GEOLOGY, PARAGENESIS, AND GEOCHEMISTRY OF SPHALERITE MINERALIZATION AT THE YOUNG MINE, MASCOT-JEFFERSON CITY ZINC DISTRICT, EAST TENNESSEE,

by

Jonathan R. Caless

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APPROVED:

James R. Craig, Chairman

J. Donald Rimstidt

J. Frederick Read

Frank D. Rasnick

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Blacksburg, Virginia

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ii

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TABLE OF CONTENTS

							page
LIST	OF TABLES	•	•	•	•	•	vi
LIST	OF FIGURES	•	•	•	•	•	vii
INTRO	DUCTION	•	•	•	•	•	1
Chapt	er						
							page
I. BA	CKGROUND	•	•	•	•	•	3
	GEOLOGIC SETTING	•	•	•	•	•	4
	MINING HISTORY	•	•	• '	•		13
	METHODS OF INVESTIGATION		•	•	•	•	20
II. O	BSERVATIONS		•		•		25
	NATURE OF THE ORE BODIES				•	•	26
	PARAGENESIS						38
	FLUID INCLUSION STUDIES		•				53
	ELECTRON MICROPROBE ANALYSES						64
		•	•	•	•	•	70
		•	•	•	•	•	73
III.	DISCUSSION	•	•	•	•	•	81
	DEPTH AND TIMING OF MINERALIZATION	•	•	•	•	•	82
	MODEL FOR ORE EMPLACEMENT IN THE DISTRICT	1	•	•	•	•	88
SUMMA	RY AND CONCLUSIONS	•		•	•	•	94
REFER	ENCES	•		•	•	•	97
APPEN	DIX:						
A.	SAMPLE PREPARATION	•	•	•			107
В.	PROCEDURE FOR SETTING UP THE FLUID INCLUS	SIC	N				
	STAGE		•	•	•	•	109

TABLE OF CONTENTS

page

APPENDIX:

C.	FLUID INCLUSION DATA GENERATED IN THIS STUDY	112
D.	COMPILATION OF YOUNG MINE FLUID INCLUSION DATA	114
E.	ELECTRON MICROPROBE DATA-INDIVIDUAL ANALYSES	127
F.	ELECTRON MICROPROBE TRAVERSES	141
G.	GEOCHEMICAL MODELING OF ORE FLUIDS	151
H.	X-RAY POWDER PATTERN OF ILLITE	159
I.	TEMPERATURE GRADIENTS IN THERMAL AREAS OF YELLOW- STONE PARK	160
VITA		161

ABSTRACT

LIST OF TABLES

Table

1.	Comparison of fluid inclusion temperatures for several mines in the Mascot-Jefferson City district	58
2.	Summary of electron microprobe traverses through sphalerite from the Young Mine	66
3.	Electron microprobe analyses of orange sphalerite from the Young Mine	67
4.	Summary of electron microprobe traverses through carbonate fracture-filling gangue - major elements	71

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LIST OF FIGURES

Figure

1.	Generalized map of Tennessee showing the location of the Young Mine in Jefferson County	5
2.	Map of the Mascot-Jefferson City zinc district showing structural relationships, and close-up of the vicinity of the Young Mine	7
3.	Generalized cross-section through the Young Mine showing relationships between mine workings and lithologies	8
4.	Stratigraphic sections	10
5.	Young Mine shaft	16
6.	Young Mill	19
7.	Map of the Young Mine showing sample localities	21
8.	Generalized stratigraphic section at the Young Mine showing principle ore zones	22
9.	Underground view near the center of the Young Mine	29
10.	Traverse through stope drift 78-55 showing the sharp transition from limestone to dolomite when entering a mineralized zone	32
11.	Occurrence of sphalerite at the Young Mine: re- placement texture at a "limestone edge"	36
12.	Occurrence of sphalerite at the Young Mine: fracture-filling ore in the Mascot Dolomite, showing essentially no replacement	37
13.	Paragenesis of the Young Mine	39
14.	Three dimensional diagram showing sphalerite from various localities at the Young Mine	44
15.	Three dimensional diagram showing vug-filling sphalerite "rosettes" from various localities at the Young Mine	49

LIST OF FIGURES

Figure				
		page		
16.	Young Mine mineralization	52		
17.	Photomicrograph of fluid inclusions in vug- filling sphalerite	55		
18.	Young Mine freezing and homogenization tempera- tures as they correspond in the paragenesis	60		
19.	Young Mine sphalerite fluid inclusion pairs show- ing 3 distinct populations	63		
20.	Traverse through a sphalerite rosette featuring all 3 phases in the paragenesis	69		
21.	Microprobe traverse through gangue dolomite show- ing luminescence as a function of Fe and Mn	72		
22.	Calcite and dolomite stability fields as a func- tion of Mg/Ca ratios and temperature	76		

Introduction

The Mascot-Jefferson City district in East Tennessee is the major source of zinc in the United States. Located in the Valley and Ridge Province between Knoxville and Jefferson City, the district is bounded by the Appalachian Plateau to the northwest and by the Blue Ridge to the southeast. Surficial oxidized ores were first mined in the district beginning in the mid-1800's, and since the turn of the century underground mining of sphalerite has been the principle method of ore extraction, which has continued intermittently until today. Mineralization occurs in solution collapse features within carbonate rocks of the Lower Ordovician Knox Group. Sphalerite is the dominant ore mineral and dolomite is the most widespread gangue. Other minerals occurring in lesser amounts include pyrite, marcasite, calcite, fluorite, quartz, and traces of chalcopyrite, barite, galena and hematite.

The Young Mine is one of the more centrally located commercial zinc mines within the Mascot-Jefferson City district. Mineralization at the mine typifies that of the entire district; sphalerite occurs as fracture fillings and as rosettes between carbonate breccia blocks along with associated gangue phases, and displays well developed growth banding characterized by variations in color, opacity, and hydrocarbon inclusions.

Previous studies within the Mascot-Jefferson City district have demonstrated the similarity of mineralization, ore fluids, and ore-bearing structures in mines throughout the district. In addition, much has been written concerning the origin of the deposits, and various suggestions have been made in regard to depth of formation and the time at which they might have been emplaced. However, the processes involved in creation of the deposits are still not well understood, and detailed studies within the district have not been conducted in more than a decade.

This study was undertaken in an effort to expand knowledge of the East Tennessee ore deposits in light of new advances and concepts in the realm of Mississippi Valleytype deposits. The primary focus of this work is on the mineralized collapse zones at the Young Mine to determine their evolution and the paragenetic relationships between the ore and gangue phases which they host. Fluid inclusion data has subsequently been placed within the framework of the paragenesis, as has compositional data obtained by electron microprobe analysis. It is hoped that the combination of geologic observations, quantitative data collecting, and geochemical arguments may provide new insight into the nature of mineralization in the Mascot-Jefferson City district.

I. Background

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Geologic Setting

The Mascot-Jefferson City district is located within the Valley and Ridge Province in East Tennessee, which is bordered on the northwest by the Cumberland Plateau and on the southeast by the Unaka Mountains (Figure 1). It is bounded to the north and south by the 36° 00' 00" and 36° 15' 00" parallels, and to the west and east by the 83° 52' 30" and 83° 22' 30" meridians. Mineralization in the district occurs in a 4 to 18 kilometer wide northeasterly trend which extends for more than 48 kilometers, from near the eastern reaches of Knoxville to about 8 kilometers east of Jefferson City.

Approximately 90% of the district lies in Knox and Jefferson counties but portions overlap Grainger and Hamblen counties as well. Karst features are widespread in the area, with hummocky terrain and sinkholes common. The surface topography in the mining district ranges from 320 to about 460 meters above sea level, but slopes are generally gentle (Crawford and Hoagland, 1970).

The Valley and Ridge Province of East Tennessee consists principally of thick Paleozoic (Cambrian to Pennsylvanian) carbonate and clastic sediments which have been disrupted and thrust northwestward during the Appalachian Orogeny. Displacement of thrusted blocks is thought to be on the order of kilometers. Principal thrust faults appear to





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extend from the Cambrian Rome Formation upward and do not extend to the basement rocks (Misra et al., 1983).

In the Mascot-Jefferson City area thrust faults extend SW-NE across the length of the district (Figure 2). The Saltville fault limits exposure of mineralization to the north and the Dumplin Valley fault limits the extent of mineralization to the south. The Mill Spring fault extends across the north-central portion of the district. The Rocky Valley overthrust stretches across the southern half of the district and causes a stratigraphic displacement of 1433 meters or more, bringing Lower and Upper Cambrian rocks on top of Middle Ordovician. Lateral crustal shortening caused by the fault is estimated to be 3 to 4 kilometers. All known commercial ore bodies from the Young Mine to Jefferson City occur in the footwall of the Rocky Valley fault (Oder and Ricketts, 1961).

The Young Mine is located in Jefferson County, just off U.S. Highway 11-E, about 11 kilometers east of Mascot (Figure 2). Surficial exposures of underlying bedrock in the immediate vicinity of the mine are primarily Mascot Dolomite of Lower Ordovician age and Mosheim and Lenoir limestones of Middle Ordovician age. Underlying strata are folded into a domal structure known locally as Hodges Dome and the principle ore-bearing horizons in the mine occur within this feature (Figure 3). Increased erosion around the periphery of



Fig. 2. Map of the Mascot-Jefferson City zinc district showing structural relationships, and close-up of the vicinity of the Young Mine (after Bridge, 1956; Bridge and Hatcher, 1973).



Fig. 3. Generalized cross-section through the Young Mine showing relationships between mine workings and lithologies (section after Bridge, 1956; mine workings courtesy of Frank D. Rasnick of ASARCO, Inc.)

the dome has exposed the Rocky Valley overthrust in an arcuate pattern to the south of the mine, while an isolated klippe of Upper Cambrian Copper Ridge Dolomite remains at the apex of Hodges Dome. A high angle reverse fault, the Cold Water fault, cuts the north flank of the dome and has caused a vertical displacement of some 30 meters as well as some minor horizontal discontinuity (McCormick and Rasnick, 1983). The fault interrupts continuation of the 276 and 412 mining levels, and the 204 and 356 haulage levels within the mine.

The stratigraphy of the Mascot-Jefferson City district has been described by a number of authors (Oder and Miller, 1948; Bridge, 1945; 1956; Neuman, 1955; Rodgers, 1956; Bridge and Hatcher, 1973; Milici, 1973). Rocks exposed in the vicinity of the Young Mine range from the Rome Formation of Lower Cambrian age to the Ottosee Shale of the Middle Ordovician (Figure 4a).

The bulk of mineralization in the district occurs in two formations, the Mascot Dolomite and Kingsport Formation of the Knox Group, both of Lower Ordovician age. Detailed studies of these formations have been carried out by several authors (Neuman, 1955; Kendall, 1960; Harris, 1969; 1971; Gorody, 1980; Churnet et al., 1982). The Mascot Dolomite is composed predominantly of very fine crystalline dolomite. It displays repeating sequences of regressive sedimentary



Fig. 4. Stratigraphic sections: a) Rock units in New Market Quadrangle b) Close-up of the Upper Knox Group c) Marker beds at the Young Mine (modified from Bridge and Hatcher, 1973; McCormick et al., 1969).

cycles, each of which represents shoaling and subsequent progradation of shallow subtidal and peritidal environments (Gorody, 1980). The underlying Kingsport Formation consists of limestone and medium to coarsely crystalline dolomite with interbeds of very finely crystalline dolomite in the upper horizons (Harris, 1971). It represents an adjacent shallow marine environment which was dotted with tidal flats. The environment of deposition of both formations appears to have shallowed toward the northwest (Churnet et al., 1982).

The Knox unconformity occurs at the top of the Mascot Dolomite and separates the Lower Ordovician rocks from those of the Middle Ordovician. A karst terrain was developed on this erosional surface, which functioned as a paleoaquifer system and led to the development of a large scale cave network throughout much of the underlying Mascot and Kingsport formations (Harris, 1971; Hoagland, 1971; LeGrand and Stringfield, 1971a; Gorody, 1980). Foundering of overlying strata into solution-induced cavities created cave breccias which were cemented, further extended by pre-ore solution and/or tectonic activity, and later mineralized by hot, ore-bearing fluids (Kendall, 1960; Oder and Ricketts, 1961; Hoagland et al., 1965; Hill, 1969; Crawford et al., 1969; Hill et al., 1971b; Kyle, 1976; Gorody, 1980).

Commercial mineralization in the district is essen-

tially limited to the lower 35 meters of the Mascot Dolomite and the upper 45 meters of the Kingsport Formation (as redefined by Harris, 1969), with the majority of the ore being located in the middle to upper Kingsport (Hathaway, 1969; McCormick and Rasnick, 1983; Misra et al., 1983). The principle ore horizon has been broken down into 5 to 6 units by mine geologists for better correlation of ore stratigraphy across the district. The intervals are, from upper to lower, Mascot, R, S, T, U (and V in some mines). Ore deposits in the northeast portion of the district are lower stratigraphically than those in the southwest portion (Crawford and Hoagland, 1970). Less important mineralization has been found within a stratigraphic range of about 200 meters, and non-commercial ore has been found as low in the section as the Copper Ridge Dolomite and the Maynardville limestone of Upper Cambrian age (Oder and Ricketts, 1961).

At the Young Mine, most mineralization occurs 25 meters above and 35 meters below the Mascot-Kingsport contact, from the G-7/-10 bed upward to the G50/55 bed (Figure 4c). Ore from an altered upper S bed and from the G108 bed has also been of sufficiently high grade to mine. Non-commercial ore has been encountered from the U bed to isolated zones high in the Mascot (McCormick and Rasnick, 1983) and surface drilling has also penetrated small amounts of ore above the unconformity (J.E. McCormick, pers. communication).

Mining History

Mining in the Mascot-Jefferson City district dates back well over 100 years. In the early 1800's oxidized zinc ores, smithsonite and calamine, were discovered at Jefferson City (Oder and Ricketts, 1961). In 1854 the first mining operation began there, and 13 years later a zinc smelter was erected for manufacturing zinc oxide. It was operated intermittently until 1894 by the Edes, Mixter and Heald Zinc Company, which also began the first substantial mining operation of oxidized ore at Mascot in 1890. In 1900, Roseberry Zinc Company began mining sphalerite underground near Mascot in the western portion of the district.

Meanwhile, near the center of the district, open pit and shallow shaft mining of oxidized ores began east of the city of New Market in 1892 and continued until 1913. These properties were acquired by Grasselli Chemical Company in 1907, which began exploratory drilling for sphalerite ore. In 1925 the company sank shafts and began mining operations (Crawford and Hoagland, 1970).

Between 1901 and 1922 several companies, including the American Metal Company, Osgood Exploration Company, American Smelting and Refining Company, and The New Jersey Zinc Company, explored for sphalerite in the district, but no new mines were opened.

The American Zinc, Lead and Smelting Co. (also called

the American Zinc Company of Tennessee) acquired the Mascot properties in 1911 and two years later began operating at a 1000 ton per day mill capacity. The success of the Mascot Mine enabled the company to begin a widespread exploration program from Jefferson City to Mascot. It was apparently at this time when ore was first discovered in the vicinity of the Young Mine. Extraction from the Young and other newly discovered mines was shipped to Mascot for processing (Crawford and Hoagland, 1970).

In 1926 Universal Exploration Company, a subsidiary of U.S. Steel Corporation, began exploring in the district on a large scale, and sizable discoveries were made just south of Jefferson City. In May 1930 a 900 ton per day mill was completed and operations began at the Davis-Bible Mine. In 1937, E.I. du Pont de Nemours acquired the property to the east of New Market and contracted sphalerite production to the American Zinc Company of Tennessee. Ore was then shipped to the Mascot mill by rail. In 1947, the American Zinc, Lead and Smelting Company bought the property from du Pont. Several other mines opened in the area and ran until the end of World War II, after which exploration was undertaken on a larger scale than ever before by The New Jersey Zinc Company, the American Zinc Company, and the U.S. Steel Corpora-These activities led to other significant discoveries tion. in the district. Among the discoveries made by the American

Zinc Company at that time were those which led to the development of the Immel, Coy and North Friends Station Mines and the larger scale development of the Young (Crawford and Hoagland, 1970).

