lineaments are essentially geomorphic features and that they are commonly or probably related to structural discontinuities (chiefly faults, shear zones, and joints) - an association emphasized but not caused by erosion."

B. DESCRIPTION OF MAJOR LINEAMENTS

Many lineament studies have been conducted in the Ozark dome area and especially in the St. Francois Mountains of southeast Missouri (El-Etr, 1967; Kirk and Walters, 1968; McCracken, 1971; G. Kisvarsanyi and E. Kisvarsanyi, 1974, 1976; G. Kisvarsanyi and J. Martin, 1977; and Toweh, 1978). Just as has previously been mentioned under structural features, the two dominant lineament directions are northwest and northeast followed by north-south and east-west. These lineaments are strongly related to structural features in the area and some coincide with the structural feature and are named after it. The following, are brief descriptions of the major (named) lineaments of the Ozark dome area.

The major northwest lineaments include: Grand River Lineament, northern segment, strike N44°W, 280 km long, and southern segment, strike N40°W, 270 km long; Bolivar-Mansfield Lineament, strike N56°W, 325 km long; Ten O'Clock Run-Chesapeake Lineament, strike N40°W, 270 km long; and Ellington fault Lineament, northern segment, strike N40°W, 65 km long, and southern segment, strike N45°W, 55 km long (Kisvarsanyi and Martin, 1977).

The major northeast lineaments include: Annapolis Lineament, strike N49°E, 225 km long; North Belleview Lineament, strike N50°E, 85 km long; Boss-Potosi Lineament, strike N47°E, 275 km long; Mansfield Lineament, strike N46°E, 85 km long; Lebanon Lineament, strike N56°E, 460 km long; Osage Lineament, strike N62°E, 340 km long; Seneca Lineament, strike N46°E, 109 km long; and Miami Lineament, strike N24°E, 71 km long (Kisvarsanyi and Martin, 1977, Toweh, 1978).

The major north-south lineament is the Roselle Lineament which strikes N7° E and is 170 km long. The major east-west lineaments include the 38th Parallel Lineament - Palmer-Ste. Genevieve fault system Lineament - Rueff Lineament which strikes east-west with the northern trace 200 km long and the southern trace 150 km long (Kisvarsanyi and Martin, 1977).

C. LINEAMENT DETECTION BY COMPUTER RATIO ENHANCEMENT

The writer was involved in a lineament study in the St. Francois Mountains near Fredericktown in southeast Missouri. The purpose of the study was to use LANDSAT imagery in an attempt to identify linear features in a humid and densely forested area.

The main procedure that digital image processing utilized was image enhancement. Image enhancement was performed to make spatial patterns displayed by tones and colors more apparent on the imagery. The best results were obtained from the ratio enhancement technique. This technique was accomplished by taking a ratio of the pixel reflectance values of two LANDSAT bands and by dividing the brightness value in one band by the brightness value in another band. The best enhancement was from the ratio 2/4 enhanced over 2, which produced good topography and linear features. A graphical overlay was used to plot the lineaments obtained from the enhancement processes.

To verify the accuracy of the lineaments with topographic maps the scene was GEOREFed. The UTM (Universal Transmercator) coordinates were obtained and the lineaments were plotted using a one kilometer unit-grid cell. At this point, topographic maps were studied to verify the lineament results with ground evidence. The largest percentage of lineaments were found along ridges/streams, while others were due to changes in vegetation or produced for no apparent reason. Northeast was the dominant lineament trend direction, followed by north, west, and northwest.

Thus, this study enhanced existing and possible linear features, enhanced stream/drainage patterns for further structural determinations and topography. As expected, this study enhanced some linear features but it also confirmed the northeast, northwest, north-south, and east-west structural patterns of Missouri by computer methods. Faults were not detected purely by reflectance values. The dense forest, various plants, and simply the humid climate caused many different things to be represented by the same spectral colors. Therefore, a purely computer program will not pick up all the faults and linear features but must be used as a tool along with other laboratory and field techniques.

D. OTHER LINEAMENT STUDIES

Scientists at Washington University in St. Louis, Missouri, utilize remote sensing, gravity, magnetic field, and topographic data for the Midcontinent to try to define the pattern, age, and origin of structural features in Missouri. It has been found that faults, fold axes, dikes, and basement topography in Missouri parallel the northwest-southeast trending Missouri gravity low. The Missouri gravity low is probably a basement feature. Seismic activity seems to be concentrated at the intersection of the

Missouri gravity low and the Reelfoot rift zone-Mississippi embayment. This area is known as the New Madrid seismic zone named after the 1812 New Madrid earthquake. Two dominant trend directions northeast and northwest seem to be related to the intersection of the Missouri gravity low and the Reelfoot rift zone. Hildenbrand *et al.*, (1977) believe that the northeast trend outlines the presently active section of faults within the Reelfoot rift zone. While the Missouri gravity low is bounded by parallel northwest trending features. This intersection seems to be a zone of weakness producing northeast and northwest trending features that are fault and basement related. Thus, this study corroborates the northeast and northwest structural pattern across Missouri.

VI. LEAD-ZINC METALLOTECTS OF THE OZARK DOME

A classification system emerged from a detailed and careful examination of the ore distribution patterns, structures, and lineaments of the Ozark dome. The metallotect elements are classified into first, second, third, and fourth order relationships. The first and second order relationships are three dimensional metallotects. While the third and fourth order relationships are one (or two) dimensional metallotects. A linear feature such as a fault trace is one dimensional but two dimensional in vertical extent. Since the ore deposits of the Ozark dome are stratigraphically limited and relatively shallow, the third and fourth order relationships in this study will be considered as one dimensional metallotects.

1). The first order relationship is between the Ozark dome, that is the dome itself, and the regional distribution and setting of all its deposits;

2). the second order relationship is between the major mineral districts and the secondary Precambrian structural highs within the dome;

3). the third order relationship is between faults and fractures, lineaments, and mineral deposits on a district to subdistrict scale;

4). the fourth order relationship is between single ore bodies, small mineral deposits or mines and any structural feature.

Although this classification system was divided only into four orders in this study, further orders may be established by subsequent researchers or mine geologists. It was observed that a wide spectrum of spatial or geometric relationships exist, but following further studies a genetic link also appears to exist between the metallotect elements.

A. FIRST ORDER

In the study of the metallotects of the lead-zinc deposits of the Ozark dome we will first analyze the first order relationship of the Ozark dome. The Ozark dome is unique in the world because within its boundary lies the richest Mississippi Valley-type metallogenic province on a structurally high platform, while the surrounding deep sedimentary basins are relatively barren of mineralization.

One might draw an analogy of the Ozark dome to the major anticlines of giant petroleum fields so that the anticlinal theory can be applied. Basically the Ozark dome can be considered as a huge "anticline" or "oil trap" for the extremely mobile brines of the basins. In the anticlinal theory oil and gas accumulates at the crests and/or flanks of anticlines. The Ozark dome just being a regional "anticline" or structural high in itself was the target of hydrodynamic flow of basin generated fluids which accumulated and trapped a vast amount of mineral deposits in structures and favorable lithostratigraphic units. This includes two of the world's largest lead-zinc districts - the Southeast Missouri District and the Tri-State District of Missouri, Oklahoma and Kansas.

The genesis of these ore deposits seems to be related to brines rich in Na-Cl and lead-zinc (Heyl, 1974, Carpenter, 1974). The metal-bearing brines were "pumped" out of the porous clays, shales, carbonates, and other sediments in the surrounding basins (and possibly the Ouachita section of the Appalachian geosyncline) by compressional forces and moved in the direction of lower fluid pressure toward the Ozark dome. These metal-bearing brines probably were akin to petroleum and gas generated brines that were subsequently trapped in the surrounding basins. These solutions were expelled by compressional forces of increasing lithostatic pressure and moved via the permeable paths that afforded the least resistance to flow. The Lamotte Sandstone, in the case of southeast Missouri, or any other basal formation having a high porosity and permeability made a good aquifer. The brines probably made their escape along the more permeable channelways to lower pressure and fluid potential. In the escape of the brines toward areas of lesser pressure or the surface, the brines flowed in sandstones or other aquifers toward pinchouts and/or zones of structural weakness such as faults (third order). Faults and fractures increased the fluid flow, are paths of solution, and hosts of precipitating metals. Thus, the hydrodynamic drive of the metal-bearing brines toward the structurally high Ozark dome greatly influenced the structural and stratigraphic environment of the loci, precipitation, and accumulation of rich sulfides and other mineral deposits (Figures 3 and 4).

B. SECOND ORDER

The second order relationship of the metallotects of the Ozark dome is between the major mineral districts and the secondary Precambrian structural highs underlying them within the dome (Figures 3 and 5). Three of the four mineral districts are located on structural highs, they include - Southeast Missouri District, Central Missouri District, and the Tri-State District. The Northern Arkansas District lies on the margin of the Ozark dome and the Northeastern Arkansas District lies off the margin of the Ozark dome (Figures 3 and 5). Figure 26 indicates a belt of intermittent Precambrian volcanics. This belt is made up of outcrops and subcrops forming what is known as the "Ancestral Ozarks". Note they include areas in southeast Missouri, northeast Oklahoma-southeast Kansas, and northwest Arkansas. Also recent drilling data indicates the presence of Precambrian highs under the thick Paleozoic section of northern Arkansas. Thus, the earlier boundary of the Ozark dome probably included northeastern Arkansas but today due to the Reelfoot rift zone and its associated faults, the Northeastern Arkansas District is not included within the boundary of the Ozark dome.

Again we could think in petroleum terminology as these Precambrian structural highs as being individual "anticlines", "oil traps", or in this case ore entrapment structures. The metal-bearing brines moved in the direction of lower fluid potential and pressure toward the structurally secondary but still "higher" positions within the Ozark dome.

The Southeast Missouri District is located on a Precambrian structural high (Figures 3 and 5) which directly controlled the development of one of the world's largest lead-zinc districts. Due to the St. Francois Mountains being the only outcrop of Precambrian rocks in the Midcontinent (and for that part the Ozark dome), the Precambrian structural high is even more pronounced in southeast

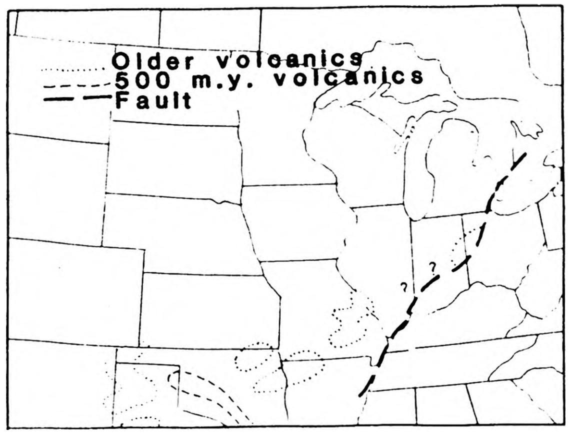


Figure 26. Ancestral Ozarks (from Snyder, 1968a). Belt of preserved volcanic rocks (Ancestral Ozarks). Generalized after Ham, Denison, and Merritt, 1964; Muehlberger, *et al.*, 1966; Lidiak *et al.*, unpublished drillhole data.

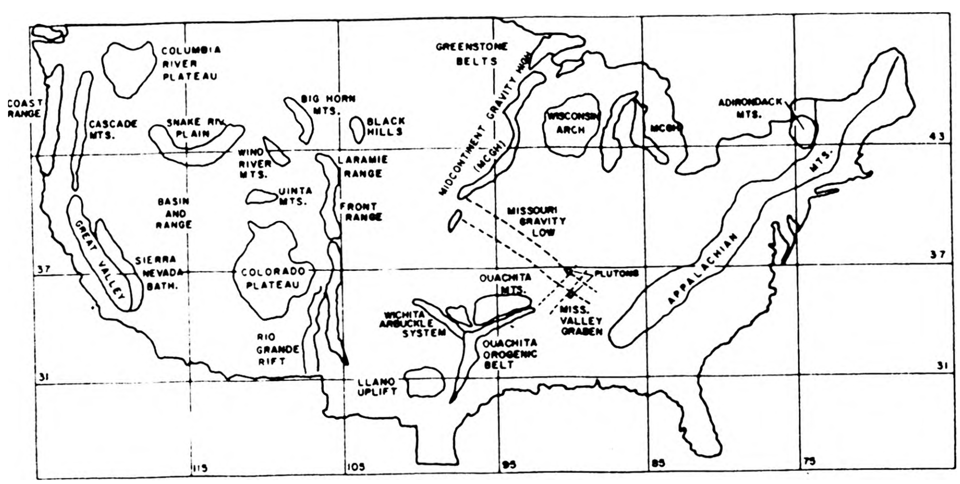


Figure 27. Sketch map showing the location of the Missouri gravity low, Mississippi Valley Graben, and various other major structures seen from gravity anomaly maps (from Arvidson, Guinness, *et al.*, 1982). The Mississippi Valley Graben location is from Kane *et al.*, 1981).

Missouri. The metal-bearing brines migrated to the hydrodynamically lower pressure environment of the structurally high Southeast Missouri District.

Due to large confining pressures in the surrounding deep sedimentary basins, the metal-bearing brines needed an escape route and the Lamotte Sandstone of southeast Missouri probably provided this. Faults, a third order metallotects, made the Lamotte Sandstone an even better aquifer and directed the metal-bearing brines to the Bonneterre Formation. The Precambrian high of the Southeast Missouri District also had a profound influence on the development of favorable neritic-shore lithofacies in the Bonneterre Formation. While the brines travelled through channelways, faults, etc., they mixed with connate, descending, and displaced waters. The mixing process cooled the brines, reduced the fluid pressure, and developed a hydrodynamic gradient toward structurally involved areas. In southeast Missouri the brines remained in the Bonneterre due to an impermeable barrier - the Davis Shale. The fluid potential was not great enough to force the brines through the Davis Shale. Thus, the Davis Shale became an effective sealing trap (like an oil trap). Organic material and H_2S gas in the carbonate sediments developed a suitable environment for the precipitation of the metals from the metal-bearing brines in the form of sulfides. Although the precipitating mechanism was not directly related to the metallotects it does serve an indirect role in the formation of ore deposits whereas third order structures such as faults serve a direct role in channelling the metal-bearing brines to favorable host rock environments.

