The Viburnum Trend, A Second Look
ASSOCIATION OF MISSOURI GEOLOGISTS

40th ANNUAL MEETING AND FIELD TRIP

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Cominco American/Dresser Industries, Magmont Mine
ASARCO Inc., West Fork Unit
ASARCO Inc., Sweetwater Unit
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Rick Dingess, Milt Bradley, Bud Walker, Bob Sappington and Jerry Vineyard.

HISTORY UPDATE

Nearly fourteen years have elapsed since our last tour to the Viburnum Trend. The “Trend” during that period was in its young stage of life. Companies with the names: St. Joe Minerals, AMAX-Homestake, Ozark Lead Company and Cominco American were the major players within the area. ASARCO Inc. held a small section of land between the Brushy Creek and Fletcher mines with no mine.

Today, almost all of the above named companies do not exist. Two long and severe down cycles in the metals market forced consolidation and sale of properties.

The period of the 1980’s saw many companies go through acquisition by larger companies and corporations. St. Joe Minerals was the first company to experience this with the buyout of its stock by the Fluor Corporation of Irvin, California.

No major changes occurred after that time until 1983 when Ozark Lead Company, shut down the Milliken mine (Sweetwater mine).

AMAX Mining Company decided that lead mining did not fit its core business and sold out its interest in the Buick Mine & smelter to Homestake Mining Company.

High warehouse stockpiles, continued low metals prices for lead, brought continued hardship for the “Trend”. Two companies realized that survival depended on putting their assets together and brought about the merging of St. Joe Minerals and Homestake Mining Company in 1986. This merger created The Doe Run Company. Fluor-Daniels Engineering, the parent company of St. Joe Minerals, held 57.5% share and Homestake Mining Company held a 42.5% share of The Doe Run Company. ASARCO announced in 1980 the capital investment of $77 million in a new mine and mill to be named West Fork Unit which went into production in 1985. Late in the 1980’s, ASARCO made the announcement of their purchase of the Milliken mine. The mine was renamed it the Sweetwater unit and reopened the mine for production in 1989.

DEDICATION

Finally, I would like to dedicate this field guide to the memory of my father, George. His sudden death this summer left me with one less best friend that cannot be replaced. His teachings and guidance made me what I am today. I became what I wanted to be a, geologist because of him. His challenging me to learn at every opportunity that comes available, will stay with me for the rest of my life. I will miss him tremendously.
Generalized Map of the Viburnum Trend Area
MAGMONT GEOLOGY

The Magmont Mine is located within the north-central part of the Buick embayment. This embayment is outlined by basement structure, defined by a Precambrian high which extends westward from Bixby, Missouri, to Boss, Missouri, and the presence of several Precambrian knobs to the east and southeast of Bixby.

No Precambrian rocks are exposed in the Magmont Mine and none of the features exposed in the Bonneterre Formation can be related to Precambrian surface irregularities.

Incipient pencontemporaneous slumping occurs within the gray beds (Silty Marker unit) along the west edge of the mineralized trend where calcarenite sand bars formed local highs during sedimentation. Breccias induced by solution and subsequent collapse are apparent in all areas of extensive mineralization.

Within the Magmont Mine, fracture patterns, except for the high ore area, consist of a few distinct fractures which can be followed for some distance. Innumerable smaller fractures, which are more properly a joint system, are oriented northeast and northwest.

One through-going fracture striking northwest can be traced for about 2,500 feet. It is open along much of its length and partially filled with calcite. No vertical displacement can be seen but slickensided material showing horizontal movement has been taken from it.

The bounding faults of the high ore zone can be traced continuously for about 4,500 feet in the Magmont Mine and extend north and south into adjoining property. This does not imply that these faults are continuous as individual fractures; they are an interlaced series of connected faults. All the high ore along this 4,500 feet is marked on both east and west sides by these distinctive shale-filled subsidence fractures. A few well-defined, northeast-trending, near-vertical fractures turn abruptly into the bounding faults. Others are traceable across the slumped areas and apparently existed prior to the major vertical movement within the breccia piles. It appears that the pre-existing fracture system has, to a certain extent, influenced the development of the slumped areas and has been responsible for the increased east-west widths of the breccia areas where northeast-trending fractures are conspicuous.

Mineralization within the mine area is almost totally restricted to the Bonneterre Formation with very minor mineralization in the Davis Formation and Lamotte Sandstone. Total thickness of the Bonneterre averages about 285 feet in the Magmont Mine area.

Three ore zones, all aligned about parallel to the north-south axis of the Viburnum Trend, occur within the Magmont Mine. East-west distance across these three trends is about 2,000 feet. Vertically, the ore is divided into A, B, C and D horizons which are defined as follows:

A - From base of Davis Formation to base of slumped False Davis,
B - Base of slumped False Davis to base of Silty Marker,
C - Base of Silty Marker to base of Upper Reef,
D - Base of Upper Reef to base of Lower Reef.
"B" is the main ore horizon and the west, central and east ore trends are well mineralized within this interval. Ore on "D" horizon within the Magmont Mine is known mostly by drilling. To date mineable ore on "C" horizon is restricted to bands of detrital material which separate individual bioherms and fill scour channels within the upper reef horizon.

The western ore zone is characterized by incipient slumping along the west edge which appears to be best explained as penecontemporaneous slumping of semi-consolidated material from a slightly raised area which was probably a calcarenite sand bar. These slumps show randomly oriented, angular blocks of the gray, fine-grained units of the Silty Marker interbedded in the brown dolomites of the same unit. Above these slumped areas a small amount of brecciation has taken place and fracture filling and replacement have proceeded within the areas of induced open space. Ore thickness within this area is commonly about 35 feet. East of the slumped zone the Silty Marker shows irregular bedding with considerable variation in the thickness of the brown dolomites of this unit. Mineralization consists of massive galena bands with lesser amounts of sphalerite and some chalcopyrite. A marcasite area is present along the east side of this trend which merges with the central ore along part of its length.

The central ore zone contains the major tonnage of the Magmont Mine. It is characterized by mineralization which extends vertically from the base of the Silty Marker up to and above the False Davis. The Silty Marker is well mineralized but shows a marked thinning beneath the high ore area. Brecciated and well-mineralized dolomites of the calcarenite units contain most of the ore above the Silty Marker. A conspicuous feature of the central ore is the slumped central portion of this zone. False Davis shales are dropped vertically as much as 14 feet. Well-defined bounding faults of this slump structure are filled by overlying Davis Formation as evidenced by the presence of glauconite. This slump has the form of an inverted graben since the bounding faults dip outward from the graben block instead of inward.

There is no apparent thinning or collapse of any rock units below the Silty Marker. The open space created to permit collapse of the overlying rocks has taken place within the 60 feet of strata between the base of the False Davis and the base of the Silty Marker. The slumping extends to the Davis Formation in some areas of very high mineralization.

Mineralization of the central ore zone consists of galena, sphalerite, chalcopyrite and marcasite. Siegenite is a minor constituent of the chalcopyrite. Drusy quartz makes up much of the cementing material in the interstitial space between breccia fragments and often lines open cavities and vugs.

This ore trend parallels the central ore zone, but in the southeast part of the Magmont Mine swings abruptly west and appears to merge with the central ore zone.

The eastern ore zone averages about 200 feet in width in an east-west direction. Maximum vertical thickness is about 50 feet and slumping is on a smaller scale, but similar to that which occurs in the central ore zone. The Silty Marker unit which thins from west to east is about 4 feet thick here, and characteristically it is distorted within the mineralized area.
North-south trending tongues of the ore east of the eastern ore zone are characterized by extremely porous lower calcarenites which contain disseminated galena. The Silty Marker unit is difficult to recognize as the gray bands become progressively thinner to the east. Digital stromatolites within Upper Reef structure have been truncated and make direct contact with the lowest gray bed of the Silty Marker in some areas of the satellite ore zone.

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GEOLOGIST
The Doe Run Company, headquartered in St. Louis, Mo., has constructed a recycling facility that recovers lead from used automobile and industrial batteries, as well as other lead-bearing scrap material. The $40 million capital investment project was constructed at the Buick Smelter site near Boss, Missouri. Doe Run is North America’s largest and only fully integrated producer of refined lead metal. Battery processing commenced in early July 1991 and lead was produced from the reverberatory furnace in late September 1991.

The facility has a work force of approximately 97 and is contributing more than $7 million to the local economy in salaries and wages paid, and goods and services purchased.

The facility will produce 70,000 tons of finished lead annually and will increase Doe Run’s capacity of refined lead from 240,000 to 310,000 tons per year. The company employs state-of-the-art industrial processes and waste management practices to ensure the utmost environmental protection.

* The facility is operated under a RCRA Part B Permit.

Advantages of the recycling technology, developed by Engitec Implanti of Milan, Italy, used at the facility by Doe Run include:

* The design of the crushing system allows whole batteries to be broken down, and each battery component to be separated cleanly.
* Sulfur dioxide emissions from processing the battery paste are reduced significantly.
* Instead of neutralizing the battery acid with lime (which produces a waste sludge that is normally landfilled), the acid is converted to a pure form of anhydrous sodium sulfate. A total of 8,000 tons of pure anhydrous sodium sulfate will be produced each year, and can be used in the laundry detergent, paper and glass industries.
* The reverberatory and blast furnace process produces an inert discard slag that is substantially less in quantity than historically produced.
* The total waste generated by this Plant is two-thirds less than the volume produced at more traditional U.S. facilities.
* 4,500 tons of very clean polypropylene resin are recovered and are recycled by other companies into various consumer products.

By recycling lead-bearing waste materials, this effort advances national resource recovery goals by annually reclaiming 70,000 tons of refined lead from 95,000 tons of spent lead-acid automobile batteries; 8,500 tons of used industrial batteries; and 25,000 tons of other lead-bearing materials. The need for recycling lead acid batteries intensified as a result of many states adopting regulations which mandates that batteries be collected and recycled.