Several years later, other substantial discoveries were made by The New Jersey Zinc Company at Jefferson City and Beaver Creek. In 1953, the company began developing the Jefferson City Mine and started construction on a 1000 ton per day mill. Production commenced in 1956 and in 1959 mill capacity was increased to 2000 tons per day.

The American Zinc Company of Tennessee continued exploring for ore bodies at the Young Mine during the early 1950's. In 1955 production reportedly began. The mine was developed from a rectangular 7-compartment shaft, 4.6 by 6.4 meters, which was sunk on the north flank of an extensive domal structure to a depth of 285 meters (Figure 5). The elevation of the collar is 309 meters above sea level. Some 16 years later, in November 1971, the American Smelting and Refining Company (now ASARCO, Inc.) purchased the Young Mine from the American Zinc Company of Tennessee and is the current operator (Hatcher and Swingle, 1973; McCormick and Rasnick, 1983).

Selective open stoping is the general mining procedure employed at the Young Mine and involves 3 stages: slabbing, backstoping and benching. Where possible pillars are



Fig. 5. Young Mine Shaft.

located in poorly mineralized areas. There are 4 existing levels at the mine. The 412 mining level is accomodated by the 356 haulage level, and the 276 mining level by the 204 haulage level. After ore is removed from a face it is hauled to production raises and lowered to the haulage level. There the ore is loaded onto bottom-dump cars which are pulled by diesel locomotive to the shaft skip pocket, from which the ore is hoisted in skips to a surface storage bin and fed to a belt leading to the adjoining mill (McCormick and Rasnick, 1983).

It has been estimated that the Mascot-Jefferson City district has 125,000,000 tons of zinc resources, but at present only 75,000,000 tons of reserves have been identified (J.E. McCormick, pers. communication). In January 1964, ore grade at the Young Mine was estimated to be 3.25% zinc and reserves were conservatively estimated to be sufficient for at least 20 years (Hatcher and Swingle, 1973). Since 1955, approximately 22 million tons of zinc ore have been extracted from the mine at 2.75% grade (F.D. Rasnick, pers. communication). Current production of crude ore has been increased to approximately 4500 tons per day which amounts to an annual production of about 1.1 million tons (McCormick and Rasnick, 1983).

Two mills are currently operating in the district. The New Market Mill, which has a capacity of 3000 tons of ore

per day, was constructed beginning in 1961 (Crawford and Hoagland, 1970). The Young Mill, which was completed in 1975, has a designed capacity of 8500 tons of ore per day (Figure 6). Zinc production can average 350 tons per day at the designed tonnage rate (McCormick and Rasnick, 1983).





Methods of Investigation

The present study of the Young Mine began in May, 1982 and continued until June, 1983. A total of 4 separate visits were made to the mine during this period; the first two visits were primarily for obtaining samples and the last two were for observation and taking photographs. All visits were coordinated by ASARCO geologists who were familiar with Young Mine operations and with ore horizons and stopes. Samples were collected from a total of 14 stopes scattered over an area of about 1.3 square kilometers (Figure 7). Approximately 50 vertical meters of the main ore-bearing horizons were represented in the sampling process (Figure 8). During the first visit to the mine on May 6, 1982, disseminated and fracture-filling ore were collected from 3 stopes: GSA, 63-18, and 67-20. The sampling range was extended during the second visit on September 29, 1982 with the addition of fracture-filling ore and rosettes from stopes 84-61, 71-56, 61-45, 65-39, 71-16, and a sequence of wall rocks and disseminated ore from stope drift 78-55. Samples of vug-filling minerals sent by Frank D. Rasnick in November, 1982 were from 4 other stopes, 67-43, 75-30, 70-17, and 66-00, and supplemented those obtained on the previous trips. Two samples collected by Dr. James R. Craig during an earlier visit to the mine were also included in this study, in particular a specimen from stope 72-74 which was analyzed by electron



Fig. 7. Map of the Young Mine showing sample localities (courtesy of ASARCO, Inc.)



Fig. 8. Generalized stratigraphic section at the Young Mine showing principle ore zones. Sample horizons from respective stopes shown by letter (after McCormick et al., 1969).

microprobe. More detailed observations were made and photographs taken on a VPI&SU geology field trip to the mine February 2, 1983, and during a Society of Economic Geologists field trip March 10, 1983.

Samples obtained at the mine were collected in situ and were selected such that they would demonstrate proper paragenetic relationships and be representative of the entire mine area. During sampling, careful record was made of the stope number and the stratigraphic horizon of each rock spe-A total of 56 doubly-polished thin sections were cimen. prepared from the samples collected at the mine. A description of sample preparation is given in Appendix A. Petrographic work was conducted on a Leitz Orthoplan microscope with both reflected and transmitted light capability. Mineral phases were identified using reflected light optics, and textural relationships were observed using transmitted light microscopy, both discussed in Craig and Vaughn (1981). Maps of several thin sections were traced on 8.5 x 11 inch paper from images projected with a Prado Universal thin section projector using a 1:2.5/90 mm lens. Detailed notes were then recorded on these maps which later facilitated petrographic interpretations.

A variety of equipment was used in more quantitative data collecting. Fluid inclusion studies were carried out using a U.S.G.S.-type gas-flow heating/freezing stage

(described in Woods et al., 1981) built at Virginia Tech. Appendix B contains a description of the procedure used to set up the fluid inclusion stage. A Nuclide Luminoscope was used in cathodoluminescence studies of white gangue dolomite and sphalerite, which helped in construction of the paragenesis. Compositional data of various phases was obtained on an ARL-SEMQ electron microprobe maintained by the Department of Geological Sciences at VPI&SU. Operating voltage for analysis of carbonate cements was 5 Kv and for sphalerite analysis was 20 Kv. Three cameras were employed in photographic work: a Pentax SP II, an Olympus OM-2, and a Beseler Topcon. II. Observations

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Nature of the Ore Bodies

Breccias

The bulk of mineralization in the Mascot-Jefferson City district occurs in breccia bodies confined to a fairly narrow stratigraphic range within the upper Knox Group. In general, the breccias are solution-collapse features consisting of angular to subangular fragments of dolomite (and occasionally limestone) of varying sizes which have been cemented by an infilling of dolomite gangue and sphalerite, as well as other minor gangue phases. These breccias have been described in detail by a number of authors (Kendall, 1960; Ridge, 1968; Crawford et al., 1969; McCormick et al., 1969; 1971; Fulweiler and McDougal, 1971; Hathaway, 1973), and distinct types of ore-bearing structures are recognized across the district. In the vicinity of the Young Mine, the main structures housing mineralization are larger than those in the west and east (McCormick et al., 1971).

There is general agreement that the breccias are related to a paleokarst terrain developed on top of the Mascot Dolomite during early Middle Ordovician time (Harris, 1969; 1971; Gilbert and Hoagland, 1970; Hill and Wedow, 1971; Hoagland, 1971; LeGrand and Stringfield, 1971a; Gorody, 1980; Churnet et al., 1982). This erosional surface was regional in extent and funneled meteoric waters through fracture systems in the sub-surface, enlarging openings and creating caverns by dissolution of the underlying Kingsport Formation. Subsequent collapse of overlying Mascot beds into the void spaces created rubble breccias, the sizes of which were governed by the thickness of the dissolved beds within the Kingsport (Harris, 1971).

At least two periods of brecciation are recognized in East Tennessee. The earliest phase, the "fine rock-matrix" breccias, often cross-cut the stratigraphic section and are believed to be cave or sink hole breccias related directly to the unconformity atop the Mascot Dolomite (Kendall, 1960; Hoagland et al., 1965; Hill, 1969). They are tabular in shape, cemented with a matrix of gray to greenish gray dolomite, and are unmineralized. The early network of caves and breccias appears to have provided a plumbing system for later fluids which may have further extended the breccia bodies and which ultimately precipitated the ores (Crawford et al., 1969; Hill et al., 1971b; Gorody, 1980). The existing structures which house mineralization in East Tennessee were produced by the second extension of these breccias. These later bodies are termed "coarse-matrix" breccias and are chiefly cemented with white and pink sparry dolomite gangue (saddle dolomite) and associated ore minerals.

In the Mascot-Jefferson City district, sub-surface dissolution occurred primarily in the R and S beds of the upper

Kingsport, and foundering of overlying strata created cave breccias at a fairly uniform stratigraphic interval. The greater thickness of the R and S beds in the vicinity of the Young Mine led to development of the large collapse breccias encountered there. In the mine, these breccias may attain lengths of 450 meters, widths of 275 meters, and reach up to 30 meters in height (McCormick and Rasnick, 1983). The fracture pattern within the upper portion of the structures is dome-like and the ore bodies have therefore been referred to as "high-domal" structures (McCormick et al., 1969; 1971). The term is misleading, however, since the structures are sinuous in cross-section and not perfectly round. The number of ore structures within the Young Mine cannot be determined because overlapping occurs and it is impossible to distinguish where one dome stops and another begins (F.D. Rasnick, pers. communication; Figure 9).

Dolomitization

Throughout East Tennessee, dolomitization of breccia blocks within collapse structures is widespread and essentially complete, although scattered limestone remnants have been observed in fine rock-matrix breccias (Hill et al., 1971b) and in wide, domal coarse-matrix structures (F.D. Rasnick, pers. communication). It is generally accepted that dolomites within the collapse breccias are not all related


Fig. 9. Underground view near the center of the Young Mine. Hollowed-out stopes show the interconnecting network of breccia bodies which house the ore. Note the remnants of unaltered limestone near the left center of the map which outline the round nature of the ore-bearing "domal structures".

to one dolomitizing event (Kendall, 1960; Hall, 1969; Hill et al., 1971b; Gorody, 1980; Churnet et al., 1982). Primary "fine-grained" dolomites of the Mascot and upper Kingsport formations formed as products of early diagenesis in supratidal and upper intertidal environments (Churnet et al., 1982). This initial dolomitizing phase was widespread and probably affected large amounts of strata that are now contained in both fine rock-matrix and coarse-matrix breccias in mineralized areas. After karstification and creation of the early breccias, a zoned dolomite grew throughout the area. It replaced previously unaltered limestones in and out of collapse zones and occurred as a cement between fine rock-matrix breccia blocks and in fractures within the earlier dolomite. This medium-grained dolomite was regional in extent and occurs throughout the Mascot and into the upper Kingsport formation. It is thought to have formed by regional mixing of transgressive marine waters with meteoric waters recharged on topographic highs (Gorody, 1980).

Following another period of brecciation, possibly related to pre-ore solution and/or tectonic activity, a final dolomite phase was introduced into the area. This saddle dolomite gangue accompanied the emplacement of ore, and many workers have concluded that it did not replace limestone as did the previous two dolomite phases (West, 1970; McCormick et al., 1971; Gorody, 1980; Churnet et al., 1982)

but instead filled in between breccia blocks and cut across or overgrew all other types of dolomite (Gorody, 1980). In the present study, the edges of several of the main ore zones were examined for indications of replacement by gangue dolomite. Such observation is admittedly difficult because fracture-filling by this same phase is widespread and it is difficult to distinguish one texture from the other. In general, it appears that replacement by gangue dolomite does occur to a limited extent around the peripheries of the ore bodies (Figure 10). Sphalerite commonly replaces host breccias along the edges of the ore structures as well, and geologists at the Young Mine and at other mines within the district have recognized a common tendency for this replace- . ment ore to be associated with coarsely recrystalline dolomites, and not to be associated with finer-grained recrystallines (J.E. McCormick and F.D. Rasnick, pers. communications). Therefore, the coarse recrystalline dolomites may actually be saddle dolomite replacements and/or overgrowths. It seems consistent that replacement sphalerite would be associated with such a phase depositing more or less simultaneously.

Saddle dolomite has been observed replacing limestones in other areas (Radke and Mathis, 1980), and it is not restricted to filling of void spaces only. Geochemical studies also suggest that replacement dolomitization could well have



Fig. 10. Traverse through stope drift 78-55 (zone G25-39) showing the sharp transition from limestone to dolomite when entering a mineralized zone. Note the disseminated nature of the sphalerite and its association with coarse saddle dolomites within the ore zone (S, sphalerite; D, saddle dolomite). been an active process at temperatures determined from fluid inclusion studies at the Young Mine and throughout the district, and will be discussed below.

Silicification

Silicification within the collapse structures appears to be intermittent and mainly associated with dissolutional processes which produced the breccias themselves. Fine rock-matrix breccias containing massive silica have been observed in various areas within the district (Oder and Ricketts, 1961). This "jasperoid" consists of insoluble material which collected at the bottom of the early breccias after being leached from surrounding limestones during development of the original karst system. At least part of this early jasperoid may have been remobilized later and new material introduced if corrosive fluids further hollowed out solution passages during enlargement of the breccia bodies. The dissolution activity may have redistributed the jasperoid and formed the haloes observed in both limestone and dolomite around the collapse structures. This later phase of silica is probably similar in appearance to that deposited in the earlier breccias. It appears as a well-bedded, black siliceous silt containing poorly-sorted crystalline dolomite rhombs and bleached chert fragments (Hill, 1969).

The local losses of permeability due to early silicifi-

cation apparently prevented entrance of later ore-bearing solutions into those areas, which explains why sphalerite rarely occurs with such silicified material (Oder and Ricketts, 1961). During emplacement of ore and gangue, probably very little new silica was introduced, since dissolution was essentially complete and deposition from deep-seated brines was widespread. Some remobilization of siliceous material deposited earlier took place; jasperoid is occasionally encountered with gangue phases, and small, corroded sphalerite and dolomite grains in a siliceous matrix have been observed around the peripheries of the ore bodies.

Emplacement of ore and gangue was the last stage in the genesis of the ore bodies, and hot, metal-bearing fluids entered areas that had been rather freshly re-brecciated. The proximity of the ore-bearing collapse structures to unaltered limestone (Figure 9) suggests that during enlargement of the early breccias, previously unaltered zones of limestone may have been exposed, and that blocks of limestone debris may have formed part of the rubble breccia, particularly along the edges, when overlying and surrounding beds foundered into newly-formed void spaces.

The presence of fresh limestone around the breccias helps explain the habit of the ore within them. Sphalerite occurs in two associations within the collapse breccias: as disseminated, replacement ore around the peripheries of the

structures, and as open-space filling in the interiors (Figures 11 and 12). As hot solutions entered the collapse breccias, two processes may have acted independently to disseminate ore along the edge. Moderate amounts of exposed limestone may have been replaced by sphalerite as corresponding dolomitization of other limestone took place. The result was an intergrowth of disseminated ore with coarse recrystalline dolomite. Fracture-filling ore showing growth features and essentially no replacement occurs in the interior of the breccias and suggests that near-equilibrium conditions were more prevalent once solutions had permeated the "limestone edge" and encountered dolomite on a larger scale. The centers of many of the breccias also frequently "assay out" and are barren to mineralization, which could be due to the reduced permeability of fine rock-matrix breccias present at the core, or to earlier internal silicification of either the early or the late breccia. Fracture-filling ore is by far the most abundant in the district. It has been estimated that at the Young Mine 95% of the minable sphalerite occurs as void-filling, while only 5% is replacement (J.E. McCormick, pers. communication).



Fig. 11. Occurrence of sphalerite at the Young Mine: replacement texture at a "limestone edge".



Fig. 12. Occurrence of sphalerite at the Young Mine: Fracturefilling ore in the Mascot Dolomite, showing essentially no replacement.

Paragenesis

A generalized paragenesis for the Mascot-Jefferson City zinc district based on underground relationships was first presented by McCormick et al. (1971); subsequently Hathaway (1973) described the paragenetic relationships at the New Market mine. In this study, a paragenetic sequence similar to the above two has been established for the Young Mine through a combination of underground observations, petrographic work, and electron microprobe analysis. Additional studies using cathodoluminescence have revealed growth bands within gangue dolomite, and other mineral phases have been placed within the framework of these bands. In general, mineralization at the mine can be divided into three phases: a pre-ore stage, a main ore stage and a post-ore stage. Three stages of sphalerite deposition are also recognized: early, late and vug-filling (Figure 13).