The Central Missouri District, like the Southeast Missouri District, is located on a Precambrian structural high (Figures 3 and 5). This district is unique in that it has a circular-shaped appearance (Figure 5). This circular-shape has probably been the result of the structural influence of the Precambrian high. Although there are no Precambrian outcrops at the surface, existence of the Precambrian structure with a very shallow apex has been determined by drillhole data (Figure 3). The local doming of the Precambrian can be seen from Precambrian structure contour lines (Figure 3) and in the deposition of the Paleozoic sediments that indicates a circular structure (Figure 5). The ore deposits are almost totally concentrated over this circular structural high (Figure 5). Again this local structural high or "anticline" became an ore entrapment structure. In being a "high" it attracted the metal-bearing brines via porous and permeable channelways to escape high pressures to this lower pressure environment. The Mississippian and Ordovician sediments became suitable hosts for the precipitation of sulfides from the metal-bearing brines.

The Tri-State District is also located on a Precambrian structural high (Figures 3 and 5) but it is more subtle than that underlying the Southeast Missouri District or the Central Missouri District. Like the Central Missouri District the Tri-State District has no Precambrian outcrops but the structure has been determined by drillhole data. The indirect influence of the Precambrian structural high (Figure 3) produced a similar hydrodynamic pattern (as has previously been discussed) of the metal-bearing brines flowing toward this area of lower pressure. The metal-bearing brines moved in channelways through porous and permeable layers toward the structural high. Then the metal-bearing brines moved to zones of structural weakness, classified in this study as third order metallotects. These structurally weak zones were due to a very extensive fault and fracture network. Faults and fractures reduced the pressures even more and caused the brines to move through these structures and possibly a window created in the Chattanooga Shale to a stratigraphically favorable environment in the Mississippian sediments. A Pennsylvanian shale effectively trapped the brines in the Mississippian sediments. Dolomitization and brecciation increased the porosity in these sediments which became excellent places for the precipitation of sulfides from the metal-bearing brines.

As previously discussed in this section, the Northern Arkansas District lies on a subtle Precambrian structural high (Figures 3 and 5) that has been concealed by a thick accumulation of Paleozoic rocks. As in the other districts, the metal-bearing brines migrated to this structurally "higher" environment of lower hydrodynamic pressures. Faults, a feature of third order metallotects, further created a release in pressure. Like in the Tri-State District the Mississippian (and also in this case the Ordovician) sediments created a favorable environment for the precipitation of sulfides from the metal-bearing brines. Also dolomitization, silicification, and brecciation further increased the porosity of the sediments.

Thus, there seems to be a strong correlation with mineralization and the secondary Precambrian highs of the Ozark dome. Basically the ore deposits are concentrated over the secondary the Precambrian highs with minor deposits scattered away from the highs (Figures 3, 4 and 5).

C. THIRD ORDER

The third order relationship is between faults and fractures, lineaments, and mineral deposits on a district to subdistrict scale. Many of the structural features, such as faults, originated by movements of Precambrian blocks and what one views today are their expressions through the Paleozoic sediments. No doubt there are a greater number of faults present in the Precambrian than what was mapped on the Paleozoic, some faults probably continued to have intermittent activity throughout the Paleozoic. Thus, these are the dominant faults which have developed a co-genetic pattern of Precambrian and Paleozoic faults. Some of the smaller faults may have however originated in the Paleozoic sedimentary cover. As previously discussed the dominant structural pattern developed on the Ozark dome are NW and NE trending structures followed by N-S and E-W trending structures (Figure 6). The northwest trending structures are best expressed by the Ste. Genevieve fault system, Ellington fault, and other northwest trending fault zones some of which have been mapped underground and on the surface. The Missouri gravity low (Figure 27) is an important manifestation of deep seated northwest trending structures (Arvidson, et al., 1982, Guinness, et. al., 1982, 1983). While the northeast trending structures may have developed by the same stress field which created the northwest trending structures. Long and persistent tectonic activity concentrated along the Reelfoot rift - New Madrid fault zone is of similar trend (Figure 10). The Reelfoot rift developed as a result of the stress field changing from compressional to tensional and possibly due to the break up of continental plates. These tensional forces developed along pre-existing zones of weakness, in the case of the Reelfoot rift - the northeast direction. Hence, the Reelfoot rift is a down-dropped block or graben that developed as a result of tensional forces. Thus, these compressional and tensional stresses played a major role in the development of the Ozark dome. The ore solutions probably moved via some of these northwest and northeast trending structures from the surrounding deep basins (Anadarko, Arkansas, Arkoma, Cherokee, Forest City and Illinois) (Figure 28) and maybe even some of the metal-bearing brines traveled from the Reelfoot rift zone and the Ouachita section of the Appalachian geosyncline where large amounts of sediments accumulated.

The Ozark dome is an area of intense faulting and fracturing fundamentally related to downwarps and periodic uplifts. These structural disturbances probably played a major role as escape routes for the metal-bearing brines to favorable stratigraphic units. The metal-bearing brines, along with other minerals and gases, moved through channelways created by these structural disturbances to areas of less pressure. When the area was relatively favorable, precipitation of lead-zinc ores occurred in large quantities partly due to chemical as well as structural reasons. These faults and fractures are basically pre-ore though they may have also occurred in the early stages of mineralization. Ground

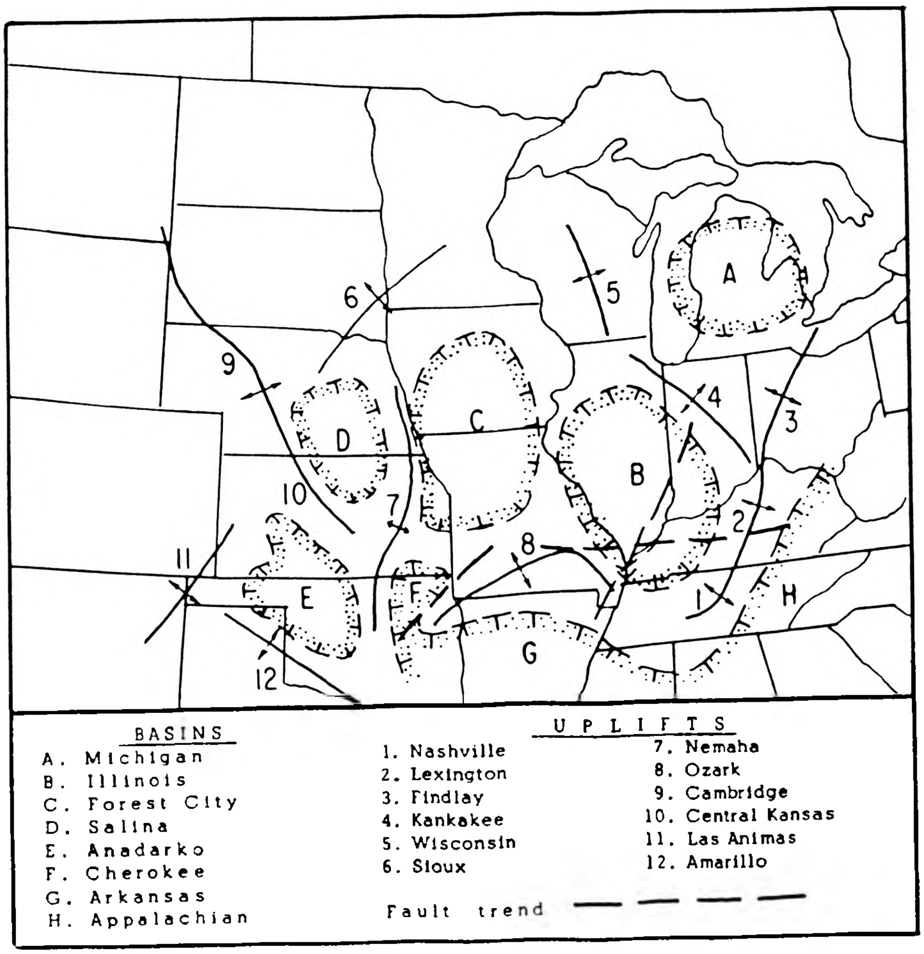


Figure 28. Major structural features of the Midcontinent (from Snyder, 1968a).

preparation through brecciation and silicification (Tri-State and northern Arkansas) created superimposed permeability that thus produced an even more favorable environment for the precipitation of lead-zinc ores. Thus, these structural disturbances played a major role in producing the large metallogenic province within the Ozark dome.

While the structural influence can be observed in every district it is substantially evident in the Tri-State area. The ore deposits of the Tri-State District are namely fault controlled (Figures 5 and 18). The dominant structural directions being northeast and northwest. This was also constantly observed by mine geologists and from the shape and distribution of underground mine workings. Good examples are the Picher field (Figure 29) and the Oronogo-Webb City-Duenwey field (Figure 30). The metal-bearing brines were directed by the influence of primary flow to a favorable site of precipitation - that being the Tri-State region. Northeast and northwest controlling structures such as fault zones (particularly the Miami and Bendelari troughs) further directed the primary flow (Figure 19). While the secondary flow moved along smaller fractures and joints with further dispersion of the ore-bearing brines into porous layers thus masking the primary structure (Figure 29). Figures 29 and 30 show highly concentrated and controlled ore bodies developed in the Tri-State District especially in the Picher field. Faults also controlled the development of the ore deposits in northern Arkansas (Figures 5 and 6). The Northern Arkansas District has essentially the same characteristics as the Tri-State District. These characteristics include the geographic proximity, age of mineralization, host rocks,

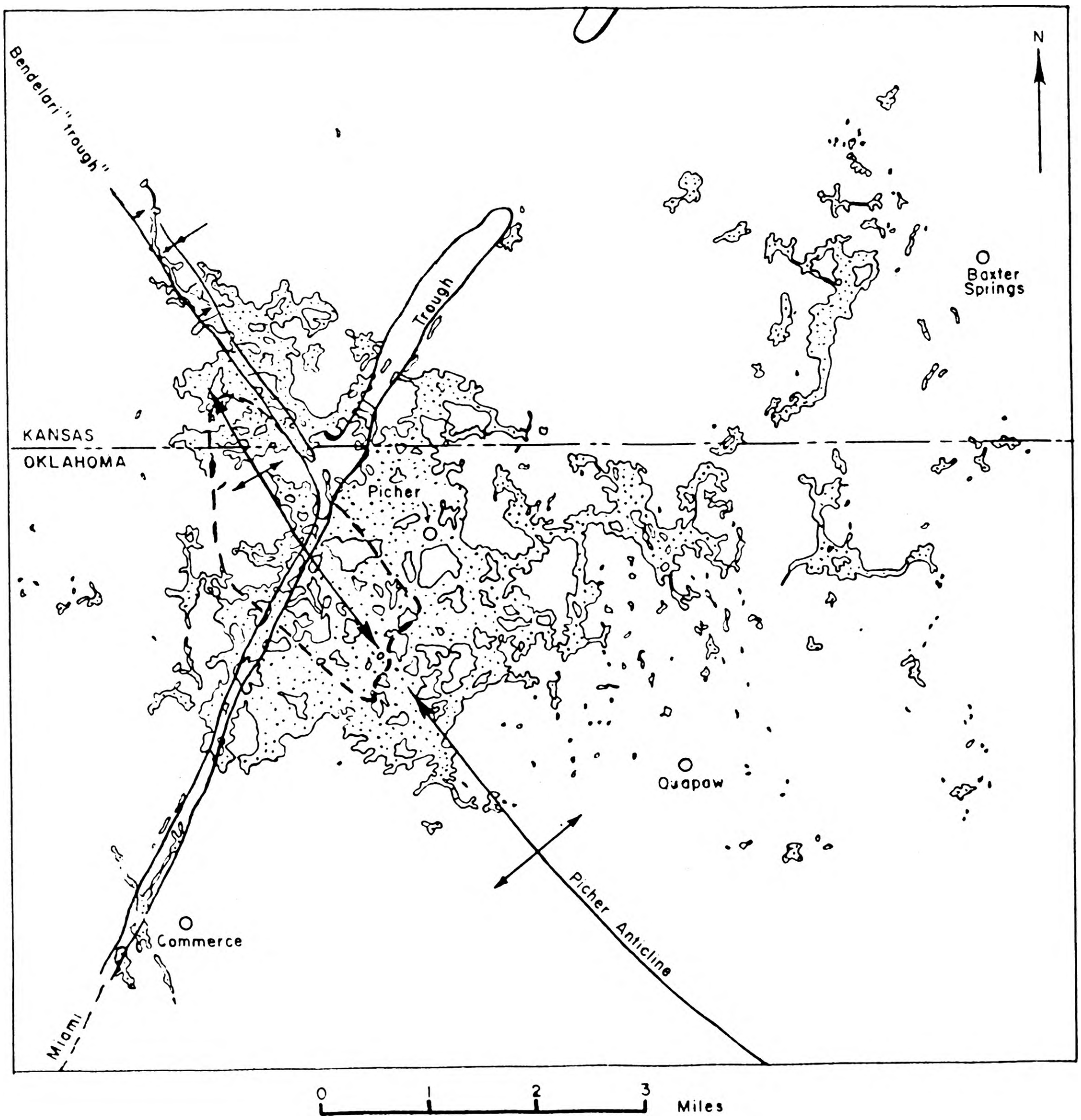


Figure 29. Map of the Picher Field, showing underground mine workings and axes and outlines of the principal structural features. A large broad dome is shown by the dashed lines (from Brockie, et al., 1968).