NOV/1992
Lead: An Essential, Recyclable Mineral

The Doe Run Company
Mission Statement

"As Doe Run employees, our mission is to build on Doe Run’s leadership position in the lead industry. Integral to this mission is the support of our customers, our employees and their families, and the society in which we live. We will accomplish this mission under the highest ethical, safety and environmental standards."

Lead: An Essential, Recyclable Mineral

The Doe Run Company and its predecessors have been mining and smelting lead in Missouri for more than 100 years. They have long supplied high quality lead to battery manufacturers, the defense and computer industries, medical and scientific research, and numerous other essential industries.

Now, Doe Run is taking another step as an environmentally responsible company by safely recycling that lead.

Doe Run’s Resource Recycling Division recycles lead from automotive and industrial batteries and other lead-bearing scrap, turning these materials into a reusable valuable resource.

Located at Bois, Missouri, 120 miles southwest of St. Louis, the facility is recognized as one of the most advanced lead recycling facilities in the nation.

One-of-a-Kind

Most of the lead that is recycled in the United States comes from car batteries, and getting the lead out safely has never been easy. Doe Run, the nation’s leading lead producer, saw the need to recycle lead in a safe and environmentally sound way.

The company began investigating the idea of a lead recycling facility in the late 1960s. Doe Run officials visited facilities around the world in order to gain further insight into designing and building the most technologically advanced lead recycling plant possible.

After much research, Doe Run selected a process developed by Engle, Implant of Milan Italy, which would live up to the company’s strict health, safety and environmental standards.

The Doe Run Resource Recycling Facility produces 60,000 tons of finished lead annually, which increases Doe Run’s production capacity of refined lead from 240,000 to 300,000 tons per year.
Clean, Safe and Environmentally Sound

Ninety percent of the lead recycled at the Buck Facility comes in the form of automotive and industrial batteries. When they arrive at the plant, the automotive batteries are stored in a specially designed and constructed bunker, approved by the Missouri Department of Natural Resources. Industrial batteries are delivered to a specially designed area for dismantling.

A sophisticated leak detection system under the bunker floor ensures that any leakage from the stored batteries is detected before it can ever reach the surrounding environment. In addition, wells around the plant continuously monitor groundwater quality.

After the batteries are dismantled, the various components are separated and collected. Some components, such as the polypropylene plastic, are sent to plastic recycling facilities, while the battery acid is used to produce a sodium sulfate solution which is crystallized and sold for use in the laundry detergent, glass and paper industries.

The metallic portions of the battery (grids and posts) go to a rotary melter in the refinery, where they are converted into lead alloys for use by the battery and ammunition industries. The battery paste is treated in a reverberatory furnace to produce pure lead.

A Good Neighbor

The Doe Run Resource Recycling Division employs about 100 people and contributes more than $7 million annually to the local economy in salaries, wages, goods and services. Statewide, Doe Run employs about 1,200 people and contributes nearly $200 million to Missouri's economy.

The Doe Run Company has established a reputation for employee safety, environmental responsibility and a product of consistent quality and excellence. The Doe Run Resource Recycling Division takes pride in its part in destigmatizing Doe Run as a full-service producer and supplier of the world's finest lead and lead alloy products, and as a good employer and neighbor.

Scales and Unloading

Trucks containing spent batteries are weighed and unloaded into a ROM-approved bunker. The battery acid is pumped to storage tanks.

Breaking and Separation

Waste batteries are dismantled in a hammer mill and the components are recovered by a combination of sorting and gravity separation in water columns. Grids and posts are collected in an acid-pretreatment before being further separated into components and used.

Desulfurization and Crystallization

The battery paste is desulfurized with soda ash and filtered. The acid from the lime process is mixed with battery acid to produce a sodium sulfate solution which is crystallized, producing a high-quality sodium sulfate grade.

Treatment of Grids and Posts

Grids and posts are melted in a rotary melter to produce antimonial lead alloy. The grid is processed in a reverberatory furnace to produce pure lead and a high antimony slag, which is then melted in a blast furnace to produce more antimonial lead and a small quantity of slag which is disposed of in a approved hazardous waste disposal facility.

Gas Cleaning

All hydrocarbon combustion gases and the roasting gases as well as process gases from the reverberatory and blast furnaces are cleaned through a 250,000 cubic foot per hour shower-house baghouse prior to the main stack.
GEOLGY OF THE ASARCO WEST FORK DEPOSIT
VIBURNUM TREND - SOUTHEAST MISSOURI

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Introduction

The West Fork ore body was discovered in January 1960, during the early exploration and discovery phase of the Viburnum trend, but development of the deposit was delayed until 1980. After partial development, the downturn in Pb prices resulted in shutdown until late 1984. Limited production of 1,000 tpd began in September 1985, increased to 1,500 tpd in May 1987, and finally to full production of 3,800 tpd in July 1988. The general location is shown in Figure 1.

The deposit is being mined by room and pillar method, with 32' support pillars located on 64' centers. Although multiple mining levels exist within parts of the ore body, only one top slice followed by a single bench pass currently is in progress. Ore is removed from the mining face by front-end loaders and transported by truck to a single ore pass leading to the crusher level below.

All ore is beneficiated in the West Fork mill, which produces Pb and Zn concentrates. These concentrates contain minor amounts of recoverable silver and cadmium. Some parts of the ore body show enriched Cu values of undetermined economic value. Lead concentrates are shipped by truck to Asarco's Glover smelter. Zinc concentrates are truck-hauled to the Big River Zinc plant in Sauget, Illinois.

The ore body is situated between, and apparently is continuous with, the Brushy Creek and Fletcher deposits of The Doe Run Company. Mineralization strikes north-south and exhibits excellent continuity in both distribution and grade. Maximum width mined to date is over 1,200', with minimum widths drill indicated to be about 200'.
Geologic Setting

The general geologic setting has been repeated in the literature by numerous authors (Thacker and Anderson, 1977). No redundancy is included here.

The ore body is situated between the Brushy Creek deposit to the north and the Fletcher deposit to the south and southeast. Unlike those two deposits, there are no Precambrian knobs protruding high into the Bonneterre formation. West Fork mineralization near the shaft is positioned nearly 100 feet structurally lower than found near the Brushy Creek and Fletcher shafts. Generalized facies patterns, shown in Figure 2, extend across this structural reentrant, but due to lack of detailed studies, no conclusions can be reached regarding the absolute age of the structure and its possible influence on detailed sedimentary patterns.

Lithologic Units

No attempt is made here to repeat detailed discussion of the lithologic units of the Bonneterre formation which hosts the ore body. The base of economic mineralization is situated approximately 40-50' below the base of the Sullivan Silt marker bed at a position which is tentatively correlated with the Upper 5/Lower 5 unit contact of Doe Run (St. Joe) terminology. Also, this base of mineralization lies approximately 40 feet above the top of the reef facies.

The parting marker present at Brushy Creek to the north (Evans, 1977) has not been recognized at West Fork; however, the brown (algal) spotted beds described at Fletcher (Paarlberg and Evans, 1977) are common, and some of these represent useful marker beds for mining.

Figure 3 summarizes the stratigraphic section at West Fork (Greene, A.V. - Asarco data) and also illustrates a schematic, generalized cross-section of the ore body.
Mineralization

The principal economic minerals are galena and sphalerite. The Pb concentrates contain 1 to 1½ opt of Ag. A ±60% Zn concentrate also contains 10-12 opt of Ag and 0.6 to 0.8% Cd. Chalcopyrite is locally abundant but seems to be concentrated within a narrow multi-level, vuggy, sparry dolomite breccia trend located near the western edge of the main mineralized trend. Colloform marcasite is abundant in at least part of the ore body mined to date and represents part of a distinct mineral zoning pattern mapped in the mine workings.

Galena is by far the most abundant mineral, followed by sphalerite. Although no quantitative studies have been completed, it is estimated that marcasite may be as abundant as sphalerite as indicated by mining through a 600 foot wide marcasite zone located on the east side of the main ore trend.

Mineral zoning for the main ore horizon ("M" bed) based on our mining experience to date is illustrated in Figure 4. Galena occurs more or less singularly along the west side. Progressing easterly, the sphalerite increases dramatically and even locally dominates over galena. (In general, sphalerite is proximal to high grade galena.) This high grade Pb/Zn zone rapidly changes into a dominant marcasite/pyrite zone which also contains galena and/or sphalerite. Marcasite/pyrite and sphalerite eventually disappear until galena is singularly present in a very narrow (5-30') zone bordering essentially barren dolomite on the east side.

Mavrogenes, 1989, has studied the mineralogy and paragenesis and attempted to relate these to the mineral zoning. His paragenetic sequence is, from early to late, ZnS, FeS2, and PbS. In addition to sphalerite, he has identified pseudomorphs of sphalerite after wurtzite. He concluded the following based on his study of the paragenesis:
The paragenetic sequence and metal zoning show that the ore forming fluids initially migrated through the inner zone where ZnS was deposited, and subsequently traveled outward depositing FeS2 followed by PbS. The presence of rapidly deposited, collomorphic ZnS and FeS2 in the central Fe-Zn zone indicates that the ore fluids that deposited the sulfides in the central zone were more saturated with respect to metals. The late stage of Zn deposition that overlap the main Fe stage are characterized by abundant yellow wurtzite. Because wurtzite is the "sulfur deficient" form of ZnS, it can be postulated that sulfur fugacities were low during this time of deposition. The close association of marcasite with wurtzite suggests that conditions were highly oxidizing and depleted in sulfur. Minerals subsequently deposited in the outer zones were precipitated more slowly from fluids that were relatively depleted in metals and enriched in sulfur.