Dolomite Gangue

Initial petrographic examinations of luminescent growth bands within the dolomite gangue show that it precipitated during seven simplified "phases" (lettered a through g in Figure 13). Each major phase is distinct in that it luminesces differently than do the other surrounding dolomite phases. The seven zones observed luminesce, in order of





crystallization, dark, bright, medium dark, medium bright, dark, bright and very dark red, respectively. These are distinguished using criteria similar to that of Ebers and Kopp (1979), wherein distinct zones are delineated by virtue of their color, hue and intensity. These zones are due to variations in concentrations of Mn and Fe in the dolomite structure, with Mn acting as an activator of luminescence and Fe as a quencher (Pierson, 1981). This has also been confirmed for dolomite in the Young mine by electron microprobe traverses through bands of differing luminescence, and will be discussed below. Episodes of sphalerite mineralization appear to be preferentially associated with certain of these dolomite zones, as do episodes of pyrite, marcasite and chalcopyrite deposition.

Ebers and Kopp (1979) used cathodoluminescence on thin sections from the Mascot-Jefferson City district (12 of which were from the Young Mine) and concluded that 6 principal zones were present within the dolomite gangue. The major zones which were observed most commonly within the Young Mine, according to the numbering system of Ebers and Kopp, were the last 4, numbers 3 through 6, while zones 1 and 2 were observed only once. In order of occurrence, these zones were observed to luminesce (i) very dark, (ii) very bright, (iii) bright medium to dark, (iv) dark, (v) bright and (vi) medium dark red, respectively.

It is apparent that the distinct dolomite growth zones recognized in the Young Mine during this study are similar to those recognized by Ebers and Kopp (1979). As in the earlier study, efforts were made here to choose major divisions that were rather easily observed and widespread. The contrast in intensity between luminescent bands was the major criterion in defining each of the major zones of dolomite Paragenetic relationships observed at the Young arowth. Mine are placed within the framework of these zones. Since Ebers and Kopp (1979) demonstrated that the dolomite "stratigraphy" is consistent throughout a wide area, and since bands of sphalerite appear similar in many of the mines (Taylor et al., 1982b), the paragenetic relationships presented here may apply elsewhere in the Mascot-Jefferson City district.

Within the ore bodies, jasperoid was probably redistributed during extension of the collapse breccias, and following this siliceous stage, a dolomite which luminesces dark in cathodoluminescence (Figure 13, zone a) was the first carbonate gangue to precipitate within the mine, but was very minor. This dolomite is only occasionally found, and always immediately surrounding breccia blocks. It is in turn overgrown by a bright dolomite (zone b) which is somewhat thicker than the first but equally scarce: zones a and b are

found in only two of the sections in this study. Phases a and b are similar to zones 1 and 2 in the study by Ebers and Kopp (1979), which they observed less frequently in the western portion of the district. A medium dark phase follows as the first dominant dolomite (c) and is the most widespread band immediately surrounding breccia fragments. Minor pyrite and marcasite occur interspersed within the dolomite at varying horizons and it is upon this third phase that nuclei of early sphalerite often grow. This dolomite matches the description of the 3a, 3b and 3c bands observed by Ebers and Kopp (1979).

Ore Stage Dolomite

Four phases of dolomite occur during the main ore stage: (d) medium bright, (e) dark, (f) bright and (g) very dark red. The first three of these occur in relatively small proportions, but are persistent throughout the mine. Examination of ore-stage dolomite and sphalerite in this study shows that both early and late sphalerite are associated with these three zones and that late sphalerite is also associated with the last (very dark red) dolomite phase (g) which fills in voids and constitutes the majority of gangue throughout the mine (Figure 13). Vug-filling sphalerite is associated with this last phase as well. All four of these

zones correlate very well with the 3d, 4, 5 and 6 bands mentioned by Ebers and Kopp (1979). They identified the first three of these as the major dolomite phases present during precipitation of ore-stage sphalerite within the district, and the last as the major vug-filling phase.

Early Sphalerite

Early sphalerite is one of the most distinct bands within the mine. It is always light yellow to light yellowgreen in hand sample and dark cloudy-green in thin section due to the abundance of fine solid and fluid inclusions. Early sphalerite commonly shows deformation twinning (Taylor et al., 1982a) and does not have hydrocarbons associated with it. This phase of sphalerite is commonly found as spherical centers or nuclei atop breccia blocks or earlier dolomite, but also occurs as continuous, traceable bands throughout the mine (Figure 14). It is virtually always overgrown by late sphalerite, and commonly forms the centers of sphalerite rosettes. Electron microprobe analyses reveal that early sphalerite consistently contains higher Fe than late and vug-filling phases. Associated with the early sphalerite and the three dolomite phases are small amounts of pyrite and marcasite which occur interspersed with the major phases (Figure 13). Pyrite generally precipitates as



euhedral cubes which assume different shapes in thin section depending on orientation, while marcasite usually occurs as blades or radiating "cockscombs".

Late Sphalerite

The last phase of ore-stage mineralization is that of late sphalerite, which is also quite widespread within the mine and probably forms the bulk of minable zinc within the district. It appears to include both the intermediate and late sphalerite phases described by Taylor et al. (1982a), although in this study no effort has been made to distinguish two separate phases because they are commonly intergrown and appear as one phase. Late sphalerite usually appears medium to dark olive-green or (rarely) brown in hand sample and nearly always has bluish or purplish hydrocarbon masses associated with it. In thin section it is characteristically transparent, but tinted either an olive green or honey yellow. Often it features subordinate deformation twins within larger, straight growth twins (Taylor et al., 1982a). It also contains usable but rare fluid inclusions. Hydrocarbon masses viewed in thin section vary in thickness and appearance; sometimes they are coalesced as smeared, large globules or they appear as distinct, parallel wisps resembling brush marks. Both forms of hydrocarbons are most

common in late sphalerite bands within rosettes, but appear with the phase ubiquitously throughout the mine. Electron microprobe analyses of late sphalerite show that it almost always contains higher Cd than other sphalerite phases. There is some indication that the Cd may be preferentially associated with the hydrocarbon inclusions (Craig et al., 1982). One horizon within late sphalerite has been observed to luminesce yellow under the luminoscope (Figure 13) and can be observed in nearly every area sampled within the mine. The luminescence may be associated with hydrocarbon masses present in the same horizon. This zone may serve as a distinct marker band for more correlative studies throughout the district. Late sphalerite is very widespread and persistent throughout the mine and is most commonly found as a uniform, traceable band immediately atop early sphalerite (Figure 14), but also as the cores of many rosettes where early sphalerite is absent. Pyrite, marcasite and very minor chalcopyrite occur with both late sphalerite and late dolomite.

Vug-Filling Sphalerite

The final stage of sphalerite mineralization, although locally present in relatively thick bands, is not persistent nor widespread. This "vug-filling" sphalerite is untwinned

(Taylor et al., 1982a), ranges in color from deep brownishgreen to dark brown or yellow in hand sample, and forms concentric bands around early or late sphalerite. In thin section, these bands appear much more pronounced in varying shades of yellow, brown and green. As many as eight different zones or bands, each of which may also vary in transparency, may comprise the vug-filling phase: zones may be virtually "crystal clear" and totally void of inclusions of any form, whereas others may be clouded with fine inclusions. Blue or brown hydrocarbon masses are very common in individual zones of vug-filling sphalerite, and may occur as either globules or "brush marks". In the latter form they frequently may encircle a rosette while remaining within the one zone. Analyses by electron microprobe reveal that compositional variations exist between different bands, but they are not consistent enough to account for color or texture variation. Instead of engulfing earlier sphalerite nuclei, vug-filling sphalerite may also form as rosettes on breccia fragments or earlier dolomite crystals (Figure 16a), or as individual crystals (Taylor et al., 1982b). In most instances, vug sphalerite is found with post-ore stage minerals such as fluorite, quartz and calcite (Figure 13). These commonly grow on top of the rosettes themselves or are perched on top of dolomite or breccia fragments.

Growth banding within rosettes follows no uniform sequence from core to exterior. The absence of consistency between rosettes from different localities (Figure 15) suggests that individual bands may have formed from pulses of mineralizing fluids during local episodes of deposition in the mine. In addition, the variety of rosette nuclei and the subsequent encircling growth bands indicates that many precipitated at various intervals within the paragenesis, and were not totally restricted to the ultimate stages. Taylor et al. (1982b) reached the same conclusion based on fluid inclusion evidence. However, the majority of rosettes examined in this study did achieve maximum growth after the early and late stages of sphalerite deposition, and therefore are shown as post-ore phases in Figure 13. It can be concluded that rosettes formed in any area that remained open to percolating ore solutions for longer periods of time than areas where they do not occur. Figure 16b shows all 3 phases of sphalerite in a rosette collected from stope 67-43.

Late Dolomite

Ebers and Kopp (1979) observed that late dolomite filled in vugs and void spaces after sphalerite mineralization. In this study thin section work coupled with cathodo-



Fig. 15. Three dimensional diagram showing vug-filling sphalerite "rosettes" from various localities at the Young Mine. Note the various phases of sphalerite which form the nuclei of the rosettes, indicating growth at different stages in the paragenesis. Note also the variation in growth bands between rosettes which suggests deposition from local pulses of ore-bearing fluids.

luminescence indicate that late sphalerite and many of the vug-filling rosettes are closely associated with this very dark dolomite phase (g). The association of the dolomite and sphalerite aids in the geochemical modeling since fluid inclusions are observed in late sphalerite but are rare to absent in all of the dolomite phases. Temperatures and salinities from late sphalerite inclusions are therefore assumed to be applicable to late dolomite.

Orange Sphalerite

A minor, less well understood phase of ore mineralization is that of precipitation of orange sphalerite, which occurs in small amounts within mineralized areas at the mine. It is found throughout the stratigraphic section but it is more common higher in the brecciated collapse structures (F.D. Rasnick, pers. communication; McCormick et al., 1971). Electron microprobe analyses of a sample of orange sphalerite from stope 67-20 are listed in Table 3. In general it appears that orange sphalerite is high in Cd and low in Zn when compared with other sphalerite in the paragenesis (Table 2).

Post-Ore Gangue Phases

The final mineralization in the mine area consisted of precipitation of post-ore stage fluorite, quartz and calcite (Figure 13). Fluorite occurs as cubic or tetrahexahedral forms (Figure 16c) surrounded by dolomite rhombs and on top of vug-filling sphalerite. Quartz often crystallizes as tiny, prismatic crystals on vug-filling sphalerite, usually with calcite (Figure 16d). Calcite is found in three associations: as rhombs, scalendohedra, or prisms perched atop vug-filling sphalerite (Figure 16d); as masses filling vugs within dolomite gangue; and as very late secondary groundwater precipitation products. The latter usually fill small fractures that offset primary features within the mine.



Fig. 16. Young Mine mineralization. (A) .Vug-filling sphalerite on dolomite rhombs (B) Three stages of sphalerite (E, early; L, late; V, vug-filling) mineralization (C) Late fluorite on vug-filling sphalerite (D) Late quartz and calcite on vug-filling sphalerite. The scale in each photo is in millimeters.

Fluid Inclusion Studies

Fluid inclusion studies have been conducted on samples from the Mascot-Jefferson City district in an effort to obtain information on the nature of the solutions which precipitated the ores. The first detailed study in East Tennessee was performed by Roedder (1971) who examined inclusions in samples of sphalerite, fluorite, quartz and dolomite obtained from various mines in the district. Previously, homogenization temperature determinations had been conducted on fluorites from the Young and New Market Mines by Miller (1968; 1969), but erroneously high readings were obtained due to miscalibration of the heating stage (Larson et al., 1973). Recently, Taylor et al. (1983) analyzed samples of sphalerite from several mines in the district and acquired data on main stage mineralization which had previously been unavailable.

In this study, homogenization and freezing temperature determinations were conducted on inclusions in sphalerite, fluorite and calcite from the Young Mine, and in fluorite from the New Market Mine. The objective of fluid inclusion studies was to supplement homogenization temperatures and salinities acquired in earlier work and, subsequently, to place the combined Young Mine data within the framework of the paragenesis. A temperature and salinity variation consistent with paragenetic relationships and illustrating the

mineralization sequence was ultimately sought.

Fluid inclusions in sphalerite proved to be the most difficult to locate and work with. Not only were they rare or absent in most samples examined, but the twinned nature and opacity of much of the early main stage ore hampered efforts to utilize potential specimens. Similar difficulties led Roedder (1971) to obtain the majority of his data from the later vug-filling phase. In this study, a total of 8 inclusions in main stage sphalerite from various localities in the Young Mine were examined. Inclusions in vug-filling sphalerite were almost equally scarce but, when located, more readily viewed due to the transparency of most of the material (Figure 17). During this study, 10 inclusions were observed in a single zone of a rosette from stope 67-43. Taylor et al. (1983) have observed large numbers of inclusions within individual rosettes extending from the centermost bands to those on the exterior.

Inclusions in post-ore, vug-filling gangue phases were generally more widespread than in sphalerite and more easily observed. However, here the number of samples examined was restricted due to time constraints. Two samples of fluorite were studied, one from the Young Mine containing 2 usable inclusions, and one from the New Market Mine containing 28. Five inclusions were obtained in 2 samples of vug-filling calcite from the Young Mine, and a vein of secondary calcite



Fig. 17. Photomicrograph of fluid inclusions in vug-filling sphalerite. Field of view is approximately 0.3 mm. yielded one inclusion.

All fluid inclusion data generated in this study are listed Appendix C. Freezing temperatures obtained from inclusions in main stage sphalerite range from -13.7° to -23.9° C, with the majority being in the -22.0° C range. Inclusions in vug-filling sphalerite show freezing temperatures between -19.7° and -21.7° C. Two anomolously low values were also obtained $(-36.4^{\circ} \text{ and } -37.0^{\circ} \text{ C})$ which are probably due to high concentrations of CaCl, and/or MgCl, which may depress the freezing point of NaCl solutions more than 20° C (Crawford, 1981). Inclusions in post-ore gangue phases generally contain fluids of lower salinity, as evidenced by their overall warmer freezing temperatures and narrower temperature range. Inclusions in fluorite from the Young Mine yielded freezing temperatures between -8.7° and -10.7° C, while New Market fluorite inclusions showed temperatures ranging from -7.1° to -8.4° C. Freezing temperatures for calcite showed similar variation, from -10.7° to -12.7° C, but an inclusion in secondary calcite (believed to be a late, groundwater precipitation product) yielded a distinctly higher freezing temperature (-2.3 $^{\circ}$ C). All of the above observations are consistent with previous work (Roedder, 1971; Taylor et al., 1983) and were reproducible within ±1° C. Individual data points are listed in Appendix C.

Homogenization temperatures obtained for inclusions in

main stage sphalerite from the Young Mine range from 139° C to 199° C. Inclusions in vug-filling sphalerite yielded homogenization temperatures between 134° and 157° C. Temperatures obtained in vug-filling gangue phases showed a range of values: fluorite varied from 156° to 159° C at the Young Mine, and from 160° to 176° C at the New Market Mine; inclusions in calcite from the Young Mine homogenized between 121° and 170° C. An homogenization temperature for secondary calcite was unobtainable. The bulk of these observations are again consistent with work done previously. However, temperatures for main stage sphalerite and post-ore fluorite are slightly higher than those reported from the Young Mine, yet are consistent with those reported from other mines in the district (Roedder, 1971; Taylor et al., 1983). Accurate fluorite data from the New Market Mine has not been previously reported, but the above observations are also consistent with work done elsewhere. Calcite data has not been reported from mines other than the Young. All homogenization temperatures were repeatable within $\pm 5^{\circ}$ C, and are listed in Appendix C.