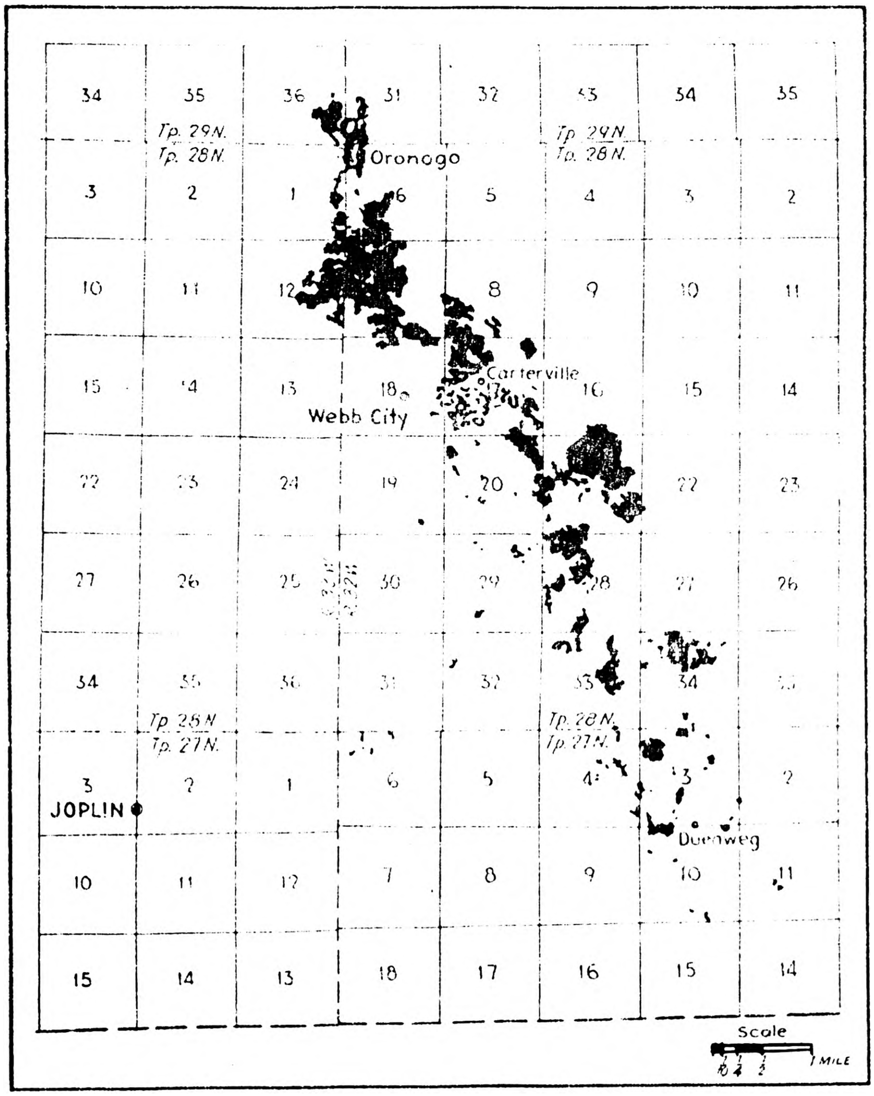


Figure 30. Underground workings of the Oronogo-Webb City-Duenweg mining field, in Southwest Missouri in the Tri-State District (from Fowler, 1938).

similar salinity and temperature of ore fluids (Leach, et al., 1975), etc. Thus, they could be classified as one enormous district encompassing the Tri-State and Northern Arkansas Districts (Figure 5).

Faults apparently did not play such a direct role in the ore distribution and development of the ore deposits of the Central Missouri District. There solution activity and brecciation predominated, while fractures were induced by slumpage features. But still the primary structure of the district may have strongly been influenced by large faults in the area (Figures 5 and 6).

Structure had a controlling influence on the emplacement of ore deposits in the Southeast Missouri District. By superimposing the mineral occurrence map (Figure 4) on the structural features map (Figure 6) it is becoming obvious that the ore concentration is related to the intensity of faulting on the east, west, and north sides of the Precambrian high. The lack of major faults possibly combined with the wrong lithology might explain the fact that ore deposits are missing on the south side of the Precambrian high where there are no known faults. This fact puzzled exploration geologists for a long time. They drilled many holes on the south side but found no new ore deposits. Therefore, the lack of faults explains the lack of ore deposits. And thus, the lack of faults (especially N-W and N-S trending) means the lack of channelways to lead the brines to favorable sites of precipitation.

Basically three primary structural environments have been recognized by James (1952) as well as many others, for the emplacement of ore deposits in southeast Missouri. One such environment is the fault zone environment which consists of individual faults. The tectonic style of southeast Missouri as a result of faults (fractures, etc.) in the Precambrian and Paleozoic rocks, directed the metal-bearing brines toward a favorable environment in the Bonneterre Formation (Dolomite). The faults and fractures reduced pressures and caused the brines to flow up them. A particularly strong fault influence can be identified in the Old Lead Belt (Figures 4 and 6). This is a dominant structural environment in the Tri-State and Northern Arkansas Districts as well. The second environment pertains to local fractures in the sediments adjacent and surrounding the Precambrian erosional knobs (Figure 31). The metal-bearing brines flowed in the porous and permeable Lamotte Sandstone toward the pinchouts next to the Precambrian highs. The hot (100 °C+) brines reacted not only with the sediments but with the Precambrian rocks as well and leached them of available metals. Fractures, faults, and breccia zones (fourth order metallotects) in the Bonneterre (above the Lamotte Sandstone) provided escape paths to lower pressures. Although the reef complex of the Bonneterre Formation is the host of several large lead-zinc deposits, the richest ores developed around the Precambrian highs and related fracture or breccia zones. The third environment consists of the structural block as seen in the St. Francois Mountains and Old Lead Belt of the Southeast Missouri District (Figure 15). These blocks are produced by tangential faults bounding the granitic ring complexes. Examples include the Belleview and Sabula blocks which are down-dropped blocks (grabens) and the Eminence block which is an uplifted block

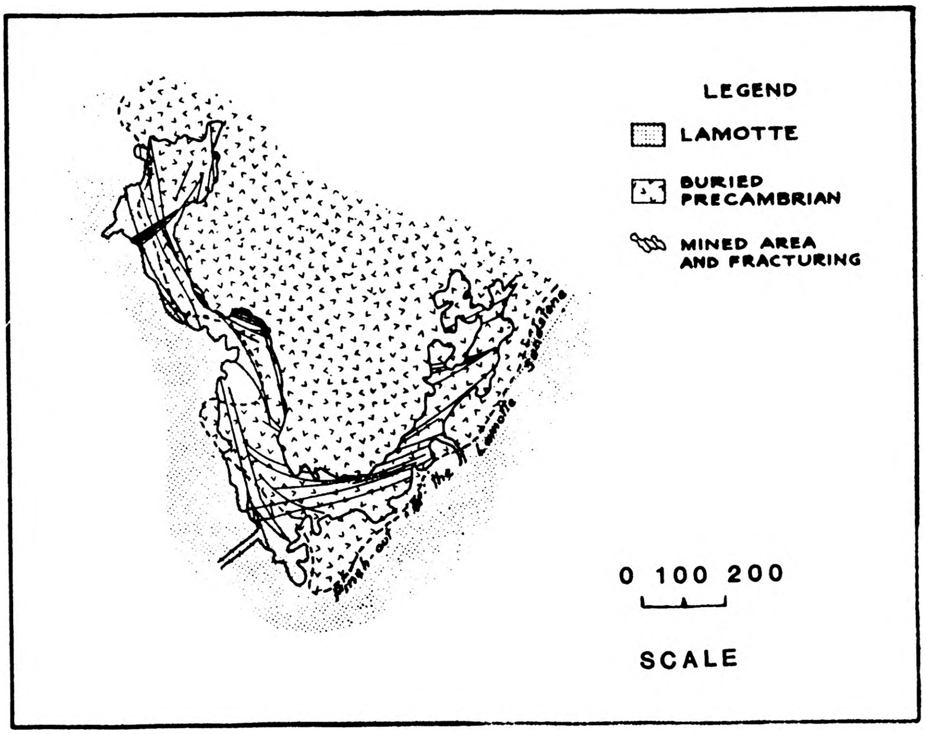


Figure 31. Local fracture pattern in mine on flank of Precambrian knob in the Old Lead Belt (from James, 1952).

(horst) (Figures 11 and 12). While most of the lead mines of the Old Lead Belt occur on a structural block, the ore deposits are also localized by Lamotte Sandstone pinchouts, faults, and breccia zones (fourth order metallotects).

In general there seems to be a basic similarity in the orientation of the lineaments and the structural features of the Ozark dome (Figures 6 and 7). Both consist of diagonal and orthogonal NW, NE, N-S, and E-W trending structures. Thus, lineaments identified from LANDSAT images showed the regional structure that controlled the formation of the ore deposits of the Ozark dome (Figures 4 and 7).

The relationship between lineaments and mapped faults and anticlines will be discussed next as an introduction to "lineament metallotects". There are numerous examples where mapped faults coincide with lineaments (Figures 6 and 7). Where this happens the lineaments probably represent fault traces that are reflected in the Precambrian basement upward into the Paleozoic rocks. In cases where lineaments are identified in known mineralized areas but no fault (or faults) have been mapped, this might be an indication that a fault(s) exists that channelled mineralization to that location. Thus, further surface mapping should be performed to identify and map the fault(s). But many lineaments are not known to be associated with mapped faults or anticlines, this can be determined by careful ground investigation. Thus, these lineaments may be a reflection of topography, drainage, vegetation, and tonal changes in the soil due to water, organics, etc. Therefore, lineament studies should be used as a reconnaissance tool to be followed up with a detailed surface mapping program.

There are numerous examples where lineaments and mapped faults and anticlines correspond. They can be particularly seen in the Tri-State District, northwestern Arkansas, and also in southeast Missouri (Figures 4, 5, 6, and 7). In the Tri-State District a lineament corresponds to the Seneca graben which is definitely a basement structure (Figures 3, 6, and 7). In northwestern Arkansas there are three northeast trending fault systems that correspond to lineaments (Figures 6 and 7). Numerous other examples can be seen throughout the study area.

Where lineaments coincide with mineral deposits, this is referred to as "lineament metallotects". Previous lineament studies have shown that mineral belts tend to occur along linear trends. Also mining districts are commonly localized by intersecting fault and fracture systems, for example in the Tri-State District - the Miami and Bendelari troughs (Figures 19 and 29). This can also be observed at lineament intersections where deposits are often located. Large scale "lineament metallotects" can be classified into the following categories with examples to follow:

1). mining fields or large groups of mineral deposits along a single major lineament;

2). mining fields or large groups of mineral deposits located at the interesection of two (or more) major lineaments.

The first category can be observed where a N-S lineament "runs" through the Viburnum Trend of southeast Missouri (Figure 32). The second category is much more common. The Northern Arkansas District is localized by lineament intersections (Figure 33). Another excellent

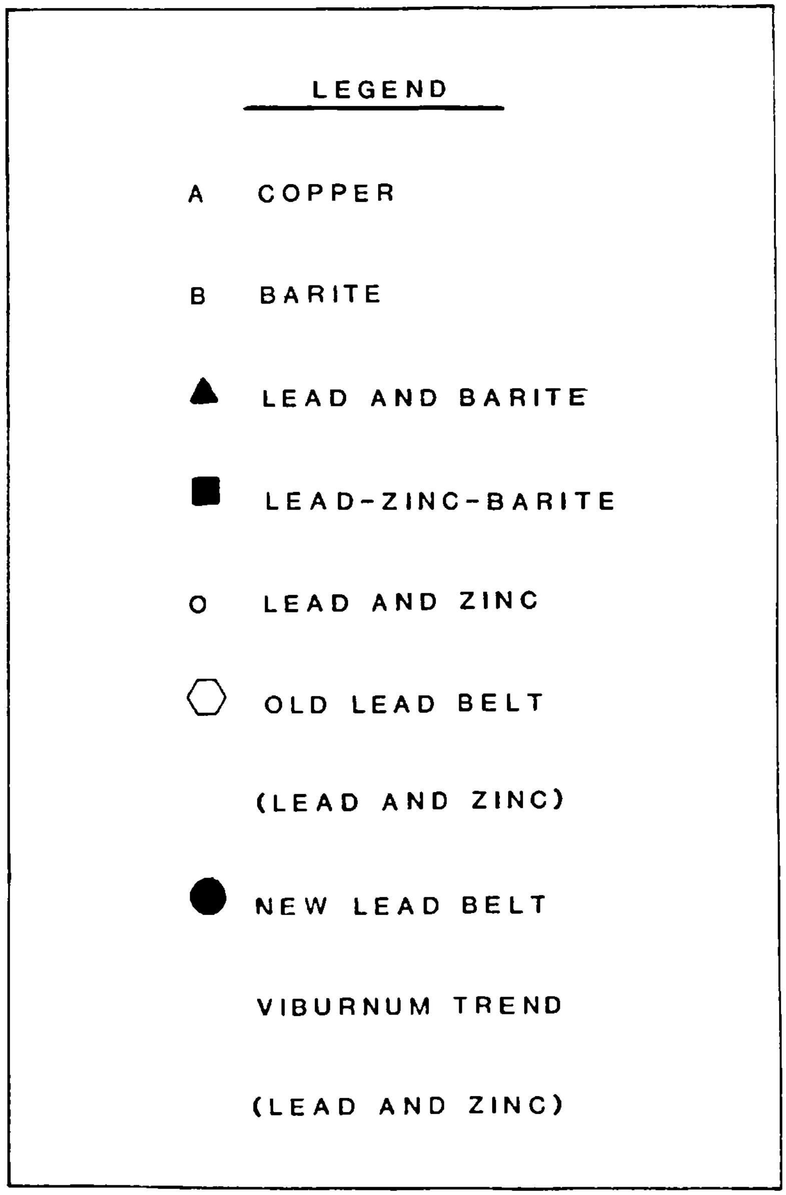
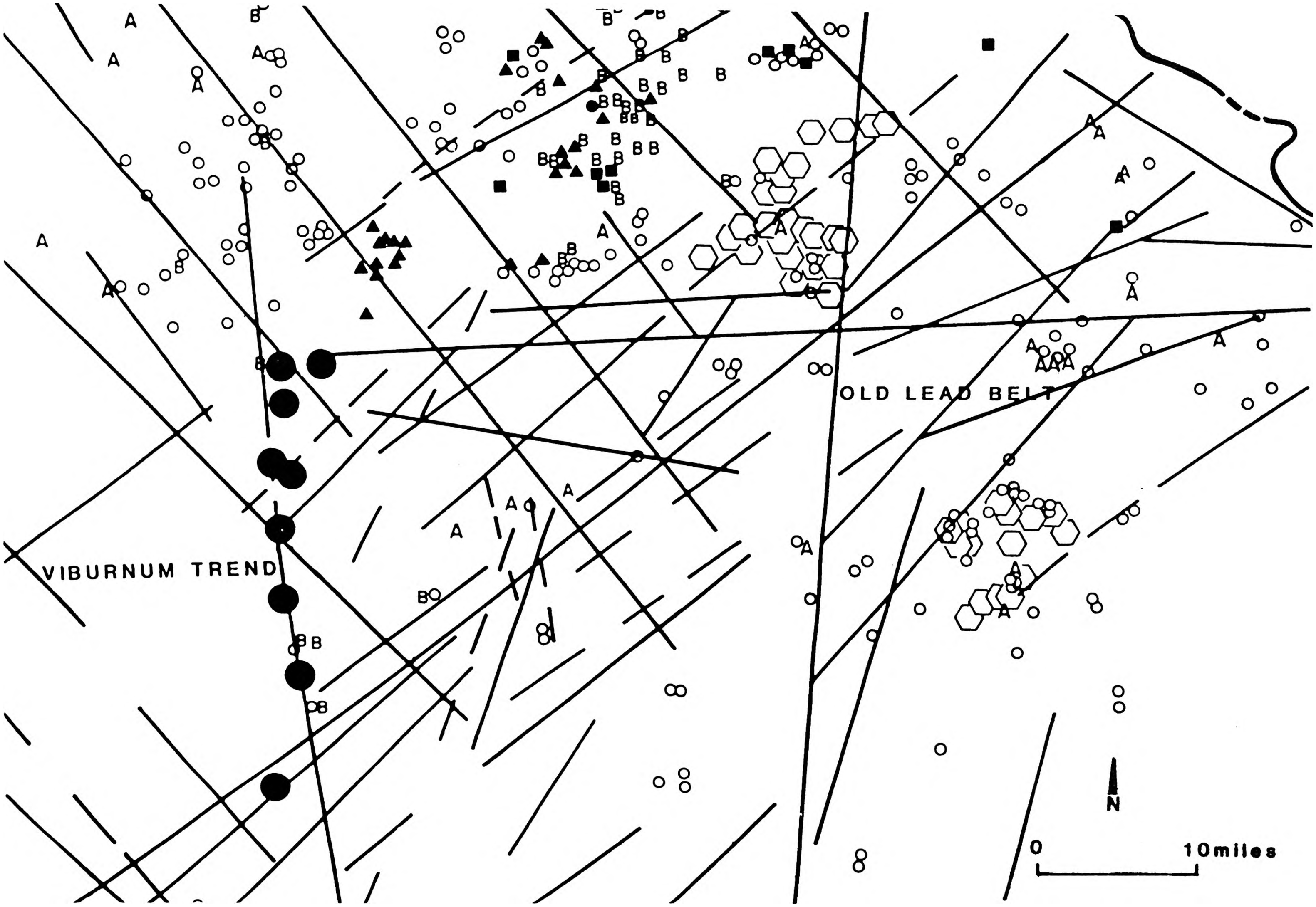