Galena mineralization occurs principally as bedded ore within favorable stratigraphic units, locally as massive total replacement, but more commonly as what appears to be selected replacement of a granular matrix of disaggregated (perhaps recrystallized) grainstones containing unreplaced, dark, thin (½" to 1") irregular clasts and broken bands of very fine grained mudstones. The main ore horizon overlies a dense brown spotted marker bed and underlies 4-6 feet of a dense even-bedded zone also containing abundant brown spots or clasts. This unit is tentatively named "M" bed for "main" ore horizon. Figure 5 illustrates this mode of occurrence in a typical mining face.

Although the galena occurs typically as described above, ore textures vary considerably within the "M" bed, from massive replacement to finely and coarsely disseminated, to dilated bedding plane fill to vuggy open space filling, and low and high angle fracture filling. Where galena occurs in the marcasite zone, it typically lines and fills the open spaces surrounding the colloform iron sulfide surfaces as well as filling fractures which break across the colloform masses.
Sphalerite likewise occurs principally within favorable stratigraphic units more or less as bedded ore, and generally is accompanied by PbS or FeS2 mineralization. Colors of sphalerite vary considerably and seem to generally correlate with position relative to the FeS2 zone. Red and reddish-brown sphalerite is typical in or near the iron zone, whereas yellow-brown and brown (extremely similar to color of the dolostone host rock) are typical of the zone outside of the iron zone. The color of the sphalerite could be related to its iron content; however, Mavrogenes (personal communication) reported 300 ppm Ge in one sample of red sphalerite, whereas other analyses report Ge values in zinc concentrates to be about 100 ppm. Red-colored sphalerites in other MVT districts, especially central Tennessee and Tri-State districts, are known to be higher in Ge and/or Ga.

Sphalerite has been observed to be disseminated in undisturbed host rock as fine replacement crystals. More often, however, massive replacement of dolomite with textures reminiscent of undissolved residues (sanded dolomite) and breccia matrix replacement are observed.

Structure

General Structure

Structure on the marker bed at the base of the main ore zone as mapped in the mine follows the structure on the top of the reef facies as determined from surface diamond drilling (Figure 6). The ore body generally is centered over a reef high located on the west side and an adjacent parallel low to the east. The ZnS and FeS2 zones seem to generally correlate with this structural low. The best ore in the "M" bed occurs near where the interval between the base of the Sullivan Silt and the base of "M" bed is significantly "thinned". This area of thinning also is the area where the higher beds above and including the Sullivan Silt are highly disturbed and distorted. These disturbed zones were logged by Asarco geologists, Del Harper, Vance Greene, and others, as slide breccias, and they envisaged gravity sliding to the
northwest originating from the south along a northwest plunging structural trough exhibited on the top of the Lamotte sand.

Breccias

Where the bedded ore zones are not totally masked by intense Pb or Zn mineralization, breccia textures are common. Most breccia fragments, where distinct, are rounded to sub-rounded, with the matrix consisting of sanded (?) recrystallized dolomite not uncommonly containing a dark, shaly residue. More commonly, breccia fragments are indistinct to incipient in their occurrence and are termed pseudo-breccias. Brecciation in the FeS2 zone appears to be more intense, with individual small fragments within the beds of breccia having been rotated. Most of these bedded breccias described above vary from 1 foot to 3 feet in thickness and commonly are overlain and underlain by dense, undisturbed dolomite beds, probably aquacludes for ore forming fluids.

Along the west side of the ore body, mineralization is less intense and occurs principally as PbS, filling a sparry dolomite cemented breccia. These breccias also are bedded, but generally have a tendency to occupy a greater stratigraphic interval. Underground drilling has delineated a lower grade, thick, narrow breccia trend along the extreme west edge of the ore body containing white sparry dolomite, galena, chalcopyrite, and minor marcasite. Detailed descriptions await exposure by mining.

Faulting

High angle normal, reverse, or strike slip faults of any significant magnitude are unknown; however, in the south and southeast of our current workings, low angle and bedding plane faulting is common. The faults are low angle, dip S40°E and ramp upward along and across the bedding to the northwest. The principal fault planes are intensely sheared and brecciated and have been observed to contain slickensided PbS and FeS2. Displacement of bedded ore zones has
been observed but nowhere does it exceed about 5 feet (Figure 7 shows rib mapping of faulting). The observed relative age obviously is post-mineral.

These faults were first encountered as mining proceeded southward and eastward out of a structural low near the center of the ore body and up the dip slope to the south and east toward Fletcher. (Figure 6). Prior to recognition of these structures, certain features such as bedded breccias and their sometimes unusual geometry, reverse movement on marker beds, and mineralized low angle fractures were explained by dissolution within certain favorable beds with subsequent minor collapse and/or sagging of overlying beds. It is now suggested that some of these bedded breccias equally could be explained by gravity sliding down the dip slope from the south and producing pre-ore structures, many of which have been destroyed by subsequent dissolution and/or intense mineralization.

Tour

Specific plans for the tour of the underground workings cannot be formulated at this time due to potential problems in coordinating with mine production activities. Attempts will be made to arrange stops which will illustrate typical geological conditions.
REFERENCES

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PLAN VIEW "M" BED MINERAL ZONING
CENTRAL PART - WEST FORK ORE BODY
SCHEMATIC
TYPICAL ORE OCCURRENCE
IN MINING FACE

MODE OF MINERAL OCCURRENCE

Bedding Plane and Fracture Fill

Disseminated and Breccia Matrix Replacement

Bedding Plane and Fracture Fill

Disseminated, Breccia Matrix and Massive Replacement

Fracture and Bedding Plane Fill

Irregular Disseminated and Fracture Fill

FRACTURE/JOINT

GENERAL DESCRIPTION

Dense, Thick Even Bedded

Bedded Breccia

Dense, Even Bedded Brown Spotted Beds

Tan Carbonate With Mud Chips and Bands, Irregular Breccia

Tan Laminated Carbonate

Shaly Undissolved Residue

Marker Bed - Brown Spotted Beds

Tan Crystalline Laminated Carbonate W/Mud Chips And Bands

5 Feet
A. Structure on marker bed in mine
   CI = 1'

B. Structure on top of reefal facies from surface diamond drilling. CI = 5'

AREA OF LOW ANGLE FAULTS

FIGURE 6
Bedded Breccia Ore
and Massive Ore

Low Angle Reverse Faults

EAST LOOKING (OBLIQUE) CROSS SECTIONS OF
LOW ANGLE REVERSE FAULTING
ALONG TWO PRINCIPAL DEVELOPMENT DRIFTS

20 Feet
COMPARISON OF SULFUR ISOTOPE GEOCHEMISTRY OF THE WEST FORK AND FLETCHER MINES, VIBURNUM TREND MVT Pb-Zn-Cu DISTRICT, SOUTHEAST MISSOURI

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ABSTRACT

The West Fork mine and equivalent mineralization in the northern portion of the Fletcher mine exhibit an atypical, zinc-rich character compared to the rest of the Viburnum Trend MVT Pb-Zn district (including the bulk of the Fletcher mine), with a different sequence of mineral deposition and distinct mineral zoning. This “West Fork-type” mineralization is characterized by zoned deposition of abundant, fine-grained, early Zn-sulfides, followed by deposition of massive and colloform iron sulfides which are in turn followed by deposition of main stage octahedral galena. This sequence represents a major reversal in paragenesis with respect to the rest of the Viburnum Trend MVT ore district. This unusual mineralization also displays a different sulfur isotope behavior.

Main Stage sphalerite in West Fork-type mineralization has lower δ³⁴S values (-1 to +11) than Main Stage sphalerite in the rest of the Viburnum Trend MVT ore district (+12 to +26). Octahedral galena from West Fork-type mineralization displays lower δ³⁴S values (-1 to +19, avg. +10.3) more frequently than in the rest of the district (avg. +13.0).

The West Fork mine and West Fork-type mineralization in the northern portion of the Fletcher mine also display a sulfur isotope zoning pattern that mirrors their unique mineral and metal zoning. Where octahedral galena occurs by itself, its δ³⁴S values (+10 to +19, mean +13.2) resemble those of octahedral galena of the other mines in the district (mean +13.0). Anomalously low δ³⁴S values of octahedral galena in the West Fork mine (-1 to +10, mean +6.7) occur where lead sulfide mineralization overprints earlier main sphalerite and main marcasite mineralization.

These data indicate that West Fork-type octahedral galena mineralization likely incorporated ³²S-enriched sulfur from earlier sulfide mineralization, which implies that the fluids that deposited Main Stage octahedral galena in the West Fork mine and the northern part of the Fletcher mine were Pb-rich, but H₂S-poor. We believe that the fluid events and processes which led to deposition of West Fork-type mineralization were fundamentally different from those acting in the rest of the Fletcher mine, as well as in the rest of the Viburnum Trend.

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Figure 1. Map showing the location of various mines of the Viburnum Trend MVT Pb-Zn-Cu ore district, Missouri, relative to the platform edge (algal facies) of the Bonneterre Dolomite. Also shown are the Precambrian-hosted Boss-Bixby Fe-Cu deposits.