For comparison purposes, all available fluid inclusion data for mines within the Mascot-Jefferson City district are summarized in Table 1. As can be noted, the most complete fluid inclusion work in the district has been performed on material from the Young Mine; data have been collected on

Name of Mine	Location In District	Numb Incl (Fr)	er of usions (Hmg)	Minerals Sampled	Freezing Temp Range	Freezing Temp Ave	Homogen Temp Range	Homogen Temp Ave	Reference
i mme i	West	16	8	Main Stage Sphalerite	-9.4 to -26.3	-20.5	112 to 143	127	2
Young	Central	82	54	Main Stage Sphalerite	-11.2 to -29.5	-20.2	101 to 199	141	2,3
		48	55	Vug-Filling Sphalerite	-17.5 to -37.0	-23.1	81 to 171	132	1,2,3
		189	87	Fluorite	-8.0 to -12.5	-12.0	89 to 159	110	1,3
		10	7	Dolomite	-8.7 to -13.0	-11.3	107 to 119	113	1
		29	33	Calcite	-8.0 to -12.7	-10.6	99 to 170	117	1,3
		19	30	Quartz	-8.0 to -18.0	-10.0	56 to 129	108	1
New Market	Central	44	42	Main Stage Sphalerite	-12.0 to -41.6	-22.5	89 to 175	134	2
		24	18	Vug-filling Sphalerite	-11.6 to -30.2	-16.6	105 to 185	138	1,2
		16	15	Fluorite	-7.1 to -8.4	-7.6	160 to 176	167	3
Coy	East	101	71	Main Stage Sphalerite	-9.4 to -27.0	-19.1	88 to 197	144	2
		2	9	Vug-Filling Sphalerite	-10.2 to -13.0	-11.6	113 to 176	143	1
		93	37	Fluorite	-7.5 to -11.4	-10.4	109 to 171	125	1,2
		9	10	Quartz	-22.0 to -31.6	-25.9	93 to 132	118	1
J efferson City	East	8		Vug-Filling Sphalerite	-20.6 to -23.0	-21.8			1
		48	20	Fluorite	-9.0 to -12.0	-10.4	139 to 156	145	1

Table 1: Comparison of Fluid Inclusion Temperatures for Several Mines in the Mascot-Jefferson City District

1 Roedder (1971) - All inclusions in sphalerite listed as vug-filling

2 Taylor et al. (1983) 3 Caless (1983)

(Temperature in Degrees C)

nearly all of the major phases in the paragenesis. A compilation of individual freezing and homogenization temperatures is given in Appendix D. The observations are listed by phase, recognized as paired or unpaired, and are identified by source.

In establishing the order of events leading to formation of the sphalerite deposits in East Tennessee the role of fluid inclusions as geothermometers and geochemical indicators cannot be underestimated. Still, homogenization temperature and salinity data by itself may prove inconclusive if not considered in light of paragenetic relationships, which place all data into a relative time framework dictated by the depositional sequence.

Homogenization and freezing temperatures determined for various phases at the Young Mine were applied to the paragenesis diagram developed earlier, in an effort to identify any systematic trends during mineralization (Figure 18). All main stage and post-ore stage phases display a wide range of homogenization temperatures. Generally, the earliest stage was hottest with later stages showing gradually declining temperatures.¹ Gaps in temperature within individual phases

¹Data are displayed as horizontal isotherms stretching the length of duration of a depositing phase, because exact location in the paragenesis is impossible to determine. Thicker horizontal isotherms represent larger numbers of observations at those temperatures.



Fig. 18. Young Mine freezing and homogenization temperatures as they correspond in the paragenesis (for sources of data, see Appendix D; pressure correction data from Potter, 1977)

are probably due to sampling inhomogeneity. Actual temperatures may have been higher than those determined from homogenization studies due to greater depth of burial at the time of ore emplacement. Figure 18 shows pressure corrections which can be applied to temperature data to adjust for depth.

Figure 18 also shows systematic variations in freezing temperatures. In general, sphalerite inclusion salinities are quite variable, particularly in main stage ore, while post-ore phase inclusions are less saline and restricted to a much narrower range. Inclusions in vug-filling sphalerite do not show the wide variation in salinity observed at other mines in the district (Table 1). This is probably a result of the limited number of samples used in this study (Appendix D) which somewhat biases the results at the Young Mine. A larger sample population probably would reveal that inclusions in vug-filling sphalerite display the same range of salinity as that observed in the main stage ore.

Paired homogenization and freezing temperature determinations from ore phases provide some of the most valuble information regarding the depositional environment and nature of the ore fluids during mineralization. Paired observations constitute about 60% of the total data obtained from main-stage and vug-filling sphalerite at the Young Mine (Appendix D), and when homogenization temperatures are plot-

ted as a function of freezing temperature, 3 distinct populations of inclusions are apparent (Figure 19). Group A inclusions show moderate homogenization temperatures and very low freezing temperatures (due to the presence of $CaCl_2$ and/or MgCl₂) and therefore qualify as a separate group. Group B inclusions vary in temperature while maintaining a high, near-constant salinity. Many of the inclusions in this group were found in successive bands within a single rosette and homogenized at progressively lower temperatures outward from the core (Taylor et al., 1983). Group C inclusions show a positive relationship between temperature and salinity. Depositional processes in light of fluid inclusion data will be discussed in greater detail below.





Fig. 19. Young Mine sphalerite fluid inclusion pairs showing 3 distinct populations: A) Moderate temperature-depressed freezing point B) Increasing temperaturenear constant salinity C) Increasing temperature-increasing salinity.

Electron Microprobe Analyses

Very little work has been done in quantitatively analyzing compositions of phases within the Mascot-Jefferson City district, particularly those of the Young Mine. Some work was conducted in the district during the 70's on wall rocks surrounding mineralized zones. West (1970) studied trace elements in wall rocks near a mineralized breccia body at the New Market Mine and Snyder (1975) conducted a study of minor element distribution in samples of wall rocks from various localities within the district. Cobb (1974) examined gangue dolomite from the district by luminoscope and electron microprobe and was the first to correlate luminescent growth banding with variations in Fe and Mn contents.

Recently, Foley (1980) and Craig et al. (1982) conducted the first detailed studies of sphalerite growth banding in Appalachian zinc deposits by electron microprobe analysis. Included in the latter study were samples from 6 mines within the Mascot-Jefferson City district: Beaver Creek, Immel, New Market, U.S. Steel, Jefferson City, and Young. Analyses conducted on samples from the district in general indicated that color was not affected by Fe contents of less than 2 weight percent, and that hydrocarbon-rich zones often displayed higher Cd values than other areas void of such inclusions. Furthermore, analyses of sphalerites from the Jefferson City and Young Mines showed that Fe and
Cd contents frequently varied in an inverse manner during traverses across growth bands, although this was not a universal tendency.

Electron microprobe analyses were conducted on Young Mine sphalerite during the course of this study in an effort to further quantify compositional variations between phases in the paragenesis. Stepped traverses were made through a total of 5 rosettes and 2 fracture-filling bands in sphalerite. Data from two additional traverses through fracturefilling ore, obtained at an earlier date, were furnished by James R. Craig to supplement data generated in this Dr. study. In most instances, Zn, S, Fe, Cd, and Cu were the only elements analyzed for, because preliminary results had shown that other elements were present only in minute quantities. The exception was sample 1431 which was also analyzed for Hg. A summary of all data gathered from traverses through sphalerite is given in Table 2, and individual data points are listed in Appendix E. In addition to traverses through main stage ore, spot analyses were conducted on orange sphalerite. These results are listed in Table 3. In general, orange sphalerite appears to contain higher Cd and lower Zn than main stage sphalerite.

The matching of individual analyses with the original traverse paths through growth bands illustrates compositional variations which exist between the different phases

Table 2: Summary of Electron Microprobe Traverses Through Sphalerite from the Young Mine

Analyst	Points	Sample	Stope	Beds	Type	Range Zn	Ave Zn	Range Fe	Ave fe	Range Cd	Ave Cd	Range Cu	Ave Cu	Range Hg	Ave Hg
J.R.Caless	21	0134	61-45	- 19	Band	66.03- 68.39	67.11	0.03- 0.31	0.14	0.00- 0.23	0.09	0.00- 0.02	0.00		
J.R.Caless	24	1427	75-30	G9-10 to 28	Band	66.98- 68.55	67.85	0.03- 0.33	0,14	0.00- 0.21	0.09	0.00- 0.05	0.01		
J.R.Craig	44	1470	63-18	94	Band	66.21- 67.13	66.73	0.04- 0.31	0.15	0.19- 0.54	0.37	0.00- 0.08	0.02		
J.R.Craig	67	1431	72-74	Lower R	Band	65.03- 67.89	67.03	0.05- 0.37	0.16	0.21- 1.79	0.39	0.01- 0.19	0.05	0.00- 0.06	0.03
J.R.Caless	53	0132	71-56	G28-34	Rosette	65.93- 68.16	67.08	0.01- 0.40	0.10	0.00- 0.39	0.18	0.00- 0.20	0.05		
J.R.Caless	42	0141	67-43	G9-17	Rosette	65.63- 67.88	66.97	0.02- 0.40	0.17	0.00- 0.49	0.17	0.00- 0.12	0.03		
J.R.Caless	28	0142	75-30	G46-50	Rosette	66.34- 68.35	67.53	0.01- 0.17	0.08	0.00- 0.34	0.12	0.00- 0.09	0.01		
J.R.Caless	24	0143	70-17	G25-34	Rosette	66.80- 68.55	67.61	0.01- 0.37	0.19	0.00- 0.34	0.11	0.00- 0.04	0.01		
J.R.Caless	36	0144	66.00	G-7 to +4	Rosette	65.66- 68.03	66.75	0.03- 0.24	0.12	0.00- 0.23	0.12	0.00- 0.06	0.01		
		Data I	sted as	elementa	l weight	percent.	Individ	lual and	lyses an	e found	l in Appe	ndix E		•••••	• • • • • • • • •

Table	3:	Electron	Microprobe	Analyses	of	Orange	Sphalerite
			from	the Young	g M:	ine	

ZINC	SULFUR	IRON	CADMIUM	MANGAN	TOTAL
65.96	32.17	0.19	0.41	0.03	98.76
66.06	34.91	0.19	0.29	0.00	101.45
64.75	33.64	0.18	0.14	0.03	98.74
63.50	37.14	0.22	0.56	0.02	101.44

Data listed as elemental weight percent.

of sphalerite at the Young Mine. One traverse through sample O132, a rosette featuring all 3 major phases of sphalerite growth, shows minor element compositional variations typical of virtually all sphalerites analyzed (Figure 20). In general, early sphalerite contains more Fe and less Cd and Cu than the other phases. Late sphalerite contains significantly more Cd overall than the early sphalerite, and somewhat more Cu. Compositional trends in vug-filling sphalerite are difficult to identify because the sequence of growth banding varies from sample to sample. Figure 20 shows that some bands may contain high amounts of some elements (i.e. Cd) but low amounts of others (Fe, Cu), or low amounts of all three. Eight remaining sphalerite traverses are contained in Appendix F.

Careful observation of zones traversed with the microprobe revealed that Cd values often show a positive correlation with zones containing even minor traces of hydrocarbons, as observed by Craig et al. (1982). An exception to this tendency is seen in sample 0141, where a zone of late sphalerite containing abundant bluish hydrocarbons shows high Cd, while a zone of vug-filling sphalerite containing what appears to be brown hydrocarbon material shows no increase in Cd.

Electron microprobe analyses were also conducted on carbonate gangue at the Young Mine to determine whether or





not compositional differences existed across various zones identified in the paragenesis. Seven stepped traverses were made through dolomite and calcite found in 5 individual samples. In general, Ca, Mg, Fe, and Mn were the only elements present in significant amounts, and data from each traverse is summarized in Table 4. Individual data points are also listed in Appendix E. Comparison between the atomic ratios of Ca and Mg in dolomites indicate that they are slightly enriched in Ca, a distinguishing feature of deep basinal saddle dolomites (Radke and Mathis, 1980). No major variations in composition were noted across growth zones in the dolomite. However, comparison of Fe and Mn values with variations in intensity of luminescence under a luminoscope indicate that the brightest zones are a function of high Mn and low Fe values, while darker zones are a function of high Fe and low Mn values (Figure 21). This is consistent with similar discoveries made by other authors (Cobb, 1974; Pierson, 1981). Another traverse through gangue dolomite showing luminescence as a function of Fe/Mn ratios is found in Appendix F.

Sample	Stope	Beds	Mineral	Points	Range Ca	Ave Ca	Range Mg	Ave Mg	Range Fe	Ava Fe	Range Mn	Ave Mi
1467	63-18	G114 -118	Dolomite	22	28.18- 29.61	28.72	17.80- 19,14	18,44	0.42- 0.79	0.61	0.02- 0.08	0.05
1467	63-18	G114 -118	Calcite	9	50.20- 53.33	52.57	0.10- 0.99	0.28·	0.05- 0.09	0.06	0.00- 0.08	0.03
1468	63-18	G114 -118	Dolomite	66	28.31- 32.46	29.37	16.43- 19.05	18.42	0.30- 0.83	0.56	0.02- 0.17	0.06
1470	63-18	94	Dolomite	48	27.45- 31.45	28.65	16.90- 18.58	18.02	0.28- 0.79	0.55	0.02- 0.12	0.06
1471	63-18	94	Dolomite	31	29.48- 31.86	30.16	17.28- 19.15	18.62	0.32- 0.96	0.63	0.02- 0.13	0.06
1471	63-18	94	Dolomite	4	28.98- 31.41	29.90	17.29- 19.19	18.28	0.36- 0.76	0.49	0.06- 0.14	0.09
1466	63-18	60	Dolomite	28	28.74- 32.00	30.73	16.60- 18.20	17.40	0.29- 0.47	0.35	0.04- 0.13	0.08

Table 4: Summary of Electron Microprobe Traverses Through Carbonate Fracture-Filling Gangue - Major Elements (in Oxide Wt.%)

Individual Analyses Listed in Appendix E



Fig. 21. Microprobe traverse through gangue dolomite showing luminescence as a function of Fe and Mn.

Geochemistry

Direct chemical analyses of fluid inclusions have been carried out by various authors in order to determine the nature of ore-depositing brines of the Mississippi Valleytype (Hall and Friedman, 1963; Roedder et al., 1963; Roedder, 1972; McLimans, 1977). In general, such analyses have shown that the brines have high Na/K, Na/Ca, and Ca/Mg ratios (Roedder, 1979). Ionic concentrations can prove useful in modeling the chemical reactions which may have occurred during ore deposition; however, the accuracy of inclusion analysis techniques may often be questionable (Roedder, 1972; 1979).

During this study, another method for approximating the composition of the ore-depositing brines which does not involve direct analysis of inclusion fluids was employed. Many authors have pointed out that bulk compositions of fluids in inclusions of Mississippi Valley-type ores are similar to those of sedimentary brines (White, 1958; 1974; Hall and Friedman, 1963; Jackson and Beales, 1967). Various authors have also suggested that oil field brine analyses may be used to estimate compositions of Mississippi Valleytype ore fluids (Sawkins, 1968; McLimans, 1977; Hanor, 1979). In this study, chemical analyses of waters from various sources were compiled and studied to determine if concentrations of certain constituents varied systematically

with respect to others. Since fluid inclusion freezing temperature determinations provide data on the minimum NaCl concentrations of ore-depositing fluids, of prime importance was establishing a correlation between concentrations of major elements and those of Cl⁻ in the water analyses. If such a correlation were to be substantiated, the concentrations of major elements in the ore fluids which permeated the area of the Young Mine could be estimated based on the NaCl content of fluid inclusions left behind in the mineral phases.

Appendix G contains a description of the regression procedure employed in this excercise and the plots which resulted. In general, a positive, linear trend is observed between Ca^{2+} , Mg^{2+} and K^+ when plotted against Cl^- . This indicates that as NaCl content increases in subsurface waters, there is a proportional increase in concentrations of these elements as well. Therefore, in light of salinities determined from fluid inclusion studies at the Young Mine, some insight is now provided as to the possible chemical nature of the ore fluids.