Figure 32. Mining fields along a single major lineament and at the intersection of two (or more) major lineaments. These fourth order relationships are seen in the Viburnum Trend and Old Lead Belt of Southeast Missouri.


VIBURNUM TREND
OLD LEAD BELT
N
0
10miles

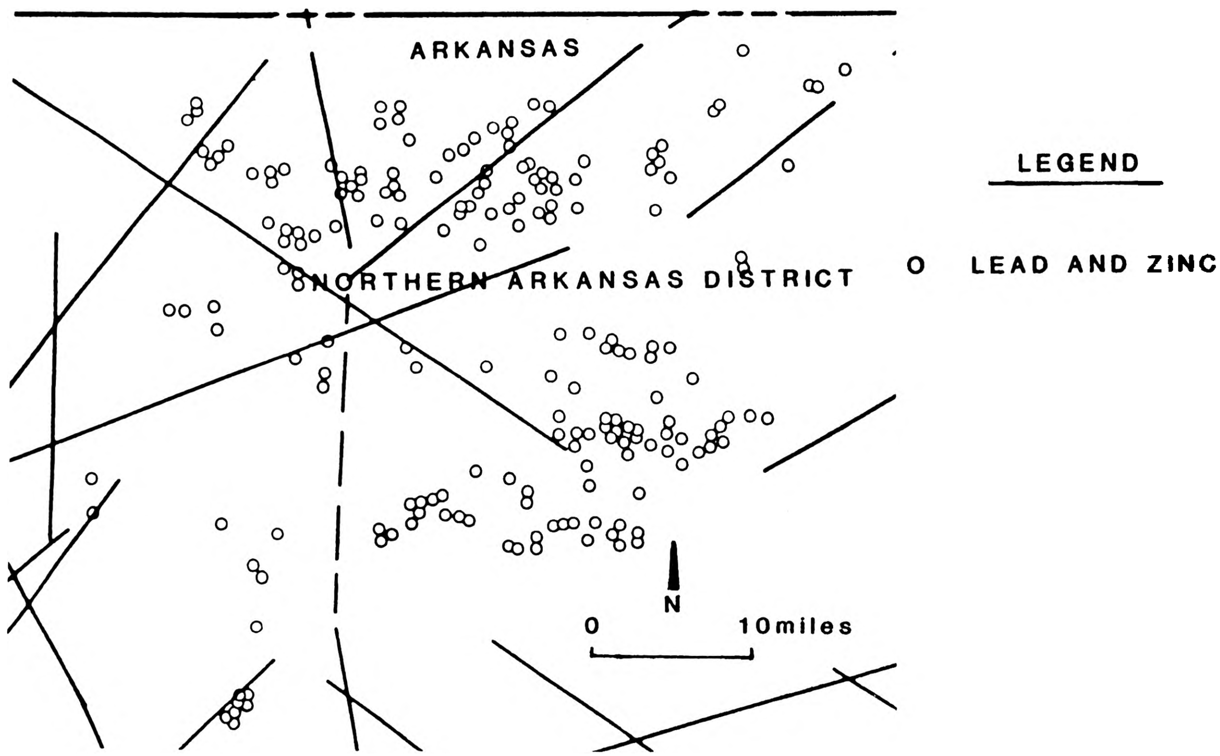


Figure 33. The Northern Arkansas District is located at the intersection of several major lineaments.

example are the intersecting lineaments of the Joplin, Picher, etc., mining fields of the Tri-State District (Figure 34). Also several intersections occur along the Viburnum Trend and Old Lead Belt of the Southeast Missouri District (Figure 32) and the Central Missouri District (Figure 35). Numerous other examples of these two cateogries exist throughout the Ozark dome.

D. FOURTH ORDER

The fourth order relationship is between single ore bodies, small mineral deposits or mines and any structural feature which includes faults, anticlines, and lineaments. Since the fourth order represents deposits more on a mine scale than on a district scale, as was the case in the third order metallotects, and this is a regional study some examples will be taken from the geologic literature. In this case the terminology "lineament metallotect" will be replaced by "linear metallotect" so as to include faults, anticlines, lineaments, and any other linear structure. Thus, "linear metallotect" can be classified into the following categories with examples to follow:

1). individual deposits or clusters along a single linear trend;

2). individual deposits or clusters located at the intersection of two (or more) linear trends;

3). individual deposits lying along or within the boundaries of linear trends;

4). individual deposits that may form some kind of geometric pattern.

An example of the first category can be seen in the breccia ore bodies of the mines of the Viburnum Trend of southeast Missouri, particularly the Buick and Magmont mines. The ore solutions followed

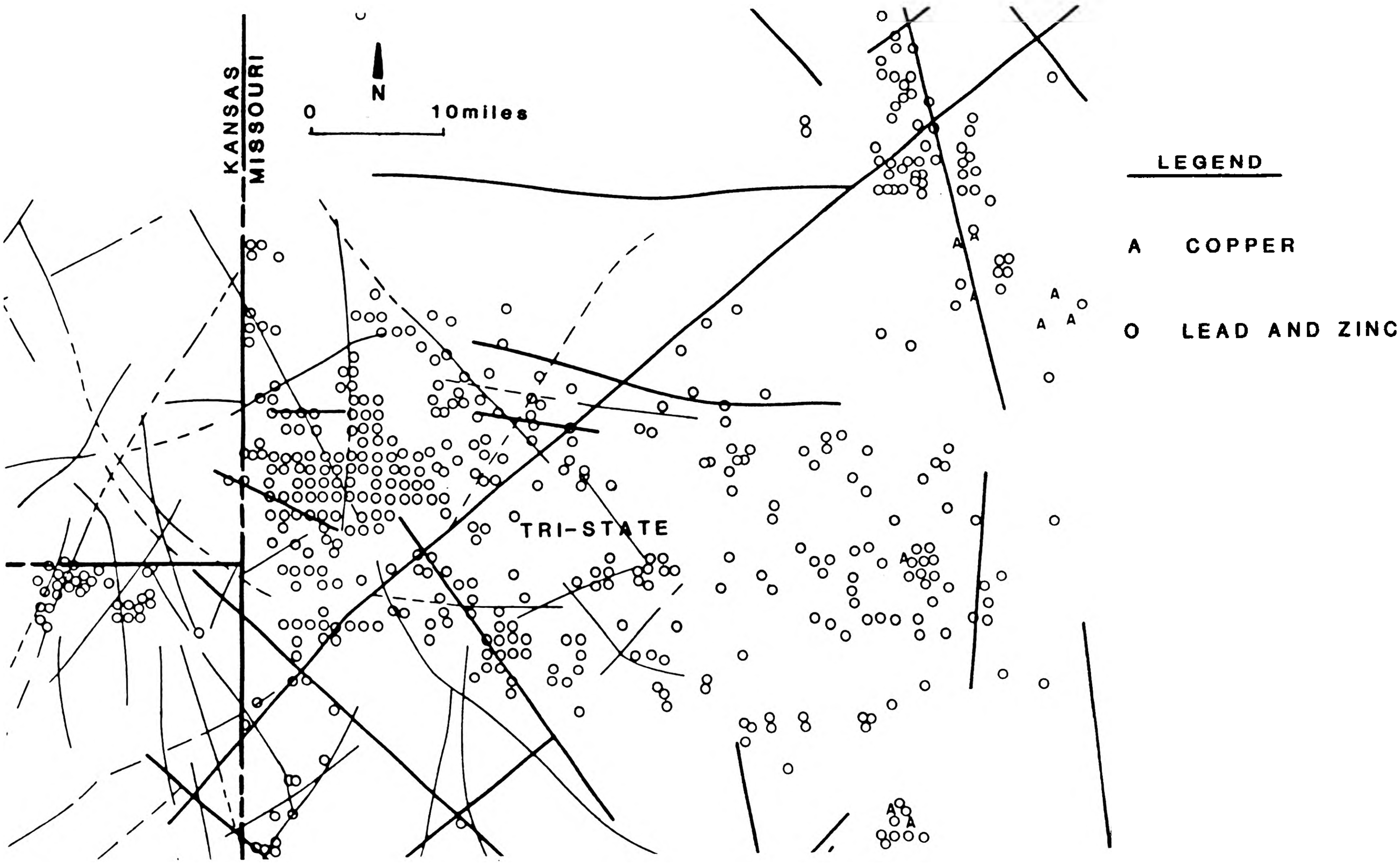


Figure 34. The Tri-State District and its various mining fields are localized by many intersecting lineaments.

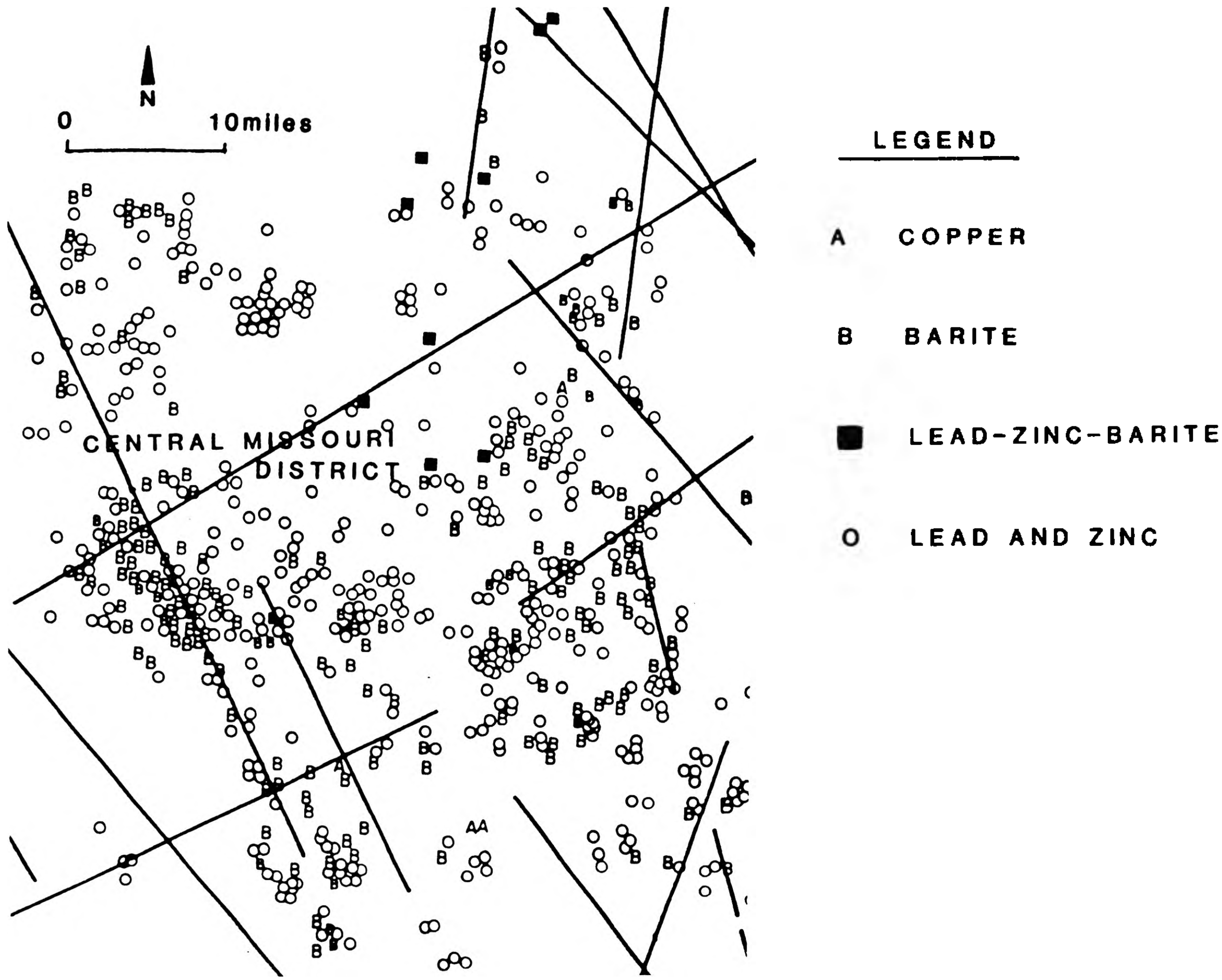


Figure 35. Major intersecting lineaments concentrated the ore deposits of the Central Missouri District.

more permeable units, initiated the ground preparation, and provided a plumbing system for the ore-bearing solutions before they could reach the Lamotte pinchouts. This interception of the ore solutions by breccia zoned defined by and in some cases bounded by faults and fractures in the Buick and Magmont mines created some of the richest breccia ore bodies in the Viburnum Trend (which itself is third order metallotects) (Figure 36).