INTRODUCTION

Most mineralization in the Viburnum Trend MVT ore district (Fig. 1) conforms to a general paragenetic sequence (Fig. 2) which, with relatively minor variations, can be traced throughout most of the district (Hagni, 1986; Voss et al., 1989). Early podiform bodies of massive bornite-chalcopyrite (BORNITE PODS, Fig. 2) are found in several mines of the district. This mineralization replaces early, disseminated Fe-sulfides (DISSEMINATED, Fig. 2) and is replaced and cross-cut by chalcocite veins (VEINS, Fig. 2). Massive and disseminated sphalerite and massive and euhedral octahedral galena constitute the Main Stage Pb-Zn ores in the district. Massive chalcopyrite occurs before, during and after deposition of octahedral galena. Octahedral galena is affected by a major dissolution event that is followed typically by deposition of colloform Fe-sulfides. Vug-filling, cubic galena is the last lead-mineralizing event in the district and is followed by deposition of vug-filling sphalerite, chalcopyrite and Fe-sulfides (CRYSTALS IN VUGS, Fig. 2).
Figure 2. Generalized paragenetic sequence of sulfide ores in the Viburnum Trend MVT Pb-Zn-

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<td>Chalcoprite (Cu₃FeS₂)</td>
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<td>Lutzenite (Cu₃AsS₈)</td>
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**DISSEMINATED** | **BORNITE PODS** | **VEINS** | **MAIN Pb-Zn ORES** | **CRYSTALS IN VUGS**

**U = DISSOLUTION**
WHAT ARE SULFUR ISOTOPE RATIOS AND WHAT DO THEY TELL US?

Sulfur has four stable isotopes with approximate natural abundances of \( ^{32}\text{S} = 95.02\% \), \( ^{33}\text{S} = 0.75\% \), \( ^{34}\text{S} = 4.21\% \) and \( ^{36}\text{S} = 0.02\% \). The sulfur isotope composition of a sulfide is typically expressed as a \( \delta^{34}\text{S} \) value, which is defined as a per mil deviation of the \( ^{34}\text{S}/^{32}\text{S} \) ratio of the sulfide relative to that of the troilite phase (FeS) of the Cañon Diablo meteorite (thought to represent average solar system sulfur):

\[
\delta^{34}\text{S}_{\text{sulfide}} \% = \left[ \frac{(^{34}\text{S}/^{32}\text{S})_{\text{sulfide}}}{(^{34}\text{S}/^{32}\text{S})_{\text{standard}}} - 1 \right] \times 1000
\]

Sulfur isotope ratios of sulfides can potentially provide information about: (1) source reservoirs of sulfur; (2) temperatures of coprecipitated minerals; and (3) changes in fluid redox chemistry (Ohmoto and Rye, 1979). Sulfide minerals in southeast Missouri MVT deposits typically are not coprecipitated, but are deposited sequentially, so sulfur isotope thermometry is not feasible. Mineral assemblages in these deposits indicate that sulfide-depositing fluids are relatively reducing and acidic, so effects of changing fluid redox conditions on sulfur isotope systematics are not significant. Thus, for studies of MVT deposits of the Viburnum Trend, possibility (1), determination of source reservoirs of sulfur, is of greatest importance.

The \( \delta^{34}\text{S} \) values of sulfides in igneous rocks are typically near 0\%, whereas seawater and Paleozoic sedimentary sulfates have \( \delta^{34}\text{S} \) values of approximately +15 to +30\%. Sedimentary sulfides have a wide range of \( \delta^{34}\text{S} \) values, but are typically depleted in \( ^{34}\text{S} \) (Ohmoto and Rye, 1979); for example, diagenetic pyrite in the Bonneterre Dolomite has \( \delta^{34}\text{S} \) values as low as -10\% (Goldhaber and Mosier, 1989).

Using these end-member values as a guide to potential sulfur reservoirs in the West Fork and Fletcher mines, \( \delta^{34}\text{S} \) values approaching 15 to 20\% likely represent sulfur originally derived from sulfate sources by basinal brines; \( \delta^{34}\text{S} \) values closer to 0\% likely represent incorporation of sulfur from igneous sources and sedimentary rocks derived from them, possibly the granitic basement underlying the Viburnum Trend MVT district.
SULFUR ISOTOPE VARIATIONS IN THE VIBURNUM TREND

Figure 3 shows the $\delta^{34}S$ values for various stages of the generalized paragenetic sequence in most mines of the Viburnum Trend MVT ore district (Burstein et al., 1993). Each stage of the paragenesis displays a specific sulfur isotope signature and general variations in sulfur isotope compositions at particular paragenetic times are relatively similar throughout the district. The $\delta^{34}S$ values are initially low and display first an increase, then a sharp decrease, and a renewed increase with increasing time (Fig. 3).

The large variations of $\delta^{34}S$ values of ore minerals through paragenetic time in the Viburnum Trend MVT ore district (from values near -10% for Early bornite pods, toward 24% for Main Pb-Zn ores, toward -19% for Main marcasite, toward 27% for Late, vug-filling mineralization) (Fig. 3) can be explained by deposition from multiple fluids that had distinct sulfur isotope compositions. Two end-member sulfur reservoirs can be identified: a more $^{32}S$-enriched source and a more $^{34}S$-enriched source. The relative importance of these two sources varied, both temporally and spatially.

More $^{32}S$-enriched mineralization may reflect fluids moving through underlying granitic basement and sediments derived from it and/or the incorporation of sulfur from early diagenetic Fe-sulfides. More $^{34}S$-enriched sulfides indicate the introduction of another fluid, likely from basinal sedimentary sources. Complex mineral parageneses and sulfur isotope systematics in the Viburnum Trend MVT ore district reflect the presence of multiple, metal-specific fluids and multiple sulfur sources whose relative importance varied spatially and temporally during ore deposition (Burstein et al., 1993).

SULFUR ISOTOPE VARIATIONS IN THE WEST FORK AND FLETCHER MINES

Two hundred thirty-seven sulfide samples from the West Fork and Fletcher mines were analyzed for their sulfur isotope compositions. The entire annotated data set can be found in Burstein (1993). Sulfide minerals were oxidized to $\text{SO}_2$ by heating to 1100°C under vacuum with excess cupric oxide in the presence of metallic copper. Isotopic analyses of the $\text{SO}_2$ gas were performed in the University of Missouri-Columbia's Stable Isotope Geology and Geochemistry Laboratories. Sulfur isotope results are reported in standard $\delta$ notation as per mil (‰) deviations relative to the Cañon Diablo troilite
Figure 3. Variation of δ³⁴S values of the generalized paragenetic sequence of sulfide ores in the Viburnum Trend MVT Pb-Zn-Cu district. Note the initial low values of early sulfides, then an increase and decrease during Main Stage Pb-Zn deposition, and a progressive increase during Late Stage, vug-filling mineralization. Abbreviations: py = pyrite; bn = bornite; cc = chalcoite; mc = marcasite; cpy = chalcopyrite; mas = massive. From Burstein et al. (1993).
standard (CDT). The standard error for each analysis is less than \( \pm 0.05\% \).

**West Fork Mine**

The West Fork mine (Fig. 1) exhibits an atypical, zinc-rich character compared to the rest of the Viburnum Trend MVT Pb-Zn district, with a different sequence of mineral deposition (Figs. 4 and 5) and distinct mineral zoning (Fig. 6A) (Mavrogenes et al., 1992). This “West Fork-type” mineralization is characterized by zoned deposition of abundant, fine-grained, early Zn-sulfides, followed by deposition of massive and colloform iron sulfides which are in turn followed by deposition of main stage octahedral galena (Fig. 4). This sequence (octahedral galena deposition after iron sulfides) represents a major reversal in paragenesis with respect to the rest of the Viburnum Trend MVT ore district (Fig. 5). This unusual mineralization also displays a different sulfur isotope behavior.

Main stage sphalerite mineralization in the West Fork mine has lower \( \delta^{34}S \) values (-1 to +11\%) than main stage sphalerite in the rest of the Viburnum Trend MVT ore district (+12 to +26\%). Massive marcasite/pyrite in the West Fork mine have similar \( \delta^{34}S \) values (-8 to +17) to massive marcasite/pyrite in the rest of the district (-19 to +15\%), despite their reversed paragenetic positions relative to octahedral galena (Fig. 5). Octahedral galena from West Fork-type mineralization has \( \delta \, ^{34}S \) values of -1 to +19\% (avg. 10.3\%). Although this range of values is similar to that of main stage octahedral galena mineralization in the rest of the district (mean 13.0\%), lower \( \delta \, ^{34}S \) values for main stage octahedral galena mineralization occur more frequently in West Fork-type mineralization (Fig. 5).

**Sulfur isotope zonation in the West Fork mine:** Four mineral/metal zones are recognized in the West Fork mine, based on the presence of sphalerite, marcasite/pyrite and galena (Fig. 6A): (1) the inner zone consists of colloform sphalerite and marcasite (and/or pyrite), bordered outward by; (2) a zone of disseminated sphalerite; (3) a zone of colloform iron sulfides; and fringed by (4) outermost zones of galena that also overprint the inner zones. A chalcopyrite-rich rim has been found on the fringes of the orebody.

The West Fork mine mineralization also displays a sulfur isotope zoning pattern that mirrors its unique mineral and metal zoning (Fig. 6). A pronounced zoning of \( \delta^{34}S \)
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**Figure 4.** Paragenetic sequence of mineral deposition in the West Fork mine. Note the reversal in position of marcasite and galena relative to other mines of the Viburnum Trend (see Fig. 2). After Mavrogenes et al. (1992).

![Graphs showing paragenetic sequence and sulfur isotope data](image)

**Figure 5.** Comparison of δ³⁴S values of sulfide ores of the Generalized Paragenetic sequence in the Viburnum Trend MVT Pb-Zn-Cu ore district (see Fig. 2) and West Fork-type mineralization (see Fig. 4). Note the relative positions of octahedral galena and massive marcasite (mass. marc.) in each paragenesis and the differences in δ³⁴S values for Main sphalerite (sphal.). West Fork-type octahedral galena shows low δ³⁴S values more frequently than elsewhere in the Viburnum Trend MVT Pb-Zn-Cu ore district. From Burstein et al. (1993).
Figure 6. (A) Mineral/metal zoning at the West Fork mine (modified from Mavrogenes et al., 1992). Distributions of $\delta^{34}$S values of Main Stage (B) sphalerite, (C) marcasite and (D) octahedral galena in the West Fork mine. Note that lower values for each mineral are located in the eastern portion of the mine where the three mineralization stages overprint one another.
values closely related to the mineral zoning can be detected in all three main stages of mineralization (Zn, Fe, Pb, see Fig. 4). It is interesting to note that the lower $\delta^{34}$S values of sulfides from the various stages occur approximately in the same area of the mine, where the three stages of mineralization overprint one another (Fig. 6).