As discussed earlier, there is geologic evidence that, at least to a limited degree, replacement dolomitization may have occurred during ore stage mineralization. The initiation of such a process would naturally require high Mg/Ca ratios and temperatures to cause dolomite to become stable

with respect to calcite. Figure 22 shows the calcite and dolomite stability fields as a function of both Mg/Ca ratios and temperature. Assuming pressure corrections could raise main stage sphalerite homogenization temperatures at least 25° C, fluids were generally around 200° C at the time of ore deposition. When combined with the Mg/Ca ratios determined from the regression studies this places ore fluids within the dolomite field in Figure 22. During ore deposition, therefore, fluids were at least capable of dolomitizing any limestone encountered in or around the collapse breccias. The large amounts of saddle dolomite gangue which accompanied deposition of sphalerite affirm that conditions were such that dolomite was a stable phase during ore deposition.

Post-ore calcite yields temperatures which, after pressure corrections of at least 25° C, would be approximately 175° C. The decrease in salinity of late-gangue inclusions implies a decrease in Mg/Ca ratios that, combined with the decreased temperature, places post-ore fluids in the calcite stability field (Figure 22). This indicates that dolomitization did not occur during the later vug-filling stage, and also explains why emplacement of dolomite gangue ceased and calcite deposited in its place.

The pH of the fluids during deposition of main stage ore can be estimated if the following equilibrium can be



Fig. 22. Calcite and dolomite stability fields as a function of Mg/Ca ratios and temperature. The tail of the arrow is where main stage ore fluids plot, indicating that dolomite was a stable phase during ore deposition. The tip of the arrow is where post-ore fluids plot, showing that calcite became stable with respect to dolomite as saline ore fluids were superseded by less saline, post-ore fluids (constructed from data in Rosenberg and Holland, 1964). established:

(K-Spar) (Musc. or Illite) (Qtz.) $3KAlSi_3O_8 + 2H^+ = KAl_2Si_3AlO_{10}(OH)_2 + 6SiO_2 + 2K^+$

A breccia block taken from stope 63-18 was dissolved for a period of days in an acetic acid solution to remove all of the carbonate material. The insoluble residue was then x-rayed to determine mineral content, and powder patterns revealed the presence of quartz, potassium feldspar and illite. Comparison with profiles calculated by Hower (1981) indicate the presence of illite with 30% smectite interlayering (Appendix H).

Substitutions of K^+ concentrations obtained earlier (Appendix G) and available equilibrium constants (J.D. Rimstidt, pers. communication) were made into the equilibrium equation for the above reaction and a pH of between 5.5 and 6.0 was obtained at 200° C. This indicates that ore fluids were probably near neutral during deposition of main stage minerals and explains the common occurrence of sphalerite atop euhedral dolomite rhombs.

The transport and deposition of the metal sulfides found in Mississippi Valley-type deposits is still an unresolved issue. A number of authors have ventured theories based on geochemical as well as geological constraints (Beales and Jackson, 1966; Skinner, 1967; Anderson, 1973; 1975; Beales, 1975; Kyle, 1976; McLimans, 1977; Giordano and Barnes, 1981). In general, 3 models have emerged for ore transport and emplacement, which have been summarized by Sverjensky (1981). These include a mixing model (suggesting that metals and sulfide were transported to the site of deposition in separate solutions), a sulfate reduction model (where metals and sulfate were transported in the same solution), and a reduced sulfide model (where metals and sulfide were also transported together in the same solution).

Although inorganic complexes (i.e. chloride, bisulfide) have long been thought to be the dominant form of transportation for base metals, recent studies by Giordano and Barnes (1981) indicate that below 200° C inorganic complexes are not capable of transporting sufficient quantities of base metals for creation of an ore deposit. Based on thermodynamic calculations, they suggest instead that organic complexes may play a role in the transport of lead since organic material is frequently associated with galena-bearing Mississippi Valley-type deposits. Clearly, more research needs to be conducted before it can be assumed that organic complexes are capable of transporting other metals. The abundant organic material noted in samples from the Young Mine suggests that, should such a process be confirmed for

Zn, it could well have been an active transport mechanism throughout the Mascot-Jefferson City district.

The processes which led to precipitation of ore in the district are not well understood. It has been suggested that migrating ore fluids may have encountered hydrogen sulfide pockets in the host carbonates, causing deposition (Hoagland, 1971). But such a process would produce a slurry of fine-grained ore material rather than the coarse-grained, delicately-banded textures observed throughout the district. Indeed, equilibrium conditions appear to have prevailed during the course of mineralization, indicating that depositition more than likely was due to only minor fluctuations in solution chemistry. Such variations are more characteristic in an area where ore fluids change chemistry slowly by reaction with host rocks and/or a dilute pore fluid. In that case, original ore fluids must have transported both metals and sulfur together. Ohmoto and Lasaga (1982) have shown that the inorganic reduction of sulfate is extremely slow below 200° C. Therefore, it appears that sulfur was probably in sulfide form during transportation.

Deposition from a metal- and sulfide-bearing brine may occur by simple cooling, by an increase in pH, or by dilution (Anderson, 1973; Sverjensky, 1981). Although it is difficult to rule out certain of these factors in the case of the Mascot-Jefferson City ores, fluid inclusion evidence

does tend to support deposition by dilution and cooling. As discussed earlier, fluid inclusion studies show distinct populations of inclusions at the Young Mine. Large numbers of inclusions show high salinity and high filling temperature, while still others show near-constant salinity at lower temperature. Such evidence indicates that deposition in the district may have been caused by dilution of the ore-bearing brine with a less saline fluid, and by gradual cooling which would accompany such a process. Both Roedder (1971) and Taylor et al. (1983) have suggested similar modes of deposition. III. Discussion

Depth and Timing of Mineralization

Various ideas have been advanced over the years concerning the age of the ore deposits in the Mascot-Jefferson City district and the depth at which they formed. Until about 30 years ago the general opinion of most workers in the district was that the ores were hypogene hydrothermal replacement bodies and fracture-fillings in tectonic collapse breccias created during the late Paleozoic (Laurence, 1971). After World War II, the opening of new mines in the district led to further studies by a number of workers (Kendall, 1960; Hoagland et al., 1965; Carpenter et al., 1971; Hill and Wedow, 1971; Hill et al., 1971a; Hoagland, 1971; Roedder, 1971). They concluded that the breccias were actually solution collapse features related to a paleoaquifer system and that the ores were deposited by deeply circulating connate brines. Furthermore, mineralization was believed to have occurred prior to or during the Middle Ordovician, shortly after development of the paleoaquifer system.

The majority of ideas relating to depth and timing of the mineralization have been based on somewhat tenuous geologic evidence (Kendall, 1960; Carpenter et al., 1971; Hill and Wedow, 1971). Moreover, much of the emphasis placed by later authors on the association of mineralization with the lower Middle Ordovician paleoaquifer system was to quell the earlier theories that the breccias were produced along tec-

tonic fractures related to Appalachian orogenic events (see Laurence, 1971). In any event, the depth and age of ore emplacement in the district (and throughout East Tennessee) should still be considered an issue open for discussion.

Fluid inclusion work conducted earlier in East Tennessee (Roedder, 1971; Zimmerman and Kessler, 1981; Taylor et al., 1983) and during the course of this study indicates that ore-stage sphalerite was deposited from brines which were somewhat hotter than those in most other districts (i.e. Northern Arkansas: Leach et al., 1975; Central Missouri: Leach, 1979; Southeast Missouri: Sverjensky, 1981). Such elevated temperatures suggest that unusually high geothermal gradients would have to have prevailed at the time of mineralization if depth of formation were between 180 and 245 meters, as has been previously estimated (Hoagland, 1971). The brines could have been heated at depth within their source basin and then later introduced into a shallower environment. However, inclusions in both main stage and post-ore stage minerals show minimum NaCl contents of about 12 weight percent. Such moderate salinities indicate that fluids which may have mixed with and/or been displaced by incoming ore-bearing brines were certainly not groundwaters, the host fluid expected in a shallow paleoaquifer system.

Furthermore, the presence of 150° to 200° C fluids 180

to 245 meters below the surface would create an active geothermal environment not unlike that found today in areas such as Yellowstone Park, Wyoming. Temperatures at Yellowstone have been observed to vary as little as 25° to 141° C and as much as 50° to 244° C from 0 to 160 meters below the surface (White et al., 1975; Appendix I). Geothermal gradients therefore show a range between 600° and 2150° C/Km, with an average around 1200° C/Km. If the ores in East Tennessee were deposited in the paleokarst system at depths of 180 to 245 meters, geothermal gradients would have ranged from 820° to 1100° C/Km for fluids at 200° C, and from 615° to 820° C/Km for 150° C fluids. The presence of sinkholes in the vicinity of mineralized areas (Oder and Ricketts, 1961) suggests that outlets toward the surface would also have existed at the time of mineralization. Hot, pressured ore fluids would inevitably have sought the areas of lowest pressure in the higher reaches of the aquifer system, and even flowed out on the surface as in Yellowstone, particularly if deposition were to have occurred before Middle Ordovician sedimentation. The absence of siliceous sinter deposits and travertine terraces in any of the rocks of the Lower and Middle Ordovician section seems to preclude such an environment of formation for the ores in East Tennessee, as does the lack of evidence of boiling features in any of the associated ore deposits.

There are other indications that a shallow depth of formation for the ores is unlikely, and that deposition may actually have occurred at greater depth. The second stage of brecciation observed in East Tennessee suggests that tectonic events associated with the Appalachian orogeny combined with pre-ore solution activity may have caused enlargement of the early collapse features and subsequent creation of the coarse-matrix breccias. During the waning stages of this event, deep basinal brines could have entered the structures and deposited the ores. Recently, Taylor et (1982a) have suggested that deformation twinning in al. sphalerite provides evidence that mineralization occurred at depth under varying tectonic conditions. Earlier sphalerite showing deformation twinning is interpreted as having been deposited during the final stages of the Alleghenian orogeny, whereas later phases showing no twinning are believed to have been deposited after thrusting had ceased.

If ore emplacement were related in time to late Paleozoic Appalachian orogenic events, the original paleoaquifer system would have been buried beneath a number of stacked thrust sheets. Such a large amount of overburden would help explain the high temperatures of the mineralizing solutions which flowed through the collapse zones, and the lack of "geothermal" features observed in the surrounding rocks. The increase in burial depth would naturally be accompanied by a

corresponding increase in temperature and pressure within the surrounding rock. As a result, hot, ore-bearing fluids would lose heat less rapidly to the host rocks and thus maintain their elevated temperatures. Any volatile phases present in the brines would remain in solution, preventing any boiling or subsequent expansion that might lead to hot spring or geyser activity at the surface. Greater overburden thickness also helps explain the absence of low groundwater salinities in any of the primary fluid inclusions studied in the district, since more saline fluids probably dominate pore space at greater depth.

A deeper depositional model is not to be confused with earlier theories which suggested that the ore bodies were formed by brecciation along fault lines and later replacement by hypogene solutions. It is recognized that solution activity played the major role in development of the earlier breccia bodies and the regional permeability, and it is only suggested here that tectonic forces combined with later solution activity may have helped to enlarge the breccias just prior to ore emplacement.

Kyle (1976) interpreted the presence of ore-bearing veins in strata as young as Lower Mississippian as indicating a younger age for deposition of ore in Central Tennessee. Cathodoluminescence studies conducted on dolomite in post-Mississippian fractures led Gorody (1980) to similarly

conclude that ore emplacement in the Central Tennessee district post-dates deposition of Mississippian sediments. The presence of sphalerite "stringers" above the unconformity in the Mascot-Jefferson City district, although previously thought to be remobilized ore, may also indicate a younger age for mineralization. Moreover, the same dolomitization sequence observed in Central Tennessee is observed throughout the Mascot-Jefferson City district (Gorody, 1980) and therefore suggests that East Tennessee ores are similar in age to those of Central Tennessee.

Model for Ore Emplacement in the District

Since work began in the Mascot-Jefferson City district various models have been presented to explain the formation of the ore bodies. As progress has continued in the understanding of Mississippi Valley-type ores, each model has been expanded to utilize and be compatible with new advances and discoveries. Any current model must naturally take into account the latest views concerning the deposits and the most recent observations which have been made of them.

It is now recognized that there is a close relationship between the processes involved in the maturation of a sedimentary basin and the emplacement of Mississippi Valley-type ores. Foremost among these processes are the diagenetic changes which occur in the basin sediments during compaction. During diagenesis, metal-bearing ("oil field") brines are believed to develop as a result of two effects: the concentration of ions in large quantities by clay-membrane filtration, and the production of hydrocarbons due to low grade metamorphism of organic-rich sediments. The expulsion of these evolved fluids by compaction and clay dehydration, a critical aspect of the diagenetic process, is believed to occur in a step-wise manner which, under the right conditions, leads to fluid migration towards the edges of the basin (Noble, 1963; Magara, 1976). This massive dewatering process is considered the principle means by which hydrocarbons and metals are flushed from their host rocks, and by which Mississippi Valley-type ores are concentrated on the crests of regional highs near the basin (Dozy, 1970; Jackson and Beales, 1967).

Evidence suggests that the Mascot-Jefferson City ores are a result of this type of process. Inclusions in ore phases from the district (Roedder, 1971; Taylor et al., 1983; Caless, this study) indicate that sphalerite was originally deposited from hypersaline, hydrocarbon-bearing solutions similar to oil field brines. Furthermore, the association of the ores with solution collapse features indicates deposition following large scale carbonate dissolution, not unlike that which might occur due to expulsion of fluids from a basin. Most Mississippi Valley-type deposits are clearly associated with similar solution features.

Of prime importance in determining whether or not the mining district fits a fluid expulsion model is the identification of a nearby basin capable of supplying sufficient amounts of fluids and metals to create the ore deposits. Hoagland (1971) proposed that thick accumulations of shale to the southeast of the district may have been a source for the metal-bearing brines. Recently, Taylor et al. (1982a) suggested that compaction of thick sequences of shale in the Sevier Basin to the southeast may have expelled potentially metalliferous brines and formed the deposits. Shanmugam and

Walker (1978, p. 553) created a palinspastically reconstructed section of the Middle Ordovician in East Tennessee which shows the large amounts (2000-2500 m) of sediment (mostly shales) deposited in the Sevier Basin. Isopach maps of the southern Appalachians (Colton, 1970) show that the Mascot-Jefferson City district was located adjacent to the basin during the Cambro-Ordovician. This is further substantiated by Roeder and Walker (1975) who state that sediment accumulation in the basin was at the rate of 15 to 20 cm/1000 years, whereas west of the Saltville Thrust (and the district, Figure 2) subsidence was less than 0.5 cm/1000 years.

Rock units in the vicinity of the district are compatible with models favoring migration of fluids to the edges of sedimentary basins. If successive sequences in a basin are of differing lithologies (and therefore porosities) the horizontal water-pressure gradient is increased and fluids flow horizontally along the more permeable paths (Magara, 1976; Noble, 1963). The Sevier and Blockhouse shales of the Sevier Basin contain interbeds of limestone and sandstone which might have enhanced lateral fluid migration (Neuman, 1955; Shanmugam and Walker, 1978). The presence of the Knox paleoaquifer system extending in all directions beneath the Middle Ordovician sediments would have provided a conduit for fluids escaping out of the basin, and may have channeled

them into the area of the Mascot-Jefferson City district.

The expulsion of water from the basin, in addition to providing metals for the later ore deposits, may also have played a role in further opening up solution cavities and enlarging the earlier breccias in the district. Most of the water trapped in compacting sediments is expelled during the upper kilometer of burial. The maximum salinities of these early fluids range from 70,000 to 170,000 ppm and temperatures are less than 50° C. Both of these figures are significantly lower than sedimentary waters containing high concentrations of metals and inclusion waters trapped during the main stage in Mississippi Valley-type deposits (Hanor, 1979). The earlier expulsion of these fluids is due to the step-wise compaction of shales which begins in the shallower portions of a layered sequence and gradually extends downward (Magara, 1976). In the Mascot-Jefferson City district, upon reaching the upper limits of the paleoaquifer system at the edge of the basin, earlier fluids could have mixed with resident groundwaters or less-saline pore waters. The mixing of two waters of different salinities which are in equilibrium with calcite can produce a solution undersaturated with respect to calcite and capable of dissolving large quantities of limestone. It has been estimated that this "mixture corrosion" effect could create increases in porosity between 10 and 16 percent in 1400 years, which is geolo-

gically significant (Runnells, 1969). Such a process operating in the mining district may have further hollowedout existing solution passages and cavities before ore emplacement. Subsequent foundering of overlying strata into the newly developed void spaces, when combined with tectonic events accompanying the Appalachian Orogeny, could have initiated the new phase of collapse.