Taylor (1983) did a study on faulting as related to lead-zinc mineralization in the west end of the Milliken mine of the Viburnum Trend. The faults in the western section of the mine are characterized by near vertical, east-west trending faults that occur in long sinuous zones. He suggested that the faults were pre-ore due to the type of sulfide mineralization present. The ore solutions probably flowed along the east-west component of the Sweetwater fault which is related to a larger series of northwest trending faults such as the Ellington and Black which are in the local mine area.

Examples of the first category which can be seen in this study are along a lineament (Figure 37) in southwest Missouri and a fault (Figure 38) several miles west of the lineament mentioned above where deposits cluster along a single linear trend. Many more examples can be seen over the study area.

Examples of the second category can be seen in northwestern Arkansas (Figure 39) and south central Missouri (Figure 40) along lineament intersections. Many examples of individual deposits or clusters of small deposits located at fault intersections can also be seen in southeast Missouri. This is particularly evident in the area

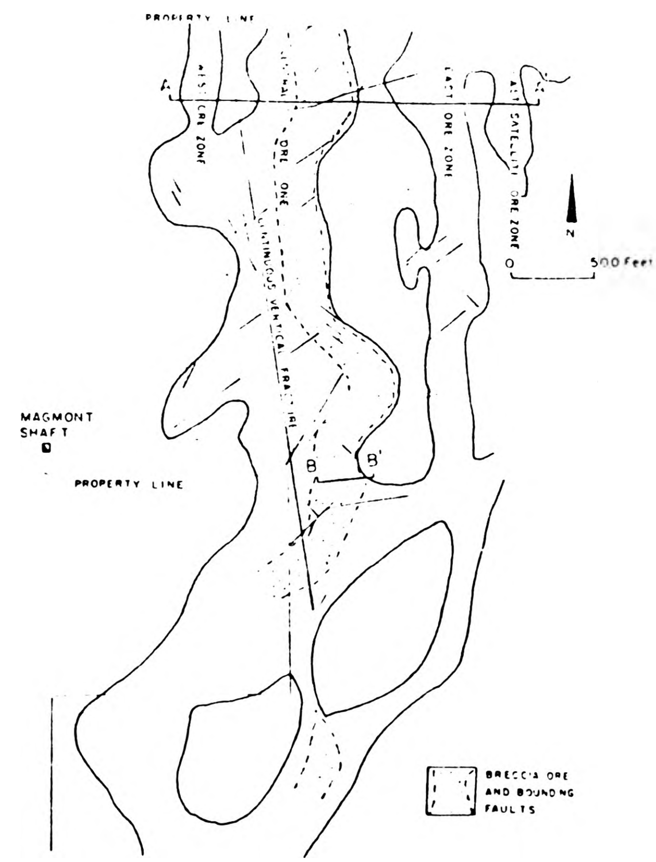


Figure 36. Plan of the northern part of the Magmont orebody showing the ore trends and fracture pattern (from Sweeney, Harrison, and Bradley, 1977).

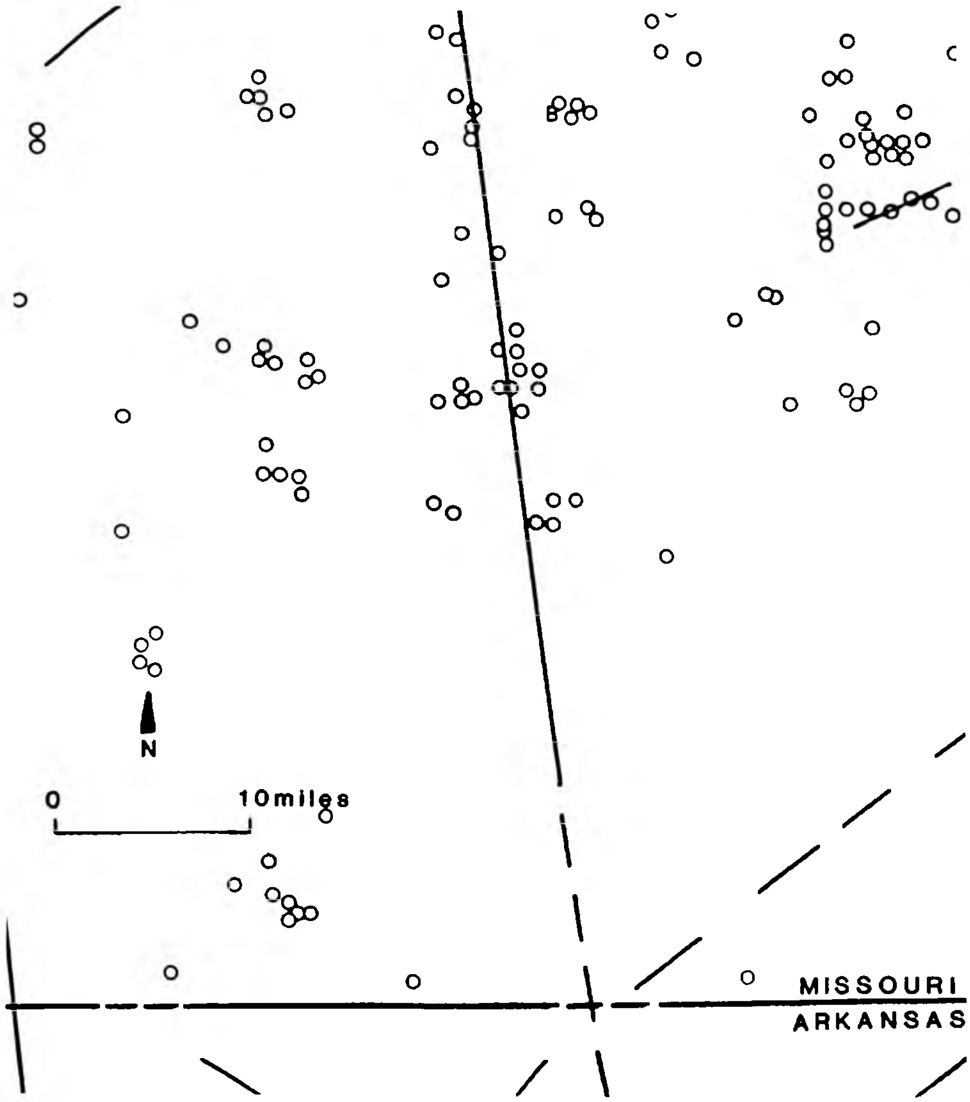


Figure 37. Individual and clusters of ore deposits along a single lineament in Southwest Missouri.

LEGEND

O LEAD AND ZINC

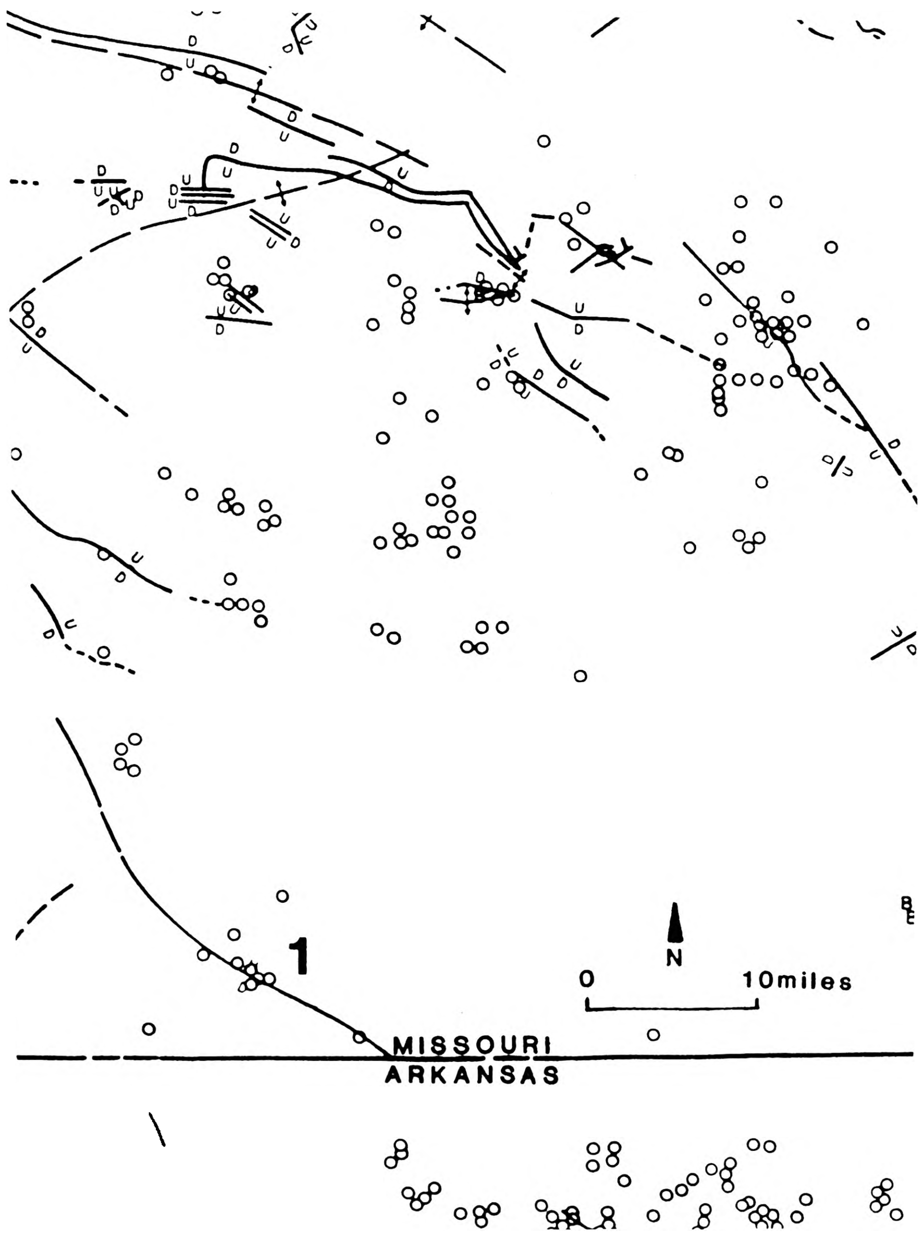


Figure 38. Individual and clusters of the ore deposits along a fault (1) in Southwest Missouri.

LEGEND

O LEAD AND ZINC

B BARITE

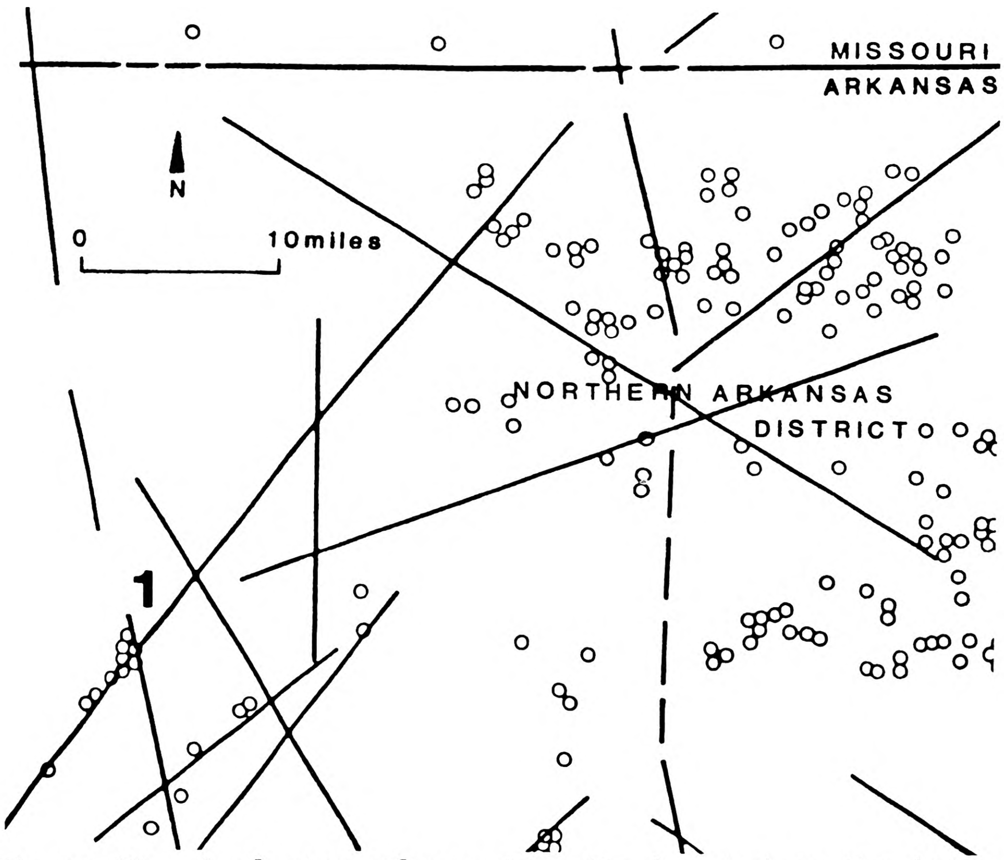


Figure 39. A cluster of ore deposits located at the intersection of two lineaments (1) southwest of the Northern Arkansas District.