Higher $\delta^{34}$S values of West Fork-type octahedral galena mineralization (10.5 to 19.4‰, mean 13.2‰), similar to those of octahedral galena in the rest of the district (5.8 to 23.7‰, mean 13.0‰), occur where main stage octahedral galena mineralization does not overprint earlier iron and zinc mineralization (Fig. 6A and D). Lower $\delta^{34}$S values (-0.7 to +10.1‰, mean +6.7‰) occur where main stage octahedral galena mineralization overprints earlier main sphalerite and massive marcasite/pyrite mineralization (Fig. 6B, C, and D).

A statistically significant correlation ($r = 0.89$) exists between the $\delta^{34}$S values of early massive marcasite/pyrite and the $\delta^{34}$S values of later main stage octahedral galena from the same localities (Fig. 7). These data indicate that West Fork-type octahedral galena mineralization likely incorporated $^{32}$S-enriched sulfur from earlier sulfide mineralization, which implies that the ore fluids that deposited Main Stage octahedral galena in the West Fork mine were Pb-rich, but H$_2$S-poor.

**Figure 7.** Correlation between $\delta^{34}$S values of early massive marcasite/pyrite and later octahedral galena from the same localities in the West Fork mine and West Fork-type mineralization in the Fletcher mine.
Fletcher Mine

The Fletcher mine (Figs. 2 and 8) is situated on a buried Precambrian ridge that stood as a topographic high during deposition of the Cambrian Bonneterre Dolomite (Paarlberg and Evans, 1977). Sulfide mineralization follows a pronounced north-south trend. Mineralization at the north end of this trend is 300 m wide and 6 m thick and contains some of the better grade mineralization. The orebody is widest at the middle, where the Precambrian knob protrudes into the Bonneterre Dolomite. South of the Precambrian knob, mineralization narrows to less than 60 m and the grade drops significantly (Paarlberg and Evans, 1977). Two narrow, north-south breccia trends extend the full length of the mine. Mineralization occurs mainly as open-space and fracture fillings, with minor replacement of dolomite. The paragenetic sequence in this north-south trend conforms to the generalized paragenetic sequence (Fig. 2) described by Hagni (1986) and Voss et al. (1989). However, in the northernmost portion of the Fletcher mine, near the neighboring West Fork mine (Figs. 2 and 7), a different orebody (an extension of the West Fork-type orebody into the Fletcher property), shows a mineral paragenesis very similar to that described by Mavrogenes et al. (1992) for the West Fork mine (Fig. 4).

The $\delta^{34}S$ values of octahedral galena in the main north-south trend of the Fletcher mine (11.4 to 19.2‰, mean 14.0‰) are similar to those of octahedral galena from other mines of the district (mean 13.0‰) and no distinct sulfur isotope zoning is present (Fig. 7). However, in the northernmost portion of the Fletcher mine (near the neighboring West Fork mine), where octahedral galena postdates massive marcasite/pyrite deposition, $\delta^{34}S$ values of octahedral galena are 5.8 to 7.4‰ (mean 6.8‰).

These octahedral galenas from “West Fork-type” mineralization in the northern part of the Fletcher mine are also part of the correlation that exists between the $\delta^{34}S$ values of early massive marcasite/pyrite and the $\delta^{34}S$ values of later main stage octahedral galena in Figure 7. These data indicate that West Fork-type octahedral galena mineralization likely incorporated $^{32}S$-enriched sulfur from earlier sulfide mineralization, which implies that the ore fluids were Pb-rich, but H$_2$S-poor. We believe that the fluid events and processes which led to deposition of West Fork-type mineralization were fundamentally different from those acting in the rest of the Fletcher mine, as well as in the rest of the Viburnum Trend.
CONCLUSIONS

(1) The West Fork mine and equivalent mineralization in the northern portion of the Fletcher mine exhibit an atypical, zinc-rich character compared to the rest of the Viburnum Trend MVT Pb-Zn district (including the bulk of the Fletcher mine), with a different sequence of mineral deposition and distinct mineral zoning.

(2) The West Fork mine and West Fork-type mineralization in the northern portion of the Fletcher mine also display a sulfur isotope zoning pattern that mirrors their unique mineral and metal zoning. Where octahedral galena occurs by itself, its δ34S values resemble those of octahedral galena of the other mines in the district. Anomalously low δ34S values of octahedral galena in the West Fork mine occur where lead sulfide mineralization overprints earlier main sphalerite and main marcasite mineralization.

(3) The data indicate that West Fork-type octahedral galena mineralization likely incorporated 32S-enriched sulfur from earlier sulfide mineralization, which implies that the ore fluids were Pb-rich, but H2S-poor. Fluid events and processes which led to deposition of West Fork-type mineralization were fundamentally different from those acting in the rest of the Fletcher mine, as well as in the rest of the Viburnum Trend.
ACKNOWLEDGMENTS

Acknowledgment is made to the donors of the Petroleum Research Fund, administered by the American Chemical Society (PRF-19809-AC2-C and PRF-25926-AC8) and the National Science Foundation (NSF-EAR-9001986 and NSF-EAR-9104590) for support of this research.

REFERENCES


This paper summarizes one portion of detailed regional sulfur isotope studies, whose results are being submitted to Economic Geology.
GEOLOGY OF THE FLETCHER MINE, VIBURNUM TREND,  
SOUTHEAST MISSOURI  

N.L. PAARLBERG, L.L. EVANS, and G.A. CHILDERS  

Introduction  

Following the discovery of lead in the Viburnum area, exploration spread southward during 1957. Encouraging results were immediately forthcoming as the first pay hole in the Fletcher area was cut in the summer of 1958. In June 1963, St. Joe Minerals Corporation authorized the development of a 14 million dollar, 5,000 ton-per-day facility located in Reynolds County, 6 miles east of Bunker, Missouri. Shaft-sinking started during the week of July 14, 1964. The 1,334-foot, 12.5 foot diameter shaft bottomed on November 23, 1965. The mill began operation February 28, 1967.  

Structural Setting  

The Viburnum Trend is in the stable interior region of the central United States. The structure is simple, consisting of essentially flat-lying sedimentary carbonates, shales, and sandstones overlapping a Precambrian erosion surface of igneous intrusive and extrusive rocks. The St. Francois Mountain complex, the dominant structural feature of the region, lies about 40 miles east of Fletcher. This complex, as well as smaller outlying igneous knobs, were positive areas during Late Cambrian deposition. The Fletcher Mine is situated on one of these smaller outlying knobs. This positive structure influenced variations on the environment of sedimentary deposition resulting in distinct facies patterns. The Bonnerterre Formation at Fletcher consists of the following facies: offshore deposits, algal stromatolites, reef complexes, back reef carbonates, off-reef sands, and shelf carbonates.  

Fracturing is common, particularly around the flanks of the knobs and a well developed east-west fracture network is developed throughout the mine, but no major faults are present in the Fletcher mine area.  

Stratigraphy  

Late Cambrian sedimentation began with the deposition of the Lamotte Sandstone, a clean orthoquartzite that is fine grained, friable, porous, permeable, and commonly cross bedded.  

The Bonnerterre Formation conformably overlies the Lamotte Sandstone and is the host rock for the base metal mineralization in the Fletcher mine area. It was deposited initially as a limestone but was dolomitized during lithification or shortly thereafter. The back reef environment consisted of algal boundstones and burrowed lime mudstones. The reef facies is composed of algal boundstones with digitate stromatolites. Clastic carbonates and reef debris fill local erosion surfaces. Interbedded shaly lime mudstones predominate in an offshore facies. Lime grainstones and wackestones, separated by the Sullivan Siltstone Member,
blanket the entire area. A description of these is given by Gerdemann and Myers (1972).

The principal stratigraphic units of the Bonneterre Formation found within the Fletcher mine are shown (figure 1). Overlying the algal stromatolitic reef are the 5 zone clastic carbonates. At the base of this unit are dense, tan crystalline, oolitic dolomites that represent a bar at the front of active reef growth (Gerdemann and Myers, 1972). The compact characteristics of the oolitic beds limits the mineralization of fractures and solution cavities. This accounts for less than 1 percent of the ore. Overlying the tan oolitic dolomites are the upper 5 zone clastic grainstones. This zone is made up of porous, thick-bedded oolitic dolomites that contain scattered brown spots, some of which are thrombolitic stromatolites. Separating the thick porous beds are several dense thin beds which serve as marker beds throughout the Fletcher mine. These thin dense beds are marked by prominent oncolite development which essentially the whole bed is made up of them. Ore is generally disseminated in the porous, thick-bedded oolitic unit that has a pseudobreccia texture, but vertical and horizontal fracture filling is also prominent. The upper 5 zone grainstones account for 92 percent of the ore. The Sullivan Siltstone Member, a thin laminated quartz siltstone that is the principal marker bed at Fletcher, separate the 5 zone from the thin-bedded mudstones and grainstones of the 1 zone unit at the top of the Bonneterre.
The Davis Formation overlies the Bonneterre. It consists of interbedded shales, carbonates and sandstone, along with flatpebble and edgewise conglomerates.

Other Cambrian formations present in the mining region, in ascending order, are Derby-Doerun Dolomite, Potosi Dolomite, and Eminence Dolomite.

**Mineralization**

Galena is confined to the 5 zone clastic grainstone unit, except in portions where the Sullivan Siltstone Member, normally the cap rock of mineralization, is brecciated and fractured by slumping and solution collapse. Here galena mineralization extends into the 1 zone mudstones and grainstones and locally into the Davis Formation.