As compaction reached its ultimate stages, metal-bearing brines concentrated in the deepest portion of the basin would also have been squeezed into the underlying paleoaquifer system. As the volume of expelled brine increased gradually, upward migration of these denser fluids would have taken place along the edges of the basin, where they would have entered the newly-enlarged collapse zones and perhaps encountered the less-saline brines expelled earlier, or other fluids present in the rock. Whether or not the denser, incoming brines would have totally displaced the less saline fluids or whether partial or total mixing of the two solutions occurred is not clear. The varying salinities of inclusions in sphalerite suggests that, at least to a limited degree, some dilution of the deep-basinal brines did occur during ore emplacement, which may or may not have caused deposition. However, if dilution were the cause of deposition, it would had to have occurred slowly and on a large scale to account for the delicate "stratigraphy"

observed in the gangue dolomite and in the sphalerite throughout the district. Interestingly enough, estimates of salinities of the earliest fluids expelled from basins (Hanor, 1979) are nearly the same as those of the least saline fluids observed during fluid inclusion studies in the Mascot-Jefferson City district. This suggests, but does not necessarily imply, that the deeper basinal brines may have been diluted by the less- saline fluids expelled from the basin during the earlier stages of compaction. If this were the case, these earlier fluids might have returned to dominate the collapse zones in the district following expulsion of the last dregs of the mineralizing brines, since post-ore gangue phases precipitated from near-constant salinity, 12-15 wt. % NaCl solutions.

Gravitational compaction alone of the sediments in the Sevier Basin could have been responsible for expulsion of the fluids which flowed through the mining district. However, this process might have been facilitated, at least in the later stages, by thrusting related to the Appalachian Orogeny if the ore deposits were emplaced late and at greater depth, as evidence tends to suggest. Taylor et al. (1982a) speculate that potentially metalliferous brines could have begun to be expelled during the late Devonian as compression of the basin proceeded from the East.

Summary and Conclusions

1. The paragenesis of the Young Mine can be divided into three major events: a pre-ore stage, characterized by dissolution and dolomitization of host limestones; a main ore stage, during which precipitation of sphalerite ore, dolomite gangue and iron sulfides occurred; and a post-ore stage, where deposition of sphalerite rosettes, fluorite, calcite and quartz concluded the mineralization sequence. Three episodes of sphalerite deposition are recognized at the mine: an early stage, characterized by light color, abundance of fine inclusions, and high Fe content; a late stage, characterized by darker color, abundant hydrocarbons, and high Cd content; and a vug-filling stage, which consists of different bands of varying width and color characterized by hydrocarbons, textural differences, and compositional variations.

2. Fluid inclusions in sphalerite from the mine show wide variations in both homogenization temperatures (81° to 199° C) and freezing temperatures (-11.2° to -37.0° C), which is indicative of a changing environment of deposition. This may represent the mixing of two solutions: a hypersaline, metal-bearing brine with a less-saline fluid resident in the host rocks. Inclusions in late gangue phases indicate that post-ore stage fluids were cooler (56° to 170° C), less

saline, and limited to a narrower range of salinities (freezing temperatures: -8.0° to -18.0° C). Inclusions from other mines in the Mascot-Jefferson City district show similar trends.

3. Electron microprobe traverses through growth banding in sphalerite support paragenetic interpretations. Early sphalerite is consistently high in Fe, late sphalerite generally contains high Cd and somewhat higher Cu, and vugfilling sphalerite shows varying compositions across bands and between localities. Analyses of orange sphalerite indicate that it is somewhat lower in Zn and higher in Cd than major sphalerite phases. Dolomites show varying Mg/Ca ratios across growth bands which affects their luminescence.

4. Episodic dolomitization of host limestones predated and, to a lesser degree, accompanied emplacement of ore in the district. Temperatures and salinities of main ore stage fluids were such that dolomite was stable with respect to calcite.

5. The pH of the solutions during the main ore stage is estimated to have been 5.5 to 6.0. At elevated temperatures the brines were probably near neutral. Fluid inclusion and textural evidence tend to favor an ore solution which transported both metals and sulfide together. Deposition in the district may have been caused by dilution and cooling.

6. The high temperature of the ore fluids (150° to 200° C), the lack of geothermal features in the surrounding rock, the presence of ore above the Knox unconformity, and other evidence suggests a greater depth of emplacement for the ores than has been previously considered.

7. A depositional model suggesting fluid expulsion due to compaction of shales in an adjacent basin as the cause of late brecciation and ore emplacement in the district is consistent with geologic evidence.

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APPENDIX A: SAMPLE PREPARATION

Cutting of samples for both doubly-polished thin sections and fluid inclusion plates was performed on a Lapcraft "L'il Trimmer" saw using 4" Felker diamond blades. Samples were cut into slabs approximately 4.5 x 2.5 x 1.5 cm which could then be handled easily during polishing steps and which fit standard 4.6 x 2.7 x .1 cm glass microscope slides. After cutting, the slabs were polished on a variable speed Buehler Ecomet III polisher using the procedure outlined in Craig and Vaughn (1981). The slabs were first ground uniformly using a 600 grit diamond abrasive wheel to remove deep scratches and irregularities caused by cutting. The next stage involved polishing the slab on a napless cloth using 600 grit silicon carbide powder, which brought the sample to nearly a peak polishing condition. The final polishing was completed using .05 gamma alumina on microcloth, which removed shallow scratches induced during the earlier steps. The sample was later submerged in a Bransonic 32 ultrasonic cleaner for up to 60 seconds to remove trapped polishing compound and other impurities.

The slab was next mounted polished-side-down on a glass slide which had been roughened with 14.5 u AlO_2 . A cold setting epoxy, Epofix, was used as the mounting medium, which required a 24 hour setting time. After setting, the sample number was recorded on the slide with a diamond scribe, and

107

the sample was prepared for wafering. Wafering was accomplished using a Buehler Isomet 11-1180 low speed saw. Slides were attached to a thin section mount using doublestick tape and the micrometer gauge on the saw set around 1.5 mm. After wafering, the above polishing procedure was again employed to create the second polished surface. Final thickness of each thin section varied depending on need and function of the section. Most sections were cut slightly thicker than that of a normal thin section (0.03 mm).

Doubly-polished fluid inclusion plates were occasionally prepared for the study of fluid inclusions, and were usually cut from the slabs left over from thin section preparation. The plates were prepared in virtually the same manner as the doubly-polished thin sections, the only differences being that they were smaller (usually 1 x 2 cm) and they were not permanently adhered to the glass slides. Instead they were temporarily mounted using Crystalbond 509, a low melting point, reusable adhesive, which is soluble in acetone. After the final polishing, the plate was reheated, removed from the glass slide, and then cleaned in acetone. Separation from the glass slide permitted the plate to be used in the fluid inclusion stage.

APPENDIX B: PROCEDURE FOR SETTING-UP THE FLUID INCLUSION STAGE

The fluid inclusion stage was mounted on a Leitz Wetzlar microscope, and a 32x Universal Stage (long focal length) objective was used during temperature determinations. Illumination was improved by removing the transmitted light unit from the microscope and substituting an Ehrenreich MK II fiber optic light with dual leads. These optic leads were manipulated to obtain maximum visibility in a given sample. Usually resolution was greatest when both leads were pointed upward from beneath the stage. Temperature measurements were accomplished using an Omega Scass 020-G 6 inch thermocouple which was connected by wire to a Leeds and Northrup Numatron with digital display.

Fluid inclusion plates were placed in the center of the sample chamber and were fastened to the underlying glass plate with a piece of tape to prevent vibration. The thermocouple wire was inserted through a hole in the chamber and rested on top of the sample plate as close as possible to the inclusion(s) of interest (usually a distance < 1 mm).

For homogenization temperature determinations, one end of a length of soft plastic tubing was connected to a compressed air valve and the other end to a Sylvania-Exeter heating coil. The plastic sheath of the coil served as a nozzle for directing hot air into the sample chamber when it was inserted into the stage. The heating unit was plugged into a Fisher Powerstat transformer and temperature control was maintained by varying current to the coil and air flow through the plastic tubing.

For freezing temperature determinations the fluid inclusion stage, out of necessity, was placed in a large zip-lock plastic bag to prevent frosting due to condensation of H_2O from the air. Two holes were cut into the bag to improve visibility: one above the stage for the microscope objective (a rubber band sealed the plastic around the lens), and one below the stage for the light (a glass microscope slide was taped over this hole which sealed the bag but permitted light to pass through undistorted).

Cooling was achieved by allowing flow of compressed N_2 from a cylinder to pass through soft plastic tubing into a Linde Super-31 nitrogen refrigerator flask containing liquid N_2 . The cooled N_2 gas then passed from the flask into the fluid inclusion stage via the tube and nozzle arrangement used during the heating process (without the heating element turned on). The zip-lock bag was closed around the nozzle as tight as possible while still allowing N_2 gas to vent around the sides. Temperature control was achieved by varying the flow rate of N_2 gas out of the cylinder.

The thermocouple was calibrated periodically to insure accuracy of all temperature determinations. This was accom-

110

plished on the high temperature end by comparing the boiling point of H_2O (corrected for elevation and the day's barometric pressure) with the reading on the numatron. Low temperature readings were tested by comparing the temperature of ice and water with the reading on the numatron. In all calibration experiments, temperatures measured by the thermocouple were high by 0.7 to 1.0° C, and all data points were corrected down by that amount. Elevation and barometric pressure for the day were also accounted for, but when compared with the other corrections they were essentially negligible.

Inclusion Freezing Homogen. Mineral Sample Number Stope Beds Temp. Temp. _____ Main Stage 1454 1 GSA G17 -22.5 ---Sphalerite ---2 GSA G17 -22.6 1454 1454 3 GSA G17 -21.7 191 1454 4 GSA G17 -23.9 199 1454 26 GSA G17 -16.2 ---GSA -13.7 ---1454 G17 28 1470 9 63-18 G94 -22.0 139 -22.3 1472 27 63-18 G94 ---Vug-filling Sphalerite -19.7 150 0141 10 67-43 G9-17 -21.7 156 0141 11 67-43 G9-17 0141 12 67-43 **G9-17** -20.2 156 -21.0 157 0141 67-43 69-17 13 0141 67-43 -21.7 153 14 G9-17 ---151 0141 15 67-43 G9-17 157 -20.1 0141 16 67-43 G9-17 -20.8 145 0141 17 67-43 G9-17 0141 18 67-43 G9-17 -37.0 150 0141 19 67-43 G9-17 -36.4 134 G-7to +4 Fluorite 0144 20 66-00 -8.7 156 0144 G-7to +4 23 66-00 -10.7 159 Vug-Calcite 1467 6 63-18 G114--12.7 121 118 G114-118 7 1467 63-18 -11.7 147 G114-1467 8 63-18 -10.7 162 118 0141 24 67-43 G9-17 ---170 0141 25 67-43 G9-17 ---155 63-18 ---Secondary Calcite 1466 5 60 -2.3 -----

Appendix C: Fluid Inclusion Data Generated in This Study (Calibrated; in °C)

Young Mine

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Mineral	Sample	inclusion Number	Stope	Beds	Freezing Temp.	Homogen. Temp.
Fluorite	NM-1	30	66-5	G-17	-7.9	170
	NM- 1	32	6F-5	G-17	-7.3	175
	NM- 1	33	6F-5	G-17	-8.4	161
	NM- 1	35	68-5	G-17	-7.4	164
	NM- 1	36	6F-5	G-17	-7.8	163
	NM- 1	37	6F-5	G-17	-7.8	
	NM- 1	38	6F-5	G-17	-7.7	
	NM- 1	39	6F-5	G-17	-7.8	
	NM- 1	40	6F-5	G-17		164
	NM- 1	44	6F-5	G-17		176
	NM- 1	45	6F-5	G-17		172
	NM-1	46	6F-5	G-17		171
	NM-1	47	6F-5	G-17		165
	NM-1	48	6F-5	G-17		171
	NM- 1	49	6F-5	G-17		168
	NM- 1	50	6F-5	G-17		160
	NM-1	51	6F-5	G-17		168
	NM-1	52	6F-5	G-17		171
	NM-1	53	6F-5	G-17		160
	NM- 1	54	6F-5	G-17	-7.3	
	NM- 1	55	6F-5	G-17	-7.5	
	NM- 1	56	6F-5	G-17	-7.1	
	NM- 1	57	6F-5	G-17	-7.3	
	NM- 1	58	6F-5	G-17	-7.5	
	NM- 1	59	6F-5	G-17	-7.1	
	NM- 1	60	68-5	G-17	-7.8	
	NM- 1	61	6F-5	G-17	-7.7	

Appendix C - Continued

New Market Mine

APPENDIX D: COMPILATION OF YOUNG MINE FLUID INCLUSION DATA

YOUNG MINE FLUID INCLUSIONS-FREEZING TEMPERATURES MAIN STAGE SPHALERITE

SOURCES OF DATA: CP=CALESS, 1983 – PAIRED CU=CALESS, 1983 – UNPAIRED TP=TAYLOR ET AL., 1983 – PAIRED TU=TAYLOR ET AL., 1983 – UNPAIRED



YOUNG MINE FLUID INCLUSIONS-HOMOGENIZATION TEMPERATURES MAIN STAGE SPHALERITE



YOUNG MINE FLUID INCLUSIONS-FREEZING TEMPERATURES VUG-FILLING SPHALERITE

SOURCES OF DATA: CP=CALESS, 1983 - PAIRED, SAME ROSETTE RU=ROEDDER, 1971 - UNPAIRED, NOT SEPARATED TF=TAYLOR ET AL., 1983 - PAIRED, FIRST ROSETTE TS=TAYLOR ET AL., 1983 - PAIRED, SECOND ROSETTE TU=TAYLOR ET AL., 1983 - UNPAIRED 10-9 8 FREQUENCY Х X Х 6 5 × × ц. З-××× × XXX X+ $\Box + \Delta \Delta$ 2 \times \times \Box \Box Δ Δ * *>>> _____ 0. TT -40 -35 -30 -25 -20 -15 -10-5 0 FREEZING TEMPERATURE (°C)

> LEGEND: SOURCE DDDCP + + + RU ΔΔΔTF ×××TS * * * TU

> > Fig. D-3.

YOUNG MINE FLUID INCLUSIONS-HOMOGENIZATION TEMPERATURES VUG-FILLING SPHALERITE



Fig. D-4.