LEGEND

O LEAD AND ZINC

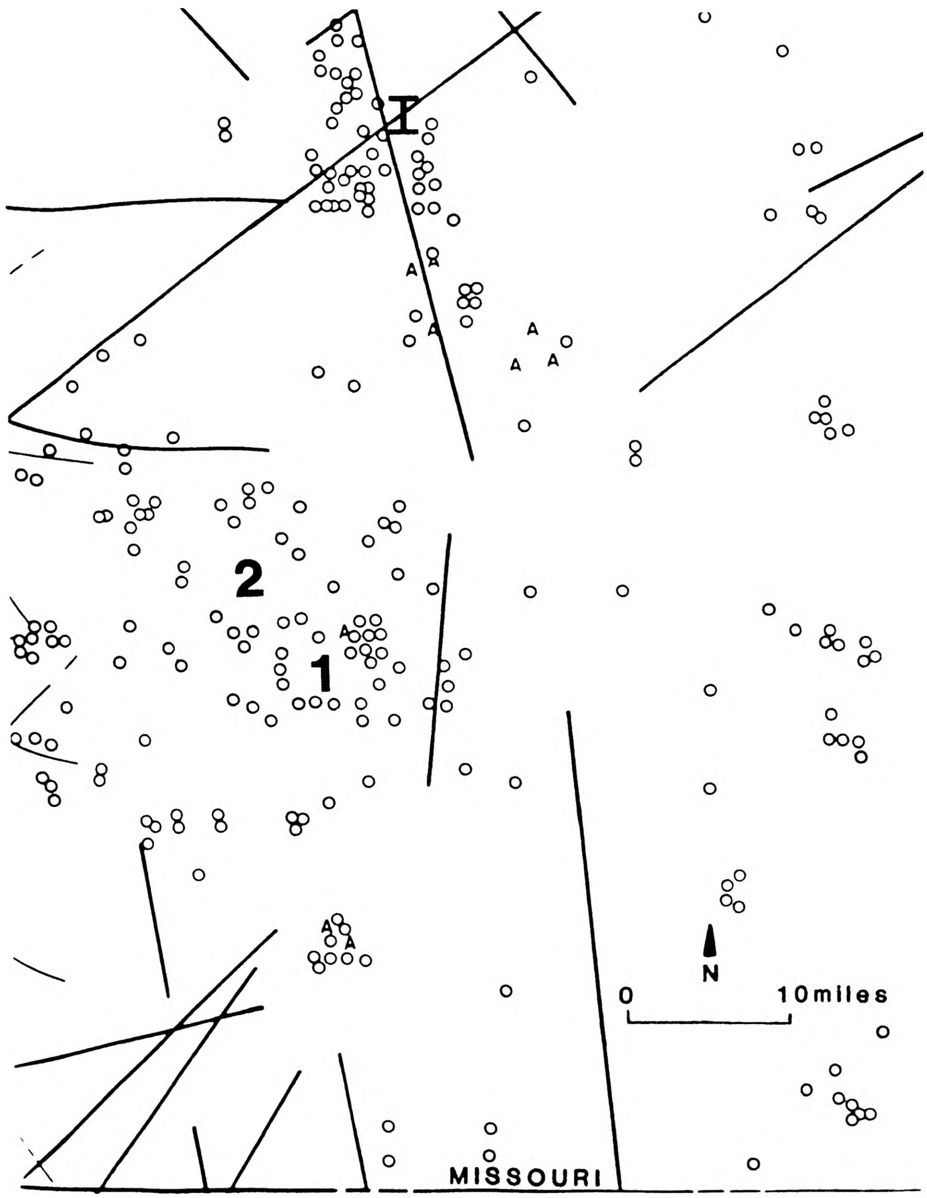


Figure 40. A large cluster of ore deposits located at the intersection of two lineament sets (I) in southern Missouri Also note where individual deposits (1,2) form geometric patterns.

LEGEND

A COPPER

O LEAD AND ZINC

of the Old Lead Belt and the Viburnum Trend (Figure 41) which themselves are located at major lineament intersections (third order metallotects).

An example of the third category can be observed where lineaments in southern Missouri bound a block of mineral deposits (Figure 42). While the opposite occurs in two fault intersection examples in southwest Missouri where an essentially barren block is next to mineralized blocks (Figure 43).

Examples of the fourth category, individual deposits that may form some kind of geometric pattern can be seen in many locations throughout the study area. A few illustrations can be seen in Figures 40, 42, and 43. These geometric patterns seem to occur in the presence and/or absence of linear trends.

Some of the ore deposits in this study exist where there are no evident reasons as far as metallotects or because more orders need to be established. The primary explanation would be to have better and more detailed surface mapping completed for the states encompassing the Ozark dome.

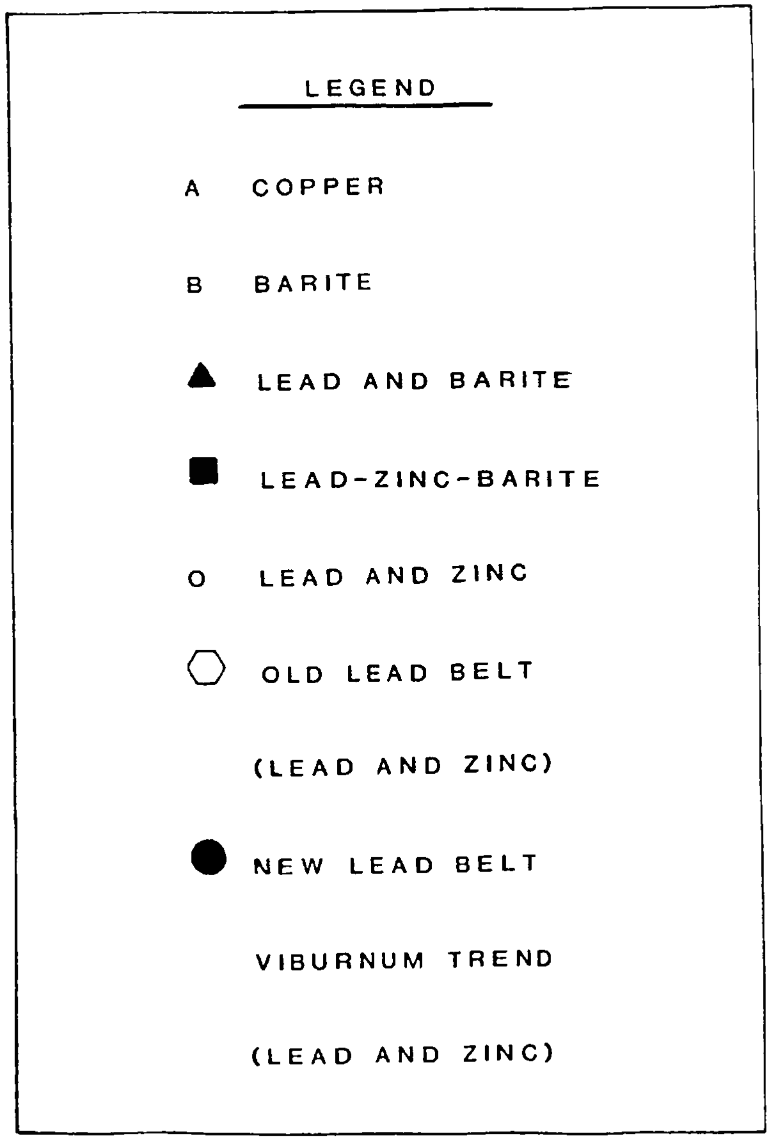
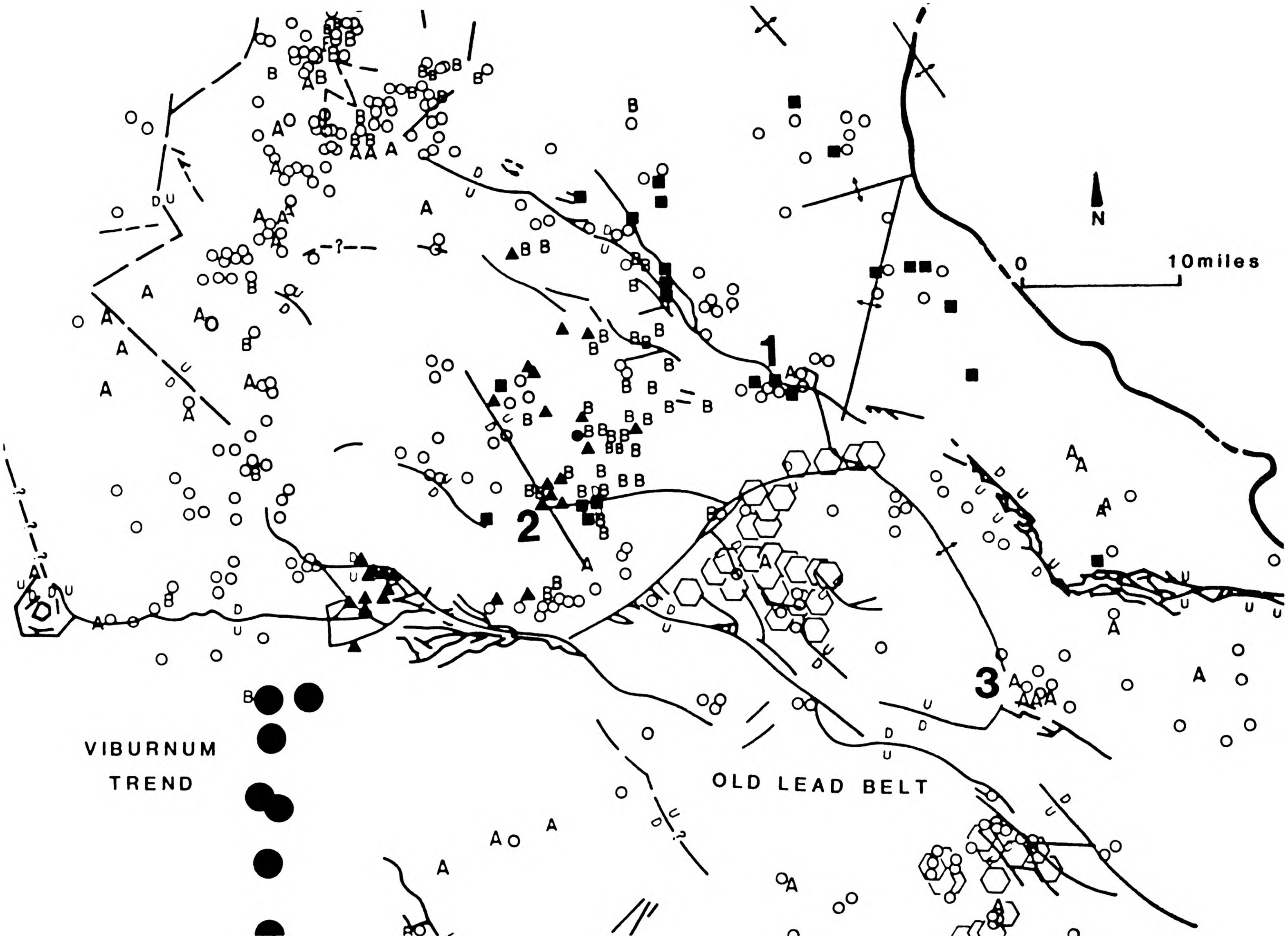


Figure 41. Individual deposits and clusters of small deposits located at lineament intersections (1,2,3) in Southeast Missouri.


VIBURNUM TREND
OLD LEAD BELT
N
0
10miles
1
2
3

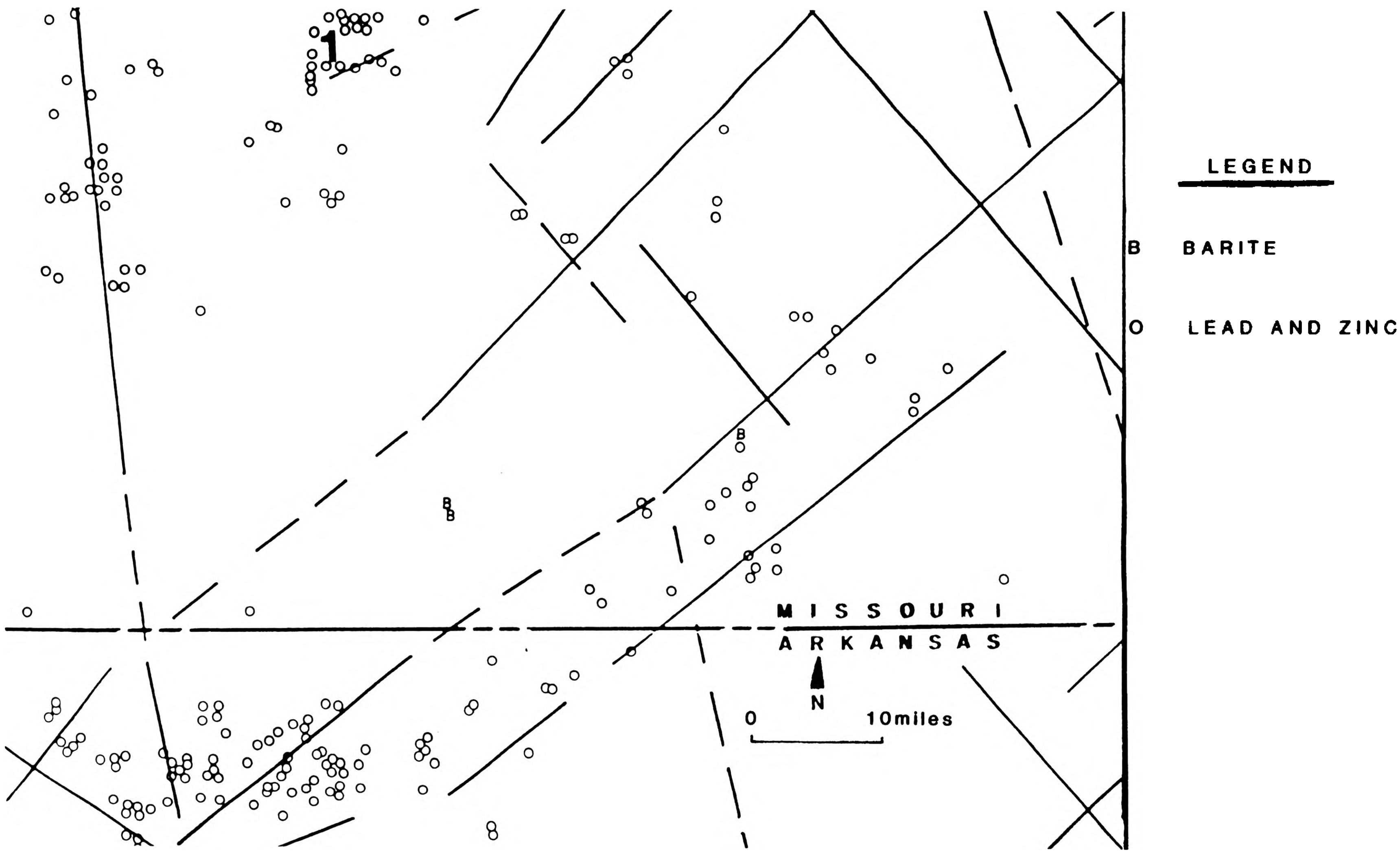


Figure 42. Mineralized blocks defined by lineaments in southern Missouri. Also note location (1) where individual deposits form geometric patterns.