The mineralization at Fletcher exhibits a pronounced north-south trend. It is continuous throughout the area, but the grade of ore varies greatly. The mineralization at the north end is 1,000 feet wide, averages 20 feet thick, and contains some of the better grade mineralization. The ore body is widest in the middle of the mine where an arc-shaped porphyry knob protrudes into the Bonneterre Formation. The orebody conforms to the changing strike of the beds as they drape over the knob. It divides south of the shaft where an elongated area of trace mineralization is surrounded by high-grade ore. The east side of the orebody overlies the axis of the Precambrian high, and the west side of the orebody is over the Lamotte pinchout. The two sides unite along the south flank of the porphyry knob. At this point the mineralized zone thickens in include the brecciated lower Davis Formation. South of the Precambrian knob, mineralization narrows to less than 200 feet and grade drops significantly.

The lead-zinc-copper ratios are approximately 40-4-1. The majority of sphalerite tends to occur within the extreme high grade zones of galena mineralization. Chalcopyrite distribution appears to be erratic in its distribution and occurs in major collapse zones located in the upper 5 zone. Calcite appears along the east-west fractures within the mine, as well within dissolution zones in the upper 5 zone.

The principal occurrence of the ore at Fletcher is open-space filling as banded disseminations of galena in porous beds and as thin seams along bedding planes. Sphalerite mineralization also occurs as banded disseminations, usually within the areas of higher grade galena mineralization. The fine grained texture of the sphalerite makes its identification difficult. There are at least six different colored sphalerites in the Fletcher mine. The colors are as follows: Black, Olive Green, Red, Yellow, Brown and Orange. Chalcopyrite commonly occurs as bands of replacement along bedding planes as well as massive replacement beds (over 5 feet thick) with collapse zones and as euhedral crystals in open spaces within cavities.

Although banded disseminations are the most common occurrence of galena, ore at Fletcher occurs in many different forms. Cross-cutting
veins are common. Many extend from the banded disseminated ore into thick seams of galena along bedding planes where galena occurs as open-spaced filling with minor replacement of the dolomite.

Galena is also found in porous beds that are separated by dense, unmineralized beds. The dense algal oncrites of the brown-spotted beds have secondary dolomite and calcite as common gangue minerals. Galena is typically concentrated above or below these brown-spotted beds. Their dense characteristics prevent mineralization from passing through them; however, when they are fractured, galena fill the fractures, and both upper and lower beds are mineralized.

Along the outer edges of orebodies, and principally on the west side of the trend, secondary dolomite fills the open spaces of the porous beds. These dolomite-filled beds often occur interbedded with dense, tight beds that thicken in and out. Often they unite to form areas of intense, open, solution breccia zones, where even the dense brown-spotted beds may be mineralized. These beds exhibit open-space filling characteristics. To the west, dolomite filling becomes more dominant, and galena is often absent, even though the beds are quite porous.

Solution breccia zones are most frequently found in orebodies on the west side of the trend. They are characteristically porous, and late-stage euhedral chalcopyrite is common. In certain cases coalescing breccias breccias lenses unite to form solution breccias at least 30 feet thick. The vugs and openings show casts of dolomite and chalcopyrite where galena octahedrons have been dissolved and removed. The chalcopyrite and dolomite apparently were unaffected by the dissolving solutions. The porous nature of these breccias is caused by the removal of the galena. The lead may have been remobilized and transported only tens of feet, as solution breccia areas adjacent to enriched zones of mineralization with grades of galena higher than normal. Although cubic galena is late and commonly occurs on top of octahedral galena, it has been dissolved in these areas, along with octahedral galena.

The Sullivan Siltstone Member normally is the cap rock to mineralization at the Fletcher mine. Galena mineralization may be intense up to the siltstone and often is very high grade just below it. Mineralization fills fractures and surrounds angular blocks and broken beds alone portions of the discontinuous linear breccia trends where the Sullivan Siltstone Member has slumped or collapsed in dissolution sags at the top of the upper 5 zone. It appears that mineralization within the upper 5 and Sullivan Siltstone has a zonation pattern based on crystal morphology. The central core of the breccia trend contains a weakly mineral zone of cubic galena. The west and east sides of the breccia trend contain the highest grades and essentially are octahedral galenas with minor sphalerite and chalcopyrite. Where brecciation is intense, galena mineralization extends through the 1 zone mudstones and grainstones along upward radiating fracture networks into the Davis Formation. In a few areas, this has produced thicknesses of up to 120 feet of continuous galena mineralization.

Acknowledgements
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INTRODUCTION

The Asarco Sweetwater Unit, consisting of an underground lead/zinc mine and mill, is the southernmost mine of the Viburnum Trend. It is located 7.5 miles southeast of Bunker and 13 miles northwest of Ellington, Mo. (Fig. 1).

Formerly owned and operated by Ozark Lead Company, a division of Kennecott Corporation, the orebody was discovered in January, 1962. Mine production began in June, 1968 and continued for over 15 years until Ozark Lead halted production in 1983 due to declining lead prices. In late 1986, Kennecott sold the Ozark mine to ASARCO, Inc. Asarco restarted operations at Sweetwater in December, 1987. Current production is at a rate of 3,400 tons of ore a day. At full production, the mine is rated as having the capability of producing 5,000 tons per day of ore grading 4.8% lead and 0.6% zinc.

Prior to terminating operations, Ozark Lead Company completed installation of new production facilities from an adjoining and interconnected mine, located immediately to the south. Asarco, following the completion of scheduled renovations, plans additional ore production from the new mine.

The open stope, room-and-pillar method is used to mine the multilevel orebody. The support pillars are 32 feet in diameter on 64 foot centers. Ore moved by truck is passed through raises between levels to a diesel rail-haulage system on a sublevel. The rail cars automatically dump into a 48x60 inch jaw crusher that reduces the material to minus six inches. The crushed ore drops to a 300-ton capacity skip pocket to be loaded into twin 15-ton skips for automatic hoisting to the surface.

Lead concentrates from the mill are trucked approximately 40 miles to the Asarco Glover plant. The plant smelts and refines the lead concentrates. The zinc concentrates are trucked to the Big River Zinc Plant in Sauget, Illinois for processing. Minor amounts of copper, silver and cadmium are recovered from the lead and zinc concentrates.

The Sweetwater Orebody, when considered as a whole, consists of a narrow, sinuous trend of lead, zinc and minor copper mineralization.
that extends for a distance of about 7 miles. The trend strikes north and northwest. Mineralization is fairly continuous, but the ore grade, width and thickness are variable throughout the length. The width ranges from 100 to about 1,000 feet and the thickness from a few inches to over 100 feet.

The trend is subdivided into three separate orebodies designated 8, 7 and 6 as numbered from north to south and from larger to smaller, respectively (Fig. 2). To date, most of the production mining has come from No. 8 orebody. Some development drifting and minor ore production have taken place in the northern end of the No. 7 orebody. No mining has occurred in the No. 6 orebody.

Fig. 2. Relative locations of Sweetwater Orebodies
GEOLOGIC SETTING

The three Sweetwater orebodies are partitioned by two faults consisting of the Sweetwater fault that lies between orebodies 8 and 7 and the Suses Branch that separates No. 7 and 6 orebodies (Fig. 2). The faults strike northwest and dip steeply to the northeast. Exhibiting a reverse relationship, the north sides of the faults are upthrown with vertical displacements of about 100 feet for the Sweetwater and about 40 feet for the Suses Branch. The Sweetwater fault is also known to have a strike-slip component of movement.

Although the orebodies have many geological characteristics in common, significant structural and stratigraphic differences make each of them unique as compared to the other. Located east of the limestone/dolostone lithofacies boundary in the Bonneterre Formation, the orebodies are hosted entirely by dolostone but occupy different positions relative to Bonneterre facies patterns (Fig. 2 and Fig. 3). Their positions differ in relation to the western limit of the "white rock" margin. The more basinward No. 8 orebody is located west of the "white rock" boundary. No. 7 straddles the fringe and No. 6 orebody lies in a more shoreward position east of the "white rock" edge.

Fig. 3. Generalized divisions of the Bonneterre Formation, Sweetwater Mine and cross sections showing approximate position of orebodies 6, 7, and 8 relative to Bonneterre facies distribution. (modified after Larsen, 1975).
When considered on the whole and as individual ore deposits, over 80% of the blocked ore reserves lie above the "reef" (Fig. 3). There are some locally significant reserves in No. 8 orebody within the reef. Conversely, an insignificant portion of the reserves is located in the "white rock" dominated lower Bonneterre sections of 7 and 6 orebodies.

The much thicker No. 8 orebody is predominately a breccia deposit with dominant structural controls; whereas, the two southern orebodies, which are thinner and more strataform in profile, appear to be more stratigraphically controlled.

A distinctive characteristic of much of No. 8 orebody is its northwest strike direction. It lies at right angles to the north-northeast regional depositional strike of the Bonneterre Formation. Conversely, portions of No. 8 and most of 7 and 6 orebodies are largely congruent with the Bonneterre facies (Fig. 2 and Fig. 3).

GEOLOGY OF NO. 8 OREBODY

The principal trend direction of the No. 8 orebody is southeast to northwest. In addition, there are important appendages that extend to the north, northeast and south off of the main trend. In most instances the ore appears to be grossly controlled by a series of Precambrian ridges or knobs. Relief on the knobs was such that the Lamotte and lower portions of the Bonneterre were pinched out against them. Their position, as depicted by isopach contours of the Lamotte, is shown relative to the orebody trend and other geologic features in Figure 4. Assuming that the map accurately reflects the position of the basement highs at the time of ore deposition, the ore is known to occur in a variety of positions relative to the ridges, but shows no consistent position preference. Other maps based on elevation contours of various marker units in the Bonneterre show similar broad relationships, but also lack specific correlations of how the ore is distributed relative to the basement highs. Ore occurs on both the crests and flanks of highs and to some extent between knobs. Proportionally, the ore is more abundant on the north flanks of knobs than on the south flanks. In other examples, ore encircles other knobs in doughnut fashion. A northeast trending ore segment extends several thousand feet beyond the nearest known basement knob. In this case the ore follows a broad ridge that is evident from elevation structure contours on top of the R-2 zone reef.