118

SOURCES OF DATA:

YOUNG MINE FLUID INCLUSIONS-FREEZING TEMPERATURES VUG-FILLING DOLOMITE

SOURCE OF DATA: RU=ROEDDER, 1971 – UNPAIRED, NOT SEPARATED



YOUNG MINE FLUID INCLUSIONS-HOMOGENIZATION TEMPERATURES VUG-FILLING DOLOMITE

SOURCE OF DATA: RU=ROEDDER, 1971 - UNPAIRED



YOUNG MINE FLUID INCLUSIONS-FREEZING TEMPERATURES POST-ORE FLUORITE

SOURCES OF DATA: CP=CALESS, 1983 - PAIRED RU=ROEDDER, 1971 - UNPAIRED, NOT SEPARATED



YOUNG MINE FLUID INCLUSIONS-HOMOGENIZATION TEMPERATURES POST-ORE FLUORITE



YOUNG MINE FLUID INCLUSIONS-FREEZING TEMPERATURES POST-ORE CALCITE

SOURCES OF DATA: CP=CALESS, 1983 – PAIRED RU=ROEDDER, 1971 – UNPAIRED, NOT SEPARATED



YOUNG MINE FLUID INCLUSIONS-HOMOGENIZATION TEMPERATURES POST-ORE CALCITE



YOUNG MINE FLUID INCLUSIONS-FREEZING TEMPERATURES POST-ORE QUARTZ

SOURCE OF DATA:

RU=ROEDDER, 1971 - UNPAIRED, NOT SEPARATED



YOUNG MINE FLUID INCLUSIONS-HOMOGENIZATION TEMPERATURES POST-ORE QUARTZ

SOURCE OF DATA: RU=ROEDDER, 1971 - UNPAIRED



APPENDIX E: ELECTRON MICROPROBE DATA - INDIVIDUAL ANALYSES

ELECTRO	ON MICROP	ROBE A	NALYSES OF	SPHALE	RITE-0141	ELECTRO	N MICROP	ROBE A	NALYSES OF	SPHALE	RITE-0141
ZINC	SULFUR	IRON	CADMIUM	COPPER	TOTAL	ZINC	SULFUR	IRON	CADMIUM	COPPER	TOTAL
66.73	32.28	0.17	0.25	0.06	99.49	67.67	32.75	0.06	0.10	0.01	100.59
67.87	'32.28	0.08	0.0	0.12	100.35	67.88	32.51	0.04	0.0	0.0	100.43
67.10	32.24	0.10	0.17	0.08	99.69	67.09	32.79	0.03	0.0	0.01	99.92
66.59	32.41	0.17	0.17	0.09	99.43	, 66.77	32.27	0.12	0.12	0.0	99.28
66.73	32.61	0.30	0.11	0.12	99.87	65.86	31.90	0.15	0.17	0.0	98.08
66.60	32.19	0.29	0.15	0.01	99.24	67.11	32.41	0.15	0.05	0.0	99.72
65.63	32.01	0.38	0.18	0.0	98.20	66.45	32.34	0.17	0.14	0.0	99.10
66.82	32.23	0.26	0.11	0.02	99.44	67.38	32.71	0.15	0.09	0.01	100.34
66.77	32.61	0.12	0.02	0.02	99.54	67.34	32.55	0.17	0.21	0.01	100.28
67.59	32.51	0.36	0.22	0.02	100.70	67.39	32.68	0.09	0.06	0.02	100.24
67.25	32.66	0.32	0.20	0.01	100.44	67.50	32.59	0.19	0.15	0.0	100.43
67.01	32.45	0.35	0.18	0.01	100.00	66.98	32.96	0.19	0.26	0.01	100.40
67.39	32.43	0.11	0.06	0.01	100.00	67.46	32.63	0.15	0.21	0.02	100.47
67.07	32.62	0.20	0.19	0.0	100.08	65.94	32.51	0.21	0.23	0.06	98.95
65.63	32.33	0.10	0.18	0.08	98.32	66.99	33.08	0.07	0.0	0.01	100.15
66.70	32.49	0.31	0.35	0.06	99.91	66.96	32.61	0.12	0.23	0.0	99.92
67.05	32.40	0.40	0.28	0.07	100.20	67.00	32.37	0.11	0.11	0.0	99.59
67.60	32.64	0.33	0.49	0.12	101.18	67.17	32.60	0.08	0.02	0.0	99.87
66.61	32.47	0.32	0.38	0.11	99.89						
67.34	32.57	0.07	0.14	0.09	100.21						
66.93	32.37	0.09	0.38	0.0	99.77						
67.29	32.41	0.02	0.04	0.02	99.78						
67.32	32.69	0.02	0.23	0.0	100.26						
66.34	32.60	0.06	0.33	0.0	99.33						

	EL	ECTRON	MICROPROBE	ANALYSES O	F SPHALEF	RITE-0142
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ZINC	SULFUR	IRON	CADMIUM	COPPER	TOTAL
66.46	32.24	0.05	0.11	0.0	98.86
67.96	32.73	0.04	0.0	0.06	100.79
68.15	32.86	0.08	0.24	0.04	101.37
67.46	32.77	0.16	0.17	0.0	100.56
67.78	32.93	0.14	0.12	0.0	100.97
68.03	32.85	0.10	0.11	0.0	101.09
67.99	33.11	0.12	0.0	0.0	101.22
67.75	33.15	0.12	0.0	0.0	101.02
67.17	33.10	0.10	0.0	0.0	100.37
68.34	33.05	0.14	0.07	0.0	101.60
67.86	33.29	0.14	0.09	0.0	101.38
67.79	32.79	0.17	0.10	0.0	100.85
67.18	32.98	0.12	0.06	0.01	100.35
67.68	32.83	0.17	0.21	0.01	100.90
68.07	33.20	0.07	0.0	0.0	101.34
66.34	32.64	0.02	0.12	0.0	99.12
67.52	32.80	0.01	0.02	0.0	100.35
68.35	33.12	0.02	0.02	0.03	101.54
67.53	32.88	0.07	0.32	0.01	100.81
68.01	32.56	0.02	0.22	0.02	100.83
66.66	32.66	0.04	0.07	0.09	99.52
67.77	32.83	0.05	0.22	0.01	100.88
66.72	32.48	0.05	0.34	0.0	99.59
67.00	32.94	0.02	0.28	0.0	100.24

ZINC	SULFUR	IRON	CADMIUM	COPPER	TOTAL
67.41	32.84	0.03	0.06	0.07	100.41
67.35	33.17	0.02	0.12	0.0	100.66
67.66	32.62	0.06	0.26	0.0	100.60
66.90	32.90	0.04	0.08 ·	0.0	99.92

	ELECTRON	MICROPROBE	ANALYSES	OF	SPHALERITE-0132
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ZINC	SULFUR	IRON	CADMIUM	COPPER	TOTAL	ZINC	SULFUR	IRON	CADMIUM	COPPER	TOTAL
67.36	33.12	0.33	0.11	0.06	100.98	67.65	32.55	0.05	0.36	0.16	100.77
67.19	'32.37	0.28	0.09	0.03	99.96	67.22	32.83	0.08	0.22	0.13	100.48
67.22	32.26	0.40	0.19	0.0	100.07	66.66	32.38	0.07	0.18	0.12	99.41
66.79	32.48	0.30	0.15	0.0	99.72	66.43	32.50	0.09	0.27	0.10	99.39
65.93	32,43	0.22	0.14	0.01	98.73	67.61	32.47	0.11	0.29	0.10	100.58
67.25	32.91	0.37	0.12	0.01	100.66	67.08	32.58	0.03	0.28	0.11	100.08
66.99	32.65	0.27	0.09	0.0	100.00	66.66	32.88	0.07	0.23	0.10	99.94
66.85	32.55	0.25	0.14	0.0	99.79	67.80	32.54	0.09	0.17	0.10	100.70
66.67	32.72	0.26	0.13	0.0	99.78	66.54	32.55	0.03	0.16	0.05	99.33
66.62	32.50	0.16	0.14	0.02	99.44	66.97	32.51	0.02	0.02	0.04	99.56
65.99	31.89	0.07	0.15	0.16	98.26	67.94	32.33	0.04	0.10	0.03	100.44
67.16	32.81	0.08	0.36	0.05	100.46	67.46	32.82	0.04	0.10	0.06	100.48
67 22	32 81	0.07	0.20	0.03	100.33	66 66	32 57	0.03	0.32	0.00	99.58
66 86	32 68	0.07	0.10	0.00	00.01	67 28	32 66	0.00	0.10	0.10	100 18
67 36	32.00	0.01	0.10	0.20	100 60	67.00	32.00 32.5h	0.04	0.10	0.10	00.86
66 62	32.00	0.04	0.20	0.00	100.80	67.00	32.94	0.12	0.11	0.01	99.00
00.93	32.03	0.06	0.20	0.03	99.51	00.71	32.51	0.05	0.04	0.10	99.41
66.57	32.67	0.06	0.29	0.04	99.63	66.84	32.33	0.01	0.0	0.05	99.23
66.63	32.53	0.09	0.18	0.02	99.45	67.61	32.51	0.06	0.07	0.07	100.32
67.29	32.67	0.06	0.24	0.13	100.39	67.23	32.51	0.03	0.01	0.0	99.78
66.51	32.28	0.07	0.17	0.18	99.21	67.88	32.20	0.03	0.33	0.0	100.44
67.23	32.68	0.06	0.24	0.12	100.33	67.45	32.78	0.04	0.26	0.0	100.53
66.93	32.70	0.10	0.38	0.09	100.20	66.73	32.29	0.03	0.01	0.0	99.06
66.64	32.26	0.18	0.39	0.09	99.56	68.16	32.50	0.03	0.07	0.02	100.78
67.46	32.97	0.12	0.34	0.06	100.95	67.42	32.59	0.04	0.14	0.01	100.20

ZINC	SULFUR	IRON	CADMIUM	COPPER	TOTAL
(7 40	20.01	0.04	0.20	0.0	100 66
07.49	32.81	0.04	0.32	0.0	100.00
67.09	'32.84	0.06	0.06	0.0	100.05
67.33	32.64	0.05	0.17	0.0	100.19
67.33	32.76	0.05	0.31	0.0	100.45
67.76	32.86	0.04	0.02	0.01	100.69

ELECTRO	N MICROP	ROBE ANA	LYSES OF	SPHALER	ITE-0144
ZINC	SULFUR	IRON	CADMIUM	COPPER	TOTAL
66.01	32.22	0.18	0.19	0.0	98.60
66.23	32.79	0.06	0.13	0.04	99.25
66.48	32.57	0.12	0.21	0.01	99.39
67.07	32.86	0.10	0.11	0.0	100.14
66.33	32.21	0.05	0.01	0.0	98.60
66.90	32.28	0.15	0.11	0.0	99.44
66.53	32.50	0.13	0.19	0.01	99.36
66.72	32.98	0.12	0.07	0.01	99.90
66.64	32.28	0.17	0.23	0.01	99.33
66.62	32.49	0.12	0.10	0.0	99.33
66.65	32.78	0.08	0.0	0.0	99.51
66.51	32.36	0.07	0.0	0.0	98.94

ZINC SULFUR IRON CADMIUM COPPER TOTAL 67.16 32.63 0.11 0.21 0.03 100.14 68.03 '32.89 0.16 0.0 0.0 101.08 67.48 32.34 0.12 0.05 0.01 100.00 67.16 32.65 100.06 0.10 0.15 0.0 67.83 32.76 0.09 0.17 0.02 100.87 67.05 32.41 0.05 0.17 0.03 99.71 66.96 32.66 0.03 0.22 0.0 99.87 67.14 32.88 0.15 0.04 100.43 0.22 67.31 32.63 0.24 0.11 0.03 100.32 67.25 32.58 0.22 0.09 0.02 100.16 66.94 32.82 0.05 0.0 0.06 99.87 66.53 32.34 0.0 0.03 98.95 0.05 66.84 32.46 0.18 0.0 99.62 0.14 66.95 32.12 0.11 0.20 0.0 99.38 67.39 32.29 0.03 0.0 0.02 99.73 66.17 32.31 0.17 0.18 0.0 98.83 66.10 32.15 0.12 80.0 0.0 98.45 65.66 32.63 0.14 0.09 0.01 98.53 66.18 32.22 0.19 0.19 0.0 98.78 66.31 31.98 0.13 0.08 0.0 98.50 66.65 31.98 0.01 0.16 0.21 99.01 66.31 32.47 0.13 0.12 0.0 99.03 66.23 33.01 0.13 0.12 0.01 99.50

0.12

0.0

0.15

99.63

66.79 32.57

ELECTRON MICROPROBE ANALISES OF ST	MALEN116-143	
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ZINC	SULFUR	IRON	CADMIUM	COPPER	MERCURY	TOTAL*	ZINC	SULFUR	IRON	CADMIUM	COPPER	MERCURY	TOTAL*
67.53	33.65	0.11	0.31	0.03	0.02	101.67	67.19	32.70	0.13	0.64	0.03	0.05	100.81
67.63	33.55	0.12	0.27	0.04	0.03	101.66	67.25	33.34	0.13	0.55	0.04	0.02	101.41
67.64	33.79	0.11	0.27	0.04	0.02	101.89	67.54	33.19	0.13	0.39	0.05	0.02	101.42
67.66	33.57	0.08	0.30	0.03	0.04	101.72	66.33	32.15	0.37	0.37	0.06	0.03	99.38
67.09	33.45	0.10	0.36	0.04	0.04	101.13	67.65	33.20	0.09	0.32	0.02	0.05	101.37
67.36	33.31	0.07	0.45	0.01	0.00	101.26	67.51	32.98	0.10	0.46	0.02	0.04	101.16
67.23	33.26	0.12	0.31	0.06	0.05	101.08	67.16	32.14	0.14	0.35	0.05	0.03	99.92
66.84	33.28	0.11	0.48	0.05	0.01	100.83	67.13	33.18	0.12	0.34	0.04	0.03	100.92
67.26	33.48	0.15	0.44	0.03	0.02	101.43	66.94	32.96	0.21	0.31	0.09	0.05	100.63
67.16	33.40	0.10	0.36	0.05	0.01	101.14	67.33	32.83	0.10	0.31	0.02	0.03	100.68
66.91	33.17	0.12	0.21	0.03	0.03	100.53	67.64	32.90	0.28	0.26	0.03	0.06	101.26
67.13	33.57	0.09	0.23	0.03	0.03	101.10	67.65	32.71	0.07	0.26	0.03	0.04	100.85
65.76	32.76	0.29	0.41	0.11	0.01	99.37	67.57	32.80	0.09	0.26	0.05	0.03	100.90
66.40	32.74	0.17	0.34	0.09	0.03	99.84	67.74	33.21	0.05	0.22	0.03	0.04	101.34
65.03	32.52	0.25	0.30	0.19	0.01	98.35	66.69	32.76	0.16	0.58	0.08	0.02	100.40
66.75	33.45	0.21	0.37	0.06	0.01	100.87	67.56	32.69	0.09	0.49	0.03	0.01	100.99
66.50	33.62	0.35	0.32	0.09	0.04	100.97	67.51	33.20	0.09	0.37	0.03	0.05	101.39
66.05	32.84	0.16	0.39	0.12	0.04	99.64	67.89	33.33	0.21	0.31	0.03	0.04	101.90
66.73	32.97	0.33	0.40	0.04	0.04	100.54	67.38	32.07	0.07	0.49	0.03	0.01	100.12
67.37	33.48	0.16	0.41	0.03	0.00	101.50	67.54	32.84	0.07	0.27	0.03	0.03	100.87
67.22	33.23	0.13	0.38	0.03	0.01	101.06	67.41	32.43	0.07	0.23	0.05	0.02	100.32
67.36	33.54	0.09	0.27	0.04	0.02	101.37	67.11	32.64	0.17	0.28	0.08	0.03	100.39
66.25	32.84	0.14	0.44	0.07	0.03	99.81	67.48	32.60	0.07	0.21	0.02	0.00	100.45
*TOTALS	INCLUDE	INSIGN	IFICANT	AMOUNTS OF	OTHER	ELEMENTS	* TOTALS	INCLUDE	INSIGN	FICANT	AMOUNTS C	F OTHER	ELEMENTS