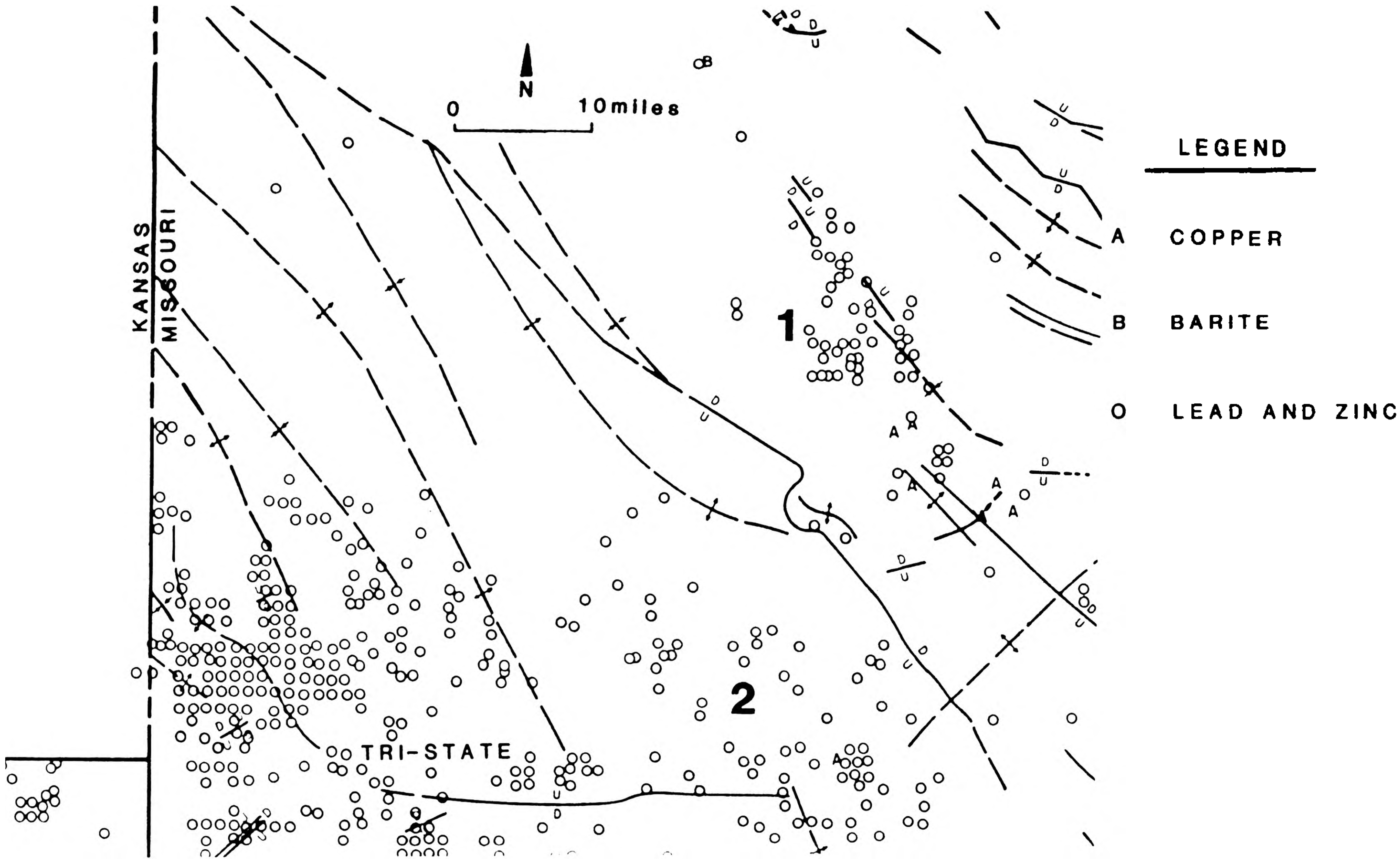


Figure 43. Linear trends in Southwest Missouri produced mineralized blocks next to a barren block. Also note location (1,2) where individual deposits form geometric patterns.

VII. SUMMARY AND CONCLUSIONS

The following conclusions were arrived at from the study of the lead-zinc metallotects of the Ozark dome:

1). The recognition that the Ozark dome itself is a major ore concentrating structure, by being a regional "anticline". Thus, similar buried or near-surface "anticlinal" structures of the Midcontinent may be ore concentrators as well.

2). Every major mineral district within the Ozark dome is related (or was at one time in the past) to a Precambrian high. This even includes the Northern and Northeastern Arkansas Districts. In Northern Arkansas a thick accumulation of Paleozoic rocks conceals a buried Precambrian high. The same applies to northeastern Arkansas where a Precambrian high probably once existed under a thick accumulation of Paleozoic rocks but due to the Reelfoot rift zone its presence cannot be detected today. Thus, even those districts, such as the Tri-State, in which ore deposits precipitated at stratigraphically high positions are underlain by secondary Precambrian highs. This means that ore, at least in the Ozark dome - Midcontinent Region, prefers to be concentrated over secondary Precambrian highs.

3). Major faults and fracture zones connecting source areas with the secondary Precambrian highs appear to have played a major role in the evolution of the mineral deposits of the Ozark dome. Obviously, their role was as avenues of ore concentrators and aiding solution movement along with creating superimposed porosity and permeability for the further dispersion of ore-forming fluids. Also local fractures and faults aided in the development of ore bodies or zones by even further dissipating the ore fluids to the "trap" or ore entrapment environment. Examples of mineralized faults, which dispensed ore-forming fluids, can be found in every major mineral district of the Ozark dome.

4). Major and high grade ore deposits that were fault induced, influenced the formation of rich breccia ore bodies. This can be especially well seen in the Buick and Magmont mines of the middle section of the Viburnum Trend of Southeast Missouri.

5). Even though there are few faults in the Lamotte Sandstone, they do serve an important role in the development of blanket ore deposits above the Lamotte pinchouts. These faults interconnected favorable lithologies with mineralized solution in the Lamotte. These faults also moved mineralized solutions up into the Bonneterre Formation, the important host rock of the lead-zinc deposits of the Viburnum Trend and elsewhere in the Southeast Missouri District.

6). Overall, more fracturing and faulting means a higher concentration and alteration of ore. Throughout the Ozark dome ore deposits tend to occur where there is a great deal of structural activity. Where the lack of structural activity or faults, in the case of the south side of the Precambrian high in southeast Missouri, occur so do the lack of mineral deposits.

7). Shales had a tendency to seal fault zones and thus block solution movement. In any formation, they acted as an impervious zone even if there were faults present. Thus, stratigraphy and lithology has to be taken in account in metallotect studies.

8). Although this study further developed the "metallotect" concept, further studies are needed to expand the concept, develop new metallotect orders, and hence discover new ore bodies in the Midcontinent region.

BIBLIOGRAPHY

Adams, G.I., Purdue, A.H., and Burchard, E.F., 1904, Zinc and Lead Deposits of Northern Arkansas: U.S. Geol. Survey Prof. Paper 24, 118p.

Anderson, K.H., et al., 1979, Geologic Map of Missouri: Missouri Geol. Survey and Water Resources, scale 1:500,000.

Ardivson, Guinness, et al., 1982, Image Processing Applied to Gravity and Topography Data Covering the Continental U.S.: EOS, v.63, no.18, pp. 261-265.

Arkansas Geol. Comm., Arkansas Mineral Resources Map: scale 1:1,000,000.

Ball, S.H., and Smith, A.F., 1903, The Geology of Miller County: Missouri Geol. Survey and Water Resources, v.1, 2nd series, 207p.

Bates, R.L., and Jackson, J.A., editors, 1980, AGI Glossary of Geology. Falls Church, VA: Amer. Geol. Inst., 749p.

Bayley, R.W., and Muehlberger, W.R., compilers, 1968, Basement Rock Map of the United States, Exclusive of Alaska and Hawaii: U.S. Geol. Survey, scale 1:2,500,000, 2 sheets.

Bickford, M.E., et al., 1979, Preliminary Geologic Map of the Precambrian Basement of Kansas: Kansas Geol. Survey, Map M-9, scale 1:500,000.

__________, et al., 1981, Rb-Sr and U-Pb Geochronology and Distribution of Rock Types in the Precambrian of Missouri and Kansas: Geol. Soc. of Amer. Bull., Part I, v.92, pp. 323-341, 26 Figs., 1 Table.

Bretz, J.H., 1950, Origin of the Filled-Sink Structures and Circle Deposits of Missouri: Geol. Soc. Amer. Bull., v.61, pp. 789-834.

__________, 1965, Geomorphic History of the Ozarks of Missouri: Missouri Geol. Survey and Water Resources, v.41, 2nd series, 137p.

Brockie, D.C., et al., 1968, The Geology of the Tri-State District of Missouri, Kansas, and Oklahoma: in Ridge, J.D., ed., Ore Deposits of the United States, 1933-1967 (Graton-Sales Volume), v.1, pp. 400-430.

Buckley, E.R., and Buehler, H.A., 1905, The Geology of the Granby Area: Missouri Bur. Geol. and Min. Repts, 2nd series, v.4, 120p.

Buckley, E.R., 1909, Geology of the Disseminated Lead Deposits of St. Francois and Washington Counties: Missouri Bur. Geol. and Mines, v.9, pt.1 and 2, 259p.

Carpenter, A.B., Trout, M.L., Pickett, E.E., 1974, Preliminary Report on the Origin and Chemical Evolution of Lead- and Zinc-Rich Oil Field Brines in Central Mississippi: Econ. Geol., v.69, pp. 1191-1206.

Cole, V.B., 1976, Configuration of the Top of Precambrian Rocks in Kansas: Kansas Geol. Survey, Map M-7, scale 1:500,000.

Croneis, C., 1930, Map Showing Structural Axes of the Arkansas Valley and Ozark Provinces: Arkansas Geol. Comm., scale (6 mi. = 1 inch).

Desai, A.A., 1966, Structure Contours on Top and Base of the M Bed, and the Relationship of Mineralization to Structures in the Tri-State District, Missouri, Kansas, and Oklahoma, unpubl. M.S. Thesis, Univ. of Missouri-Rolla, 84p.

Eardley, A.J., 1951, Structural Geology of North America. New York: Harper and Brothers Publishers, 624p.

El-Etr, H.A., 1967, The Technique of Lineaments and Linears Analysis and its Application in the Minerogenic Province of Southeast Missouri, unpublished Ph.D. Dissertation, University of Missouri-Rolla, 249p.

__________, 1964, Proposed Terminology for Natural Linear Features: Proceedings of the 1st Int. Conf. in the New Basement Tectonics, Hodgson, R.A., ed., Utah Geol. Assoc., Publ. no.5, pp. 480-489.

Fenneman, N.M., 1938, Physiography of Eastern United States. New York: McGraw Hill Book Company, Inc., 714p.

Fisk, H.M., 1944, Geological Investigation of the Alluvial Valley of the Lower Mississippi River: Publ. of U.S. Corps. of Engineers, Mississippi River Comm., Vicksburg, MS, 78p.

Fowler, G.M., 1938, Structural Control of Ore Deposits in the Tri-State Zinc and Lead District: Eng. and Min. Jour., v.139, no.9, pp. 46-51.

__________, 1960, Structural Deformation and Ore Deposits: Eng. and Min. Jour., v.161, no.6, pp. 183-188.

Frye, J.C., et al., 1951, Kansas Mineral Resources: Kansas Geol. Survey.

Gay, S.P., Jr., 1974, Aeromagnetic Lineament Study of Covered Precambrian Basement, Southeastern Missouri: Proceeding of 1st Int. Conf. in the New Basement Tectonics, Utah Geol. Assoc., Publ. no.5, pp. 183-191.

Graves, H.B., Jr., 1938, The Precambrian Structure of Missouri: Trans. Acad. Sci., St. Louis, MO, v.29, no.5, pp. 111-164.

Guinness, Arvidson, et al.,1982, Identification of a Precambrian Rift through Missouri by Digital Image Processing of Geophysical and Geological Data, Journal of Geophysical Research, v.87, no.B10, pp. 8529-8545.

__________, et al., 1983, Digital Image Processing Applied to Analysis of Geophysical and Geochemical Data for Southern Missouri: Econ. Geol., v.78, pp. 654-663.

Hagni, R.D., 1962, Mineral Paragenesis and Trace Element Distribution in the Tri-State Zinc and Lead District, Missouri, Kansas, Oklahoma, unpubl. Ph.D. Dissertation, Univ. of Missouri-Columbia, 252p.

__________, 1976, Tri-State Ore Deposits: The Character of their Host Rocks and their Genesis: in Wolf, K.H., ed., Handbook of Stratabound and Stratiform Ore Deposits II, v.6, pp. 456-494.

Haley, B.R., et al., 1976, Geologic Map of Arkansas: Arkansas Geol. Comm., scale 1;500,000.

__________, 1982, Geology and Energy Resources of the Arkoma Basin, Oklahoma and Arkansas: UMR Journal, no.3, pp. 43-53.

Ham, W.E., Dennison, R.E., and Merritt, C.A., 1964, Basement Rocks and Structural Envolution of Southern Oklahoma: Oklahoma Geol. Survey Bull. 95, 302p.