The relationship of the orebody to the pinch-out of the Lamotte is also inconsistent. A greater portion of the ore is situated proximate
to where the Lamotte begins to thin, but is laterally separated several hundred feet down slope from the pinch-out. Locally, ore does occur selectively in the Bonneterre section above the pinch-out of the Lamotte, preferentially but not exclusively, in the lower "reef" ore zones. Ore grade mineralization is not known to occur in the Lamotte sandstone, in the sandy dolostone transition zone, or at contacts between the Bonneterre and basement rocks where the Lamotte is absent.

Stratigraphy and ore zones

In the No. 8 orebody mineralization is blocked and has been mined from 10 different mining zones (Fig. 3). They consist of vertically intermittent mineralization of selective horizons that extend from near the top to bottom of the 300 foot thick Bonneterre Formation. In portions of the orebody ore grade mineralization is present in all 10 zones. Although variable in width and thickness, they are essentially stacked one over the other. The zones are frequently vertically interconnected with narrow and weak mineralization. However, it is more typical to find that the vertical continuity is poorly developed and one or more of the upper or lower zones will lack ore grade mineralization.

Each zone represents a discrete stratigraphic unit in which it is common to find ore ponded in a favorable unit below a more impervious one. However, mineralization is generally absent where structural preparation is weak or lacking. Thus, lateral and vertical ore distribution depend upon the subtle interplay of stratigraphic and structural features. This takes place simultaneously at several different scales ranging from microscopic to regional.

The bulk of the ore blocked in the No. 8 orebody lies in the middle portion of the Bonneterre Formation in the Q1, Q2, Q3 and P ore zones above and in contact with an unconformity. The unconformity lies at a point separating two different sedimentary cycles (Larsen, 1977). As shown in the generalized cross section in Figure 3, it lies at a conspicuous reversal of Vs formed by different Bonneterre facies. The reversal occurs when there was a shift from a dominantly regressive to one of a transgressive environment. According to Larsen (1977), the general stratigraphic relationships record a prograding sedimentation during lower Bonneterre time. This prograding culminated in an unconformity in the mine area at the end of lower Bonneterre deposition. The unconformity, which is positioned at the top of the main mass of the digitate stromatolite reef, is best developed in the more shoreward eastern portion of the orebody. Eastern mine exposures reveal an irregular paleotopographic surface
that exhibits erosional relief of up to 10 feet. The crestal portions of the elevated irregular surface are emphasized by bleaching of the medium brown dolostone to a light tan to white color. An assumption common to most geologists of the district is that the bleaching is caused by subaerial exposure. The relief and bleaching on the unconformity become increasingly less pronounced until they are largely absent toward the more basinward, west end of the orebody. The Q1 zone, which lies immediately above the unconformity, represents the beginning of a transgressive period.

In the eastern one half of the orebody a second zone of digitate stromatolites (Q2 zone) lies in contact with the Q1 zone (Fig. 3). According to Larsen (1977), this zone of digitate stromatolite represents a 6,000 foot shift of the "reef" environment to the east. Based on exposures in the mine, the Q2 reef lacks the erosional relief and crestal bleaching typical of the R-2 unconformable surface. A well developed oolitic grainstone and packstone formed immediately west of this uppermost zone of digitate stromatolite growth. The general strike direction of the Q2 reef is to the northeast. This strike is disrupted by basement Precambrian highs (Fig.4). The basement highs caused narrow appendages or lobes of the reef to be extended several hundred feet to the west. Conversely, the reef retreated eastward in the structurally lower areas between the highs. This facies change in the Q2 zone, which is well exposed in the western mine workings, appears to coincide with fundamental changes in the geometry and continuity of the orebody.

Breccia

The bulk of the ore in the No. 8 orebody is hosted by a central breccia and by associated parallel breccias present along each flank (Fig. 4 and 5). The bordering breccias are referred to in local mine terminology as "marginal break zones" and will be discussed separately. The term breccia is applied loosely here. It encompasses a range of structural preparation that varies in intensity from mildly dilated beds with little distortion to chaotic rubble.

The Sweetwater breccias are interpreted to have formed in multiple stages as listed in order of occurrence:

1. An initial stage that involves gravity sliding off of local highs,
2. Further brecciation induced by carbonate dissolution,
3. Brecciation formed by gravity sliding in response to voids created by earlier solution brecciation,
4. Further solution brecciation and additional response
Fig. 4. Relationships of NO. 8 Orebody to Lamotte pinch-out, breccia trend and Q2 "Reef" facies.
structures. The development of the aforementioned model is credited to former Ozark Lead Company geologists Larsen and Clendenin and is largely extracted from their previous work (Larsen and others, 1979 and Larsen, personal communication, 1988). The writer notes that he has also mapped many of the structures relevant to the model and concurs with its fundamental premise.

![Diagram of Breccia Structures](image)

Fig. 5. Schematic cross section of the Bonneterre showing gravity slide and subsequent solution collapse breccia structures (after Niewendorp, 1987).

Probably after burial but prior to complete lithification, various units of the Bonneterre Formation slid downdip off local highs. The sliding is characterized by bedding plane slickensides with an apparent downdip direction of movement, shear fractures concordant with the bedding, folding and multiple overthrusts. Structures at the boundaries of the slide zone are typically indistinct. Nonetheless, remanents of distinguishable structures are present often enough to assign definitive descriptions, relative positions and a structural interpretation of their origin (Fig. 6). The updip edge of the breccia, which consists of an extensional regime, consists of a cusp-shaped listric normal fault. Multiple listric faults may be present in a lateral sense and stacked vertically in section. In the downdip compressional regime various structural forms were fashioned ranging from mild fracturing to an asymmetrical fold with outward thrust faulting through its crest.

Total lateral displacement is difficult to determine. Possibly it amounted to a few feet, but more probably it was only a few inches. Nonetheless, it appears that there was movement enough for sufficient
Fig. 6. Schematic cross section of Sweetwater gravity slide zone (after Niewendorp, 1987).

structural preparation to allow for the access and concentration of ore fluids. These, in turn, generated solution collapse brecciation which obscured the earlier sliding.

The base of the slides is present in the Q1 zone immediately above the digitate stromatolite boundstone (Fig. 5). Multiple slides, which responded to the same high and lie above the Q1 zone, moved independently at various stratigraphic levels.

When the initial sliding occurred is open to question, though the presence of slickensides usually at the base of the slide indicate that lithification had already begun. The gravity sliding probably took place after burial but prior to complete lithification in decollement fashion, rather than as slumping penecontemporaneous with deposition.

The central solution collapse breccia, which strikes to the north and northwest, is remarkably continuous in strike, stretching for several thousand feet (Fig. 4). It extends both parallel to and across the depositional strike of the sediments as it roughly follows the aforementioned series of Precambrian knobs. Locally the breccia is very sinuous in strike and variable in width. Right angle turns are fairly common. The width of the breccia pinches and swells from 80 to 300 feet. Typically, a reduction in width takes place during the course of a rapid change in strike direction.

The width is also narrower on the average in the western one third of the orebody. Ranging from 120 to 150 feet thick, the breccia occupies the middle and upper portions of the Bonneterre. It begins at the top of the Q2 zone digitate stromatolite in the eastern one half of the mine and at the top of the main reef (R-2 zone) west of the Q2 reef facies. The upward extension of the breccia reaches to the base
of the Davis shale. In the eastern one half of the orebody the base of the breccia is generally basin shaped and is commonly bordered by inward-dipping listric faults of 45° to 60° that are concave upward. Faults along the margins of the upper portion of the breccia dip outward at 70 to 80°. They exhibit a reverse relationship where the edge of the breccia collapses down and inward. Shale and glauconite from the Davis Formation are present in wedge shaped openings in these faults. Bedding in the lower one half of the breccia is chaotic with angular rotated blocks. Gray beds that normally lie 10 to 12 feet above the top of the uppermoststromatolite zone have been broken and down-dropped. Typically, the breccia zone as compared to a normal section is thinned by 20 to 30%. Vugs, cavities, enlarged fracture openings, watercourses, and shaley insoluble residues attest to the removal of substantial amounts of material. In the upper breccia zones the bedding is less disturbed. Thick intervals of section appear to have partially collapsed forming a sagged beam. Locally, fracturing and brecciation are intensified along the breccia margins.

The breccia, which is fairly continuous in the western one half of the orebody, changes in character as it responds to different stratigraphic and structural conditions. The gray beds increase in number and thickness toward the west. Solution thinning in the breccia is less pronounced, although brown units that lie between the less susceptible gray beds have been selectively thinned or are completely missing. Locally, bedding appears deceptively undisturbed until compared to a normal section a few feet beyond the breccia edge.

The breccia trend becomes more narrow and intermittent as the orebody crosses between two large basement highs (Fig. 4). In this area the breccia forms over the crests of narrow, linear arch structures. As observed in the mine, the R-2 reef stands up in relief by as much as 10 feet. The breccia, which is present over the top and flanks of the structure is in contact with the top of the reef. Evidence is insufficient at this time to interpret the origin of the arch structures.

Further to the northwest the breccia and associated arch structures become more continuous as the orebody crosses the large westernmost high.

Ore grade mineralization is almost as continuous as the breccia, but is typically more concentrated along the breccia edges and near the base. Galena is the principal breccia ore mineral with minor amounts of sphalerite, chalcopyrite and iron sulfides. Mineralization is typically bedded and disseminated replacement. Open-space
fillings, although common, are less abundant. Euhedral crystals of galena consist of the more common, early stage octahedral variety with minor late stage cubic galena. In the eastern breccia, galena is characteristically etched and corroded, suggesting that the remobilization of galena has occurred (Clendenin, 1977). Chalcopyrite and iron sulfides are typically present along the margins of the breccia. Euhedral crystals white sparry (hydrothermal) dolomite commonly fill vugs and fractures throughout the orebody. They are particularly abundant in the eastern breccias.

PARALLEL MARGINAL BRECCIAS

In the eastern two thirds of the No. 8 orebody breccias lie off the flanks of and strike parallel to the central breccia zone (Fig. 5 and Fig. 7). The peripheral breccias (marginal breaks), which often contain high grade ore, are laterally separated from the central

Fig. 7. Portion of the orebody showing the parallel relationship between the central breccia and marginal breccia zones.
breccia by a zone that is barren of brecciation and mineralization. At least one of the marginal breccias, usually located on the updip side, is continuous in strike as it follows the central breccia. The downdip flanking breccia is less continuous, narrower and poorly mineralized. The width of the marginal breccias range from 30 to 100 feet. In the western one third of the orebody, the marginal breccias are poorly developed to nonexistent both in terms of brecciation and mineralization.

The marginal breccias have a large vertical extent relative to their width. They are more or less vertically continuous from the top of the gray beds (upper Q3 zone) to the J2 zone. Thus, they occupy about the same portion of the section as the central breccia with one significant exception. The base of the marginal breccias rests 10 to 15 feet above the bottom of the central breccia.

Solution brecciation has also taken place in the marginal breccias. Nevertheless, ore controlling structures have been preserved as remnants of structural development occurring prior to the solution activity. They consist of well-defined, listric shaped normal faults. These structures have been interpreted by Larsen and Clendenin (1979) as pull-apart structures that formed by gravity movement in response to the partial void created by solution thinning in the central breccia. The response listric faults have pronounced reverse drag and deformation in the footwall. Ore generally occurs on the footwall side of the faults. The listric faults exist as separate faults that are stacked more or less vertically at various stratigraphic horizons, rather than as one single throughing fault (Fig. 5).

STRIKE-SLIP FAULTING

Ore concentrations in selective areas of the western portion of the No. 8 orebody are in part influenced by zones of vertically dipping east-west faults. Also present are other vertically dipping faults that are closely associated with and subordinate to the east-west faults. Field observations suggest that the various faults had more than one period of movement and are both pre- and post-ore.

Knowledge of the distribution of the faults is incomplete. Insofar as they are known from mine exposures and from a limited number of exploration core holes, they are chiefly concentrated in the northwest section of the mine north of the central breccia. Although less abundant, they are also present in mine exposures south of the breccia (Fig. 4 and Fig. 8). East-west fractures are frequently congruent with and closely associated with the southern boundary of east-west segments of the central breccia in the west end of the mine.
Periodic and indistinct traces of east-west fractures are present within the central breccia and are interpreted to have been preserved as remnants of the solution collapse. As indicated from drill core, the east-west faults extend for several thousand feet to the west and north of the known limits of the orebody.

Knowledge of the vertical extent of the faulting is also incomplete. Exposures of the faults in the mine are confined to the middle Bonneterre. As interpreted from drill core, they extend into the underlying Lamotte sandstone and penetrate into the overlying Davis Formation.

The main east-west faults are en echelon in strike and in section and exhibit strike-slip movement. It is usually difficult to determine the amount of horizontal offset, but it appears to range
from fractions of an inch to up to 75 feet (Taylor, 1983). Field evidence for the strike-slip movement includes:

1. Horizontal slickensides in the fault plane oriented parallel to strike,
2. Apparent vertical displacement produced by horizontal movement coupled with gently dipping strata. And along the same fault plane, opposite apparent vertical displacement as the dip of the beds change along the strike of the fault,
3. Slickensided ore and offset ore edges and
4. Offset fold axis.

The faults are typically accompanied by a gray-green K-feldspar alteration that locally extends outward from the fault planes into the surrounding rock. Fault plane brecciation is common and occasionally includes breccia fragments of the altered dolostone. Mineralization in the fault planes is characterized by various late stage varieties, including marcasite, pyrite, chalcopyrite, sparry dolomite and calcite. Typically, galena and sphalerite are conspicuously absent from the fault planes, even though they may be abundant in the surrounding rock. In those instances where galena is present in the fault planes, euhedral crystals consist of the late stage cubic variety. The earlier octahedral galena is missing from the fault planes, even though it commonly exists in vuggy rock near the fault planes.

It is evident that the mineralized east-west faults functioned as conduits for at least some of the lead ore and that other ore was displaced. However, it is unclear as to the magnitude of their control over ore distribution. There were other controls and constraints operating in concert with the east-west faulting that have dictated ore distribution. For example, individual ore runs in the northwest portion of the orebody typically trend north-south. They cross multiple east-west faults unaffected. Ore edges do not extend outward along the strike of the faults. Yet, some lateral ore edges appear to be displaced by east-west faulting. East-west faults cut across large barren islands within the orebody and extend well beyond the known limits of the orebody.

Temporal relationships between the east-west faulting and gravity sliding are also unclear. Evidently, the latest period of movement post-dates gravity sliding, because vertical fault planes are not laterally offset.

The east-west faults consist of a system made up of a primary set of wrench faults with left-lateral displacement and other faults and
folds formed in association with the main wrench faulting. The faulting and accompanying structures form patterns comparable to experimentally produced wrench fault systems described as Riedel's model for simple shear (Larsen, personal communication, 1988; Taylor, 1983; Closs, 1928; Riedel, 1929; Morgenstern and Tchalenko, 1967). There are six principal elements in the wrench fault model. These are discussed as follows along with a description of what are interpreted to be structures at Sweetwater that coincide with the model (Fig. 9):

1. Major wrench fault system - At Sweetwater this main wrench system consists of a series of multiple vertical faults that strike N65 to 75°W. In terms of the amount of displacement, width and continuity of strike, this set dominates over other faults. Lateral displacement is left-lateral. Vertical displacement measures up to one foot. Horizontal slickensides and/or breccia are commonly found in the fault plane.

2. Riedel synthetic strike-slip fault - This group of vertically dipping faults, which is subordinate to the main wrench system, strikes N85°W and forms an en echelon pattern along the main fault zone. The strike-slip displacement direction is left-lateral.

3. Ridel conjugate (antithetic strike-slip fault) - This set, which occurs much less frequently in the mine, has a vertical dip and strikes about N30°E. It forms a 60° angle with its conjugate and an 80° angle to the main wrench direction. The theoretical relative direction of displacement is right-lateral. The direction of movement has not been observed by the writer. It was described by former staff geologist Don Taylor (1983). The bisector of the acute angle between the two sets of Ridel's forms a direction of N35°E. This would correspond to a theoretical direction of maximum compressive stress for the entire system.

4. P-shears - This set, which has also developed in an en echelon pattern along the main fault system, forms an angle to the main wrench direction of about 5 to 10°. This results in a strike of about N60 to 65°W. The relative direction of movement is left-lateral.

5. X-shears - According to the experimental model this set of faults forms an angle of 75° with the main wrench direction. This should result in a strike direction of about N50°E at Sweetwater with right-lateral strike-slip displacement. This strike direction has not been observed by the writer. Nevertheless, numerous vertical fracture (faults ?) strike at N5° to 10°W and are evidently associated with the wrench fault area. These fractures may represent the X-shear faults predicted by the model.
6. Other compressive features (folds, thrust or reverse faults) - The writer is unaware of any thrust or reverse faults associated with the wrench faults at Sweetwater. Folds were mapped by former staff geologists Clendenin (personal communication, early 1980's) and Taylor (1983) in the northwest section of the mine. They are described as a series of low magnitude asymmetrical anticlines arranged in an en echelon pattern. Their axial traces, which form an angle of 15 to 30° with the strike of the main wrench faults, strike at N40° to 55°W. Taylor (1983), who described the folds as a left hand fold set, cited this as evidence to support left-lateral apparent movement of the fault system.

Fig. 9. Sweetwater strike-slip faulting as compared to Riedel's (1929, and Tchalenko's (1967) models for left-lateral simple shear (modified after Taylor, 1983.)
NO. 7 OREBODY

Because mine exposures are very limited and restricted to the northern end of the ore deposit, the geology of the No. 7 orebody remains largely undefined, making the discussion that follows somewhat premature.

Knowledge of geologic relationships is based on information mostly derived from exploration drill core. The orebody is stratabound and fairly strataform in cross section. Over 90% of the blocked ore reserves are hosted by the P zone (Fig. 3). In regard to Bonneterre facies, the ore is located several hundred feet further shoreward as compared to No. 8 orebody (Fig. 2 and Fig. 3). Consisting of a porous, brown oolitic grainstone with local interbedded burrowed mottled wackestones, the P zone marks the beginning of the middle Bonneterre transgressive period. The orebody, which is mostly confined to this zone, is constrained at the top by the relatively impervious mottled unit (Fig. 3). The P zone ore climbs the Bonneterre section from west to east. As measured from the top of the Bonneterre, the elevation increases from 175 feet down to 120 feet below the top. The base of the ore overlaps the intertongued facies of digitate stromatolite and planar stromatolite/white rock facies.

P zone lead mineralization is widespread. Sub-ore grade, sporadic mineralization extends for several hundred feet east and west of the blocked ore boundaries.

Structurally, the No. 7 orebody consists of a bedded breccia. It is porous and vuggy but overall solution thinning is minor. The bedding is dilated and locally distorted. Bedding plane shear fractures are common. Ubiquitous sparry dolomite fills the various types of open spaces.

The applicability of the gravity slide model to No. 7 orebody, although appealing, remains an open question at this time; but because of the relationship of ore to slopes, it may prove valid for this orebody as well.

East-west and north-south fracturing are present locally in mine exposures but have not yet been evaluated as to their significance as related to ore distribution. Mineralized faults are cut by exploration drill core. The orientation of the faults, sense of movement and age relative to mineralization are not presently known.

MINE TOUR

Because of the access problems associated with an active mining operation, specific tour stops have not been selected at this time.
Insofar as possible, various sites will be selected and described prior to the tour, so as to demonstrate as many characteristic features of the orebody as is practical.

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