Hayes, W.C., 1962, Configuration of the Precambrian Surface showing Major Structural Lineaments: Missouri Geol. Survey and Water Res., open file map.

Heyl, A.V., Jr., et al., 1965, Regional Structure of the Southeast Missouri and Illinois-Kentucky Mineral Districts: U.S. Geol. Survey Bull., 1202-B, 20p.

__________, 1972, The 38th Parallel Lineament and its Relationship to Ore Deposits: Econ. Geology, v.67, pp. 879-894.

Heyl, A.V., Landis, G.P., and Zartman, R.E.; 1974, Isotopic Evidence for the Origin of Mississippi Valley-Type Mineral Deposits: a review: Econ. Geol., v.69, pp. 992-1006.

__________, and McKweown, F.A., 1978, Preliminary Seismotectonic Map of Central Mississippi Valley and Environs: U.S. Geol. Survey Misc. Field Studies Map MF-1011.

Hobbs, W.H., 1904, Lineaments of the Atlantic Border Region: Geol. Soc. Amer. Bull., v.15, pp. 483-506.

__________, 1911, Repeating Patterns in the Relief and in the Structure of the Land: Geol. Soc. Amer. Bull., v.22, pp. 123-176.

__________, 1912, <u>Earth Features and Their Meaning</u>. New York: McMillian Co., 506p.

Huffman, G.G., 1953, Field Conference on Pre-Atoka Rocks in the Ozark Uplift Northeastern Oklahoma: Oklahoma Geol. Survey, Guide Book 1, 41p.

Hunt, C.B., 1967, <u>Natural Regions of the United States and Canada</u>. San Francisco: W.H. Freeman and Co., 725p.

James, J.A., 1951, The Relationship of Regional Structural Geology of the Ore Deposits in the Southeastern Missouri Mining District: unpubl. Ph.D. Dissertation, Univ. of Missouri-Rolla, 196p.

__________, 1952, Structural Environments of the Lead Deposits in Southeastern Missouri Mining District: Econ. Geol., v.47, pp. 650-660.

Jewett, J.M., <u>et al.</u>, 1964, Geologic Map of Kansas: Kansas Geol. Survey, Map M-1, scale 1: 500,000.

Johnson, K.S., 1969, Mineral Map of Oklahoma (Exclusive of Oil and Gas Fields): Oklahoma Geol. Survey, Map GM-15, scale 1:750,000.

Kane, M.F., Hildenbrand, T.G., and Hendricks, J.D., 1981, Model for the Tectonic Evolution of the Mississippi Embayment and its Contemporary Seismicity: Geology, v.9, no. 12, pp. 563-568.

Kirk, J.N., and Walters, R.L., 1968, Preliminary Report on Radar Lineaments in the Boston Mountains of Arkansas: The Compass of Sigma Gamma Epsilon, v.45, no.2, pp. 122-127.

Kisvarsanyi, E.B., 1965, Mineral Resources Map of Missouri: Missouri Geol. Survey and Water Res., scale 1:500,000.

__________, 1975, Data on Precambrian in Drillholes of Missouri Including Rock Type and Surface Configuration (Contribution to Precambrian Geology no.5): Missouri Geol. Survey and Water Res., Rept. Inv. no.56, 1 pl., 1 tbl., 24p.

__________, 1979, Geologic Map of the Precambrian of Missouri (Contribution to Precambrian Geology no.7): Missouri Geol. Survey and Water Res., scale 1:1,000,000.

Kisvarsanyi, E.B., 1979, Structure Contour Map of Buried Precambrian Basement - Rock Surface, Rolla 1 X 2 Quadrangle and Adjacent Areas, Missouri: U.S. Geol. Survey, Miscellaneous Field Studies Map MF-1001 B, scale 1:250,000.

__________, 1980, Subsurface Geology of the Precambrian St. Francois Terrane, Southeast Missouri (Contribution to Precambrian Geology no.8): Missouri Geol. Survey and Water Resources, Open-File Map OFM-80-1-GI, scale 1:125,000.

Kisvarsanyi, E.B., and Kisvarsanyi, G., 1974, Ortho-Polygonal Tectonics Patterns in the Exposed and Buried Precambrian Basement of Southeast Missouri: Proceeding of the 1st Int. Conf. on the New Basement Tectonics, Hodgson, R.A., ed., Utah Geol. Assoc., Publ. no.5, pp. 169-182.

__________,1976, Structural Lineaments and Mineralization in Southeast Missouri: Missouri Geol. Survey and Water Res. Rept. Inv. 61, pp. 174-183.

Kisvarsanyi, G., 1976, Precambrian Metallogenesis in the St. Francois Mountain Igneous Province, Southeast Missouri: Missouri Geol. Survey and Water Res., Rept. Inv. 61, pp. 164-173,

__________, 1977, The Role of the Precambrian Igneous Basement in the Formation of the Stratabound Lead-Zinc-Copper Deposits in Southeast Missouri: Econ. Geol., v.72, pp. 435-442.

__________, 1982, Regional Depositional Facies of the Cambrian-Bonneterre Formation, Rolla 1° X 2° Quadrangle, Missouri: U.S. Geol. Survey, Miscellaneous Field Studies Map MF-1002-I, scale, 1:250,000.

Kisvarsanyi, G., and Martin, J.A., 1977, Structural Lineament and Pattern Analysis of Missouri, Using LANDSAT Imagery, Goddard Space Flight Center, Special Rept., Contract no. Nas-5-20937.

Koening, J.W., ed., 1961, Stratigraphic Succession in Missouri: Missouri Geol. Survey and Water Res., v. XL, 2nd series, 185p.

Leach, D.L., Nelson, R.C., and Williams, D., 1975, Fluid Inclusion Studies in the Northern Arkansas Zinc District: Econ. Geol. v.70, pp. 1084-1091.

Levorsen. A.I., 1967, Geology of Petroleum. San Francisco: W.H. Freeman and Co., 2nd ed, 724p.

Lidiak, E.G., et al., 1966, Geochronology of the Midcontinent United States, Part 4: Jour. Geophys. Research, v.71, pp. 5427-5438.

__________, 1982, Basement Rocks of the Main Interior Basins of the Midcontinent: UMR Journal no. 3, pp. 5-24.

Lyden, J.P., 1950, Aspects of Structure and Mineralization used as Guides in the Development of the Picher Field: Amer. Inst. Min. Met. Eng. Trans., v.187, pp. 1251-1259.

Marbut, C.F., 1907, The Geology of Morgan County: Missouri Geol. Survey and Water Res., v.7, 2nd series, 97p.

Mather, W.B., 1946, The Mineral Deposits of Morgan County, Missouri: Missouri Geol. Survey and Water Res., Rept. Inv. 2, 193p.

__________, 1947, Barite Deposits of Central Missouri: AIME Tech. Publ., no. 2246, 15p.

McCracken, M.H., 1971, Structural Features of Missouri: Missouri Geol. Survey and Water Res., Rept. Inv. 49, 99p., plus map, scale 1:500,000.

McKeown, F.A., and Pakiser, L.C., eds., 1982, Investigations of the New Madrid, Missouri, Earthquake Region: U.S. Geol. Survey Prof. Paper 1236, 201p.

McKnight, E.T., 1935, Zinc and Lead Deposits of Northern Arkansas: U.S. Geol. Survey Bull. 835, 331p.

__________, and Fisher, R.P., 1970, Geology and Ore Deposits of the Picher Field, Oklahoma and Kansas: U.S. Geol. Survey Prof. Paper 588, 165p.

Miller, M.H., 1982, Mines, Prospects, and Occurrences of Metallic Minerals in the Rolla 1 X 2 Quadrangle, Missouri: U.S. Geol. Survey, Miscellaneous Field Studies Map MF-1005-B, pamphlet.

Miser, H.D., 1954, Geologic Map of Oklahoma: Oklahoma Geol. Survey, scale 1:500,000.

Missouri Geological Survey County Mineral Occurrences (spot) maps.

Muehlberger, W.R., et al., 1966, Geochronology of the Midcontinent United States, Part 3: Jour. Geophys. Research, v.71, pp. 5409-5426.

NASA, 1976, LANDSAT Data Users Handbook: Goddard Space Flight Center, Greenbelt, MD., Document no. 76SD-4258.

Oetking, P., Feray, D.E., and Renfro, H.B., 1966, Mid-Continent Region, Kansas-Missouri- Oklahoma-Arkansas, Publ. by A.A.P.G., scale 1:1,875,000 (1 inch = approx. 30 miles).

O'Leary, et al., 1976, Lineament and Linear, a Terminological Reappraisal: Proceedings of 2nd Int. Conf. in the New Basement Tectonics, Utah Geol. Assoc., pp.571-577.

Proctor, P.D., Toweh, S.H., and Kisvarsanyi, G., 1979, LANDSAT Image Analysis of the Tri-State District: Abst., Geol. Soc. Amer., North-Central Section, 13th Annual Meeting - Abst. with Programs, v.11, p.254.

Rogers, R.K., and Davis, J.H., 1977, Geology of the Buick Mine, Viburnum Trend, Southeast Missouri: Econ. Geol., v.72, pp. 372-380.

Sabins, F.F., Jr., 1978, Remote Sensing Principles and Interpretation. San Francisco: W.H. Freeman and Co., 426p.

Saunders, D.F., and Hicks, D.F., 1976, Regional Geomorphic Lineaments on Satellite Imagery - Their Origin and Applications: Proceedings of the 2nd Int. Conf. on the New Basement Tectonics, Utah Geol. Assoc., pp. 326-352.

Schuchert, C., 1943, Stratigraphy of the Eastern and Central United States. New York: John Wiley and Sons, Inc. 1013p.

Schwalb, H.R., 1982, Geologic - Tectonic History of the Area Surrounding the Northern End of the Mississippi Embayment: UMR Journal, no.3, pp. 31-42.

Siebenthal, C.E., 1908, Mineral Resources of Northeastern Oklahoma: U.S. Geol. Survey Bull. 340, pp. 187-320.

__________, 1915, Origin of the Zinc and Lead Deposits of the Joplin Region - Missouri, Kansas and Oklahoma: U.S. Geol. Survey Bull. 606, 283p.

Skinner, B.J., ed., 1977, An Issue Devoted to the Viburnum Trend, Southeast Missouri: Econ. Geol., v.72, no. 3, 525p.

Smith, J.W., et al., 1974, Structural and Photographic Lineaments, Gravity, Magnetics and Seismicity of Central USA: Proceedings of the 1st Int. Conf. of the New Basement Tectonics, Hodgson, R.A., ed., Utah Geol. Assoc., Publ. no. 5, pp. 163-168.

Snider, L.C., 1912, Preliminary Report on the Lead and Zinc of Oklahoma: Oklahoma Geol. Survey Bull. 9, 97p.

Snyder, F.G., 1968a, Tectonic History of Midcontinental United States: UMR Journal, no.1, pp. 65-77.

__________, 1968b, Geology and Mineral Deposits, Midcontinent United States: in, Ridge, J.D., ed., Ore Deposits of the United States, 1933-1967 (Graton-Sales Volume), v.1, pp. 257-286.

Snyder, F.G., and Gerdeman, P.E., 1968, Geology of the Southeast Missouri Lead District: in, Ridge, J.D., ed., Ore Deposits of the United States, 1933-1967 (Graton-Sales Volume), v.1, pp. 326-358.

Sonder, R.A., 1947, Discussion of "Shear Patterns of the Earth's Crust" by F.A. Vening Meinesz: Amer. Geophys. Union Trans., v.28, pp. 939-945.

Sweeney, P.H., Harrison, E.D., Bradley, M., 1977, Geology of the Magmont Mine, Viburnum Trend, Southeast Missouri: Econ. Geol., v.72, pp. 365-371.

Taylor, D.R., 1983, Faulting as Related to Lead-Zinc Mineralization, West End of the Milliken Mine, Reynolds County, Missouri, unpubl. M.S. Thesis, Univ. Missouri-Rolla, 82p.

Thornbury, W.D., 1969, Principles of Geomorphology. New York: John Wiley and Sons, Inc., 2nd ed., 594p.

Tikrity, S.S., 1968, Tectonic Genesis of the Ozark Uplift, unpubl. Ph.D. Dissertation, Washington University, St. Louis, MO, 196p.

Tolman, C., and Robertson, F., 1969, Exposed Precambrian Rocks in Southeast Missouri (Contribution to Precambrian Geology no.1): Missouri Geol. Survey and Water Res., Rept. Inv. 44, 68p.

Toweh, S.H., 1978, LANDSAT Image Analysis of Linears and Lineaments in the Tri-State District, Missouri-Oklahoma-Kansas, unpubl. M.S. Thesis, Univ. Missouri-Rolla, 98p.

Ulrich, E.O., 1911, Revision of the Paleozoic Systems: Geol. Soc. Amer. Bull., v.22, pp. 281-680.

Van Horn, F.B., 1905, The Geology of Moniteau County: Missouri Geol. Survey and Water Res., v.3, 2nd series, 104p.

Weidman, Samuel, 1932, The Miami-Picher Zinc-Lead District, Oklahoma: Oklahoma Geol. Survey Bull. 56, 177p.

Wharton, H.M., 1973, Mining History of the Central Missouri District of Missouri: Missouri Mineral Industry News, v.13, no.5, pp. 84-89.

Winslow, A., and Robertson, J.D., 1894, Lead and Zinc Deposits: Missouri Geol. Survey Rept., v.7, 763p.

VITA

Linda Leigh Mallery was born on January 17, 1957 at Sewart A.F.B., Tennessee to the parents of Major Richard C. and Eula Illeen Mallery. She received her primary and secondary education in Noblesville, Indiana. She graduated in 1975 from Noblesville High School in the upper 10 percent of her class and was a member of the National Honor Society. She acquired her college education from Purdue University in West Lafayette, Indiana. She received a Bachelor of Science Degree in Geology from Purdue University in December 1979 and continued her studies there until May 1980. She enrolled in Graduate School at the University of Missouri-Rolla in August 1980. She was on a USOE Fellowship from September 1980 through December 1982. Her college activities included - Purdue Geoscience Society, Purdue Chapter of AEG, C.L. Dake Geological Society, student member of AIME, student member of American Society of Photogrammetry, student member of Society of Economic Geologists, and Sigma Gamma Epsilon - National Honorary Society in the Earth Sciences.