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ZINC	SULFUR	IRON	CADMIUM	COPPER	MERCURY	TOTAL*	ZINC	SULFUR	IRON	CADMIUM	COPPER	TOTAL
67.81	32.72	0.07	0.24	0.04	0.03	101.00	67.45	32.83	0.08	0.01	0.01	100.38
66.85	31.24	0.18	0.33	0.07	0.04	98.81	67.86	32.63	0.21	0.16	0.0	100.86
66.95	31.98	0.14	0.30	0.04	0.02	99.53	67.92	32.86	0.11	0.11	0.02	101.02
66.51	31.11	0.14	0.27	0.07	0.05	98.24	68.20	32.40	0.19	0.09	0.01	100.89
65.96	31.78	0.26	0.35	0.07	0.03	98.53	66.98	32.60	0.33	0.11	0.02	100.04
66.43	31.59	0.26	0.36	0.11	0.02	98.86	67.16	32.64	0.26	0.13	0.0	100.19
66.43	30.91	0.28	0.36	0.13	0.04	98.21	67.89	32.87	0.27	0.12	0.01	101.16
66.19	31.14	0.25	0.32	0.11	0.00	98.07	67.52	32.62	0.28	0.13	0.01	100.56
66.16	31.25	0.30	0.41	0.06	0.01	98.25	67.00	32.71	0.33	0.18	0.05	100.27
66.23	31.05	0.37	0.50	0.04	0.04	98.29	67.74	33.07	0.16	0.13	0.01	101.11
66.72	32.24	0.34	0.50	0.04	0.02	99.93	68.44	33.28	0.03	0.0	0.04	101.79
67.05	31.47	0.12	0.42	0.04	0.04	99.21	68.32	32.84	0.12	0.16	0.05	101.49
67.11	31.52	0.08	0.46	0.03	0.04	99.36	68.55	32.65	0.03	0.0	0.02	101.25
67.32	32.48	0.15	0.39	0.05	0.05	100.53	68.24	33.12	0.08	0.16	0.0	101.60
67.10	32.05	0.16	0.45	0.05	0.03	99.94	68.11	33.15	0.06	0.0	0.02	101.34
67.15	32.40	0.14	0.43	0.05	0.02	100.30	67.94	32.95	0.10	0.21	0.02	101.22
66.75	32.15	0.16	0.42	0.07	0.02	99.68	67.82	32.96	0.04	0.06	0.0	100.88
66.91	31.95	0.12	0.44	0.04	0.02	99.54	67.63	32.83	0.11	0.21	0.01	100.79
67.23	33.04	0.10	0.34	0.07	0.04	100.91	68.27	32.89	0.05	0.0	0.01	101.22
67.19	32.74	0.20	0.43	0.09	0.03	100.78	68.43	33.33	0.06	0.0	0.01	101.83
66.99	32.42	0.24	1.79	0.07	0.04	101.59	67.93	32.83	0.08	0.0	0.0	100.84
*TOTALS	INCLUDE	INSIGN	IIFICANT /	AMOUNTS OF	OTHER	ELEMENTS	67.80	33.13	0.12	0.10	0.0	101.15
							67.63	32.95	0.09	0.01	0.0	100.68
							67.53	32.83	0.09	0.15	0.02	100.62

ELECTRO	N MICROP	ROBE A	NALYSES OF	SPHALE	RITE-0143	ELECTRO	N MICROP	ROBE	ANALYSES OF	SPHALE	RITE-0134
ZINC	SULFUR	IRON	CADMIUM	COPPER	TOTAL	ZINC	SULFUR	IRON	CADMIUM	COPPER	TOTAL
68.01	32.49	0.03	0.34	0.0	100.87	67.54	32.64	0.08	0.20	0.02	100.48
68.55	32.92	0.02	0.0	0.0	101.49	67.00	32.54	0.07	0.05	0.0	99.66
66.97	32.87	0.01	0.27	0.01	100.13	68.39	32.94	0.07	0.03	0.0	101.43
67.83	32.69	0.09	0.26	0.0	100.87	68.18	32.90	0.03	0.0	0.0	101.11
67.46	32.91	0.37	0.09	0.02	100.85	66.13	32.28	0.10	0.23	0.0	98.74
67.64	32.99	0.21	0.17	0.0	101.01	67.58	32.57	0.09	0.05	0.0	100.29
67.97	33.32	0.13	0.12	0.0	101.54	67.74	32.87	0.09	0.05	0.0	100.75
67.98	33.15	0.31	0.05	0.0	101.49	67.67	32.60	0.06	0.0	0.0	100.33
68.37	32.93	0.28	0.0	0.0	101.58	66.40	32.14	0.09	0.0	0.0	98.63
67.24	32.71	0.08	0.0	0.03	100.06	67.14	32.21	0.05	0.0	0.0	99.40
68.00	32.95	0.17	0.21	0.0	101.33	68.18	32.27	0.05	0.04	0.0	100.54
67.87	32.99	0.14	0.03	0.0	101.03	66.61	32.49	0.19	0.03	0.0	99.32
67.32	32.46	0.17	0.20	0.02	100.17	67.41	32.09	0.22	0.10	0.0	99.82
67.50	32.99	0.20	0.08	0.0	100.77	66.03	32.03	0.22	0.12	0.01	98.41
67.39	32.63	0.18	0.14	0.0	100.34	66.47	32.21	0.22	0.05	0.01	98.96
66.80	32.69	0.18	0.19	0.0	99.86	65.93	31.97	0.31	0.15	0.0	98.36
67.20	32.74	0.15	0.08	0.0	100.17	66.51	32.45	0.22	0.15	0.01	99.34
67.63	32.87	0.34	0.07	0.0	100.91	66.57	32.00	0.27	0.18	0.01	99.03
67.55	32.87	0.15	0.12	0.01	100.70	67.70	32.48	0.19	0.09	0.0	100.46
68.27	32.56	0.09	0.0	0.04	100.96	67.75	32.66	0.20	0.20	0.0	100.81
67.06	33.26	0.28	0.16	0.0	100.76	66.34	32.07	0.13	0.18	0.01	98.73
67.52	32.73	0.37	0.01	0.02	100.65						
67.29	32.81	0.35	0.03	0.0	100.48						
67.12	32.60	0.32	0.07	0.01	100.12						

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ELECTRO	N MICROP	ROBE AN	NALYSES OF	SPHALER	ITE-1470	ELECTRO	N MICROP	ROBE A	NALYSES OF	SPHALEF	RITE-1470
ZINC	SULFUR	IRON	CADMIUM	COPPER	TOTAL	ZINC	SULFUR	IRON	CADMIUM	COPPER	TOTAL
67.09	31.36	0.26	0.35	0.02	99.08	66.86	31.88	0.06	0.34	0.03	99.17
67.13	31.28	0.27	0.39	0.01	99.08	66.84	32.09	0.07	0.39	0.01	99.40
67.06	31.56	0.29	0.39	0.0	99.30	66.71	32.11	0.06	0.44	0.0	99.32
66.98	31.29	0.27	0.33	0.0	98.87	66.70	32.01	0.09	0.38	0.0	99.18
66.97	31.43	0.31	0.34	0.03	99.08	66.71	32.06	0.08	0.29	0.0	99.14
66.63	31.38	0.29	0.33	0.0	98.63	66.37	31.89	0.07	0.32	0.0	98.65
66.92	31.50	0.29	0.31	0.02	99.04	66.63	31.92	0.07	0.37	0.0	98.99
66.84	31,47	0.20	0.19	0.0	98.70	66.36	31.99	0.04	0.23	0.0	98.62
67.11	31.62	0.23	0.29	0.0	99.25	66.85	32.94	0.04	0.42	0.0	100.25
67.02	31.69	0.20	0.29	0.01	99.20	66.84	32.17	0.09	0.46	0.0	99.56
66.42	31.53	0.28	0.35	0.02	98.60	66.39	32.16	0.09	0.54	0.0	99.18
66.74	31.67	0.28	0.34	0.02	99.05	66.69	32.21	0.07	0.44	0.0	99.41
66.92	31.80	0.29	0.37	0.01	99.39	66.36	32.16	0.12	0.45	0.0	99.09
66.72	31.56	0.27	0.38	0.0	98.93	66.61	32.19	0.07	0.45	0.0	99.32
66.80	31.87	0.27	0.40	0.0	99.34	66.53	32.18	0.07	0.48	0.0	99.26
66.64	31.74	0.26	0.36	0.02	99.02	66.65	32.33	0.08	0.47	0.0	99.53
67.11	31,93	0.07	0.40	0.05	99.56	66.21	32.22	0.07	0.46	0.0	98.96
66.38	31.73	0.08	0.41	0.05	98.65	66.63	32.38	0.14	0.37	0.0	99.52
66.57	31.82	0.08	0.36	0.08	98.91	66.68	32.39	0.13	0.37	0.0	99.57
66.69	31.99	0.13	0.51	0.02	99.34	66.39	32.36	0.07	0.40	0.0	99.22
66.67	31.88	0.05	0.30	0.05	98.95						
66.93	31.89	0.05	0.33	0.08	99.28						
66.97	31.87	0.06	0.30	0.07	99.27						
66.89	31.96	0.08	0.29	0.05	99.27						

ELECTRON	MICROPROBE	ANALYSE	S OF DOLOMI	TE-1468	ELECTRON	MICROPROBE	ANALYSE	S OF DOLOMI	TE-1468
CALCIUM	MAGNESIUM	IRON	MANGANESE	TOTAL*	CALCIUM	MAGNESIUM	IRON	MANGANESE	TOTAL*
29.70	18.06	0.57	0.11	48.53	28.53	18.78	0.63	0.04	48.06
29.98	18.16	0.59	0.17	49.04	29.07	18.67	0.64	0.05	48.56
30.95	17.11	0.39	0.09	48.75	28.88	18.59	0.61	0.05	48.28
30.52	18.06	0.36	0.06	49.06	28.66	18.96	0.71	0.06	48.54
29.02	18.29	0.52	0.07	49.52	28.50	18.76	0.68	0.02	48.07
30.37	17.60	0.46	0.09	48.72	28.76	18.89	0.61	0.04	48.43
29.41	18.48	0.54	0.09	48.58	29.08	18.63	0.55	0.04	48.51
28.79	18.39	0.40	0.13	47.82	28.60	18.67	0.54	0.03	48.05
28.53	18.96	0.38	0.08	48.13	28.39	18.87	0.55	0.05	48.10
28.94	19.05	0.42	0.09	48.60	28.31	18.70	0.57	0.03	48.04
29.17	18.68	0.37	0.08	48.38	28.58	18.85	0.54	0.04	48.32
29.61	18.35	0.41	0.09	48.57	28.80	18.65	0.63	0.07	48.30
28.95	18.98	0.42	0.12	48.58	28.57	18.99	0.77	0.04	48.58
28.82	18.93	0.38	0.06	48.24	28.94	18.46	0.81	0.05	48.72
28.54	18.82	0.55	0.07	48.21	28.91	18.56	0.71	0.04	48.44
28.85	18.94	0.61	0.07	48.57	29.40	18.62	0.67	0.05	48.84
28.62	18.85	0.68	0.06	48.28	29.38	18.46	0.79	0.07	48.87
29.18	18.63	0.69	0.04	48.62	29.04	18.91	0.83	0.04	48.91
28.82	19.03	0.62	0.02	48.65	28.80	18.80	0.69	0.06	48.48
30.46	17.75	0.74	0.05	49.23	29.21	18.88	0.57	0.04	48.85
29.31	18.30	0.67	0.05	48.46	29.01	19.04	0.57	0.02	48.73
28.88	18.52	0.52	0.07	48.11	28.79	18.96	0.65	0.07	48.65
28.31	18.32	0.68	0.04	48.57	28.77	18.75	0.70	0.02	48.46

*TOTALS ALSO INCLUDE LESSER AMOUNTS OF OTHER ELEMENTS

***TOTALS ALSO INCLUDE LESSER AMOUNTS OF OTHER ELEMENTS**

136
ELECTRON	I MICROPROBE	ANALYSI	ES OF DOLOM	TE-1468	ELECTRON	MICROPROBE	ANALYSI	ES OF DOLOMI	TE-1467
CALCIUM	MAGNESIUM	IRON	MANGANESE	TOTAL*	CALCIUM	MAGNESIUM	IRON	MANGANESE	TOTAL*
28.90	18.73	0.68	0.05	48.56	29.27	18.36	0.71	0.04	48.41
29.06	18.80	0.64	0.03	48.75	28.63	17.96	0.57	0.08	48.18
30.14	18.24	0.56	0.03	49.25	29.61	18.13	0.42	0.02	48.32
29.47	18.38	0.75	0.06	48.90	28.57	18.52	0.69	0.08	48.02
28.80	18.89	0.70	0.07	48.84	28.18	17.95	0.63	0.06	47.29
29.83	18.02	0.62	0.07	48.86	28.68	18.05	0.53	0.03	47.33
32.46	16.43	0.49	0.04	49.52	28.49	17.80	0.49	0.03	46.91
29.44	18.54	0.57	0.05	48.78	29.33	18.32	0.53	0.04	48.30
30.05	18.26	0.44	0.05	48.96	29.48	18.23	0.42	0.03	48.31
30.24	18.19	0.35	0.07	49.01	28.67	17.85	0.46	0.05	48.10
30.07	17.98	0.36	0.07	48.73	29.44	18.41	0.52	0.05	48.47
30.51	17.44	0.32	0.08	48.57	29.04	18.10	0.59	0.06	48.33
30.01	18.18	0.41	0.05	48.83	28.22	18.25	0.78	0.05	47.72
29.65	18.27	0.48	0.03	48.79	28.23	18.45	0.79	0.07	47.80
30.34	17.76	0.34	0.04	48.90	28.25	18.72	0.69	0.06	47.90
30.16	18.22	0.35	0.10	48.97	28.29	18.70	0.73	0.06	47.91
29.71	18.00	0.32	0.11	48.38	28.31	18.71	0.71	0.06	48.04
31.16	17.13	0.30	0.05	48.77	28.58	18.85	0.71	0.05	48.30
29.89	17.80	0.64	0.13	48.80	28.67	18.99	0.58	0.06	48.43
31.77	16.80	0.58	0.13	49.38	28.55	19.06	0.61	0.05	48.51
OTALS ALSO	INCLUDE LES	SSER AMO	UNTS OF OTH	ER ELEMENTS	28.70	19.14	0.56	0.05	48.51
					28.55	19.02	0.66	0.03	48.47

ELECTRON MICROPROBE ANALYSES OF DOLOMITE-1466

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ELECTRON	MICROPROBE	ANALYSI	ES OF DOLOMI	TE-1466
CALCIUM	MAGNESIUM	IRON	MANGANESE	TOTAL*
30.18	18.10	0.40	0.05	48.80
28.74	17.71	0.41	0.04	47.05
30.25	17.57	0.41	0.05	48.35
31.41	16.85	0.36	0.07	48.82
30.25	17.88	0.32	0.06	48.60
32.00	17.19	0.31	0.08	49.61
31.44	17.35	0.31	0.08	49.23
30.65	17.57	0.37	0.11	48.80
30.59	17.56	0.36	0.13	48.87
30.07	16.67	0.29	0.09	47.27
30.98	17.43	0.30	0.11	48.88
31.18	17.41	0.33	0.10	49.07
31.11	17.62	0.38	0.13	49.30
30.31	17.77	0.37	0.09	48.62
29.27	16.60	0.34	0.09	46.58
30.59	17.93	0.39	0.11	49.07
30 .39	18.03	0.40	0.12	49.02
30.36	18.01	0.47	0.08	49.17
31.98	16.91	0.34	0.04	49.39
31.11	17.36	0.33	0.05	48.95
30.28	18.20	0.33	0.04	49.06
31.93	17.06	0.30	0.05	49.42
31.65	17.05	0.29	0.05	49.08

#TOTALS	AL SO	INCLUDE	LESSER	AMOUNTS	OF	OTHER	FLEMENTS
TUTALS	ALSU	INCLUDE	LLJJLN	ARIOUNIS		OTHER	LLLILINIS

CALCIUM	MAGNESIUM	IRON	MANGANESE	TOTAL*
30.63	16.61	0.33	0.07	47.77
29.93	16.65	0.31	0.07	47.16
31.06	17.46	0.32	0.09	48.95
30.88	17.30	0.30	0.09	48.62
31.09	17.36	0.36	0.08	48.95

***TOTALS ALSO INCLUDE LESSER AMOUNTS OF OTHER ELEMENTS**

ELECTRON MICROPROBE ANALYSES OF CALCITE-1467 MANGANESE TOTAL* CALCIUM MAGNESIUM I RON _____ 52.95 0.17 0.05 0.04 53.54 0.05 53.26 52.81 0.17 0.06 53.33 0.15 0.07 0.00 53.63 50.20 0.99 0.09 0.01 53.17 0.37 0.03 53.15 52.18 0.05 52.68 0.32 0.05 0.08 53.40 53.43 53.11 0.10 0.05 0.04 53.20 0.13 0.07 0.03 53.64 52.68 0.15 0.06 0.02 53.08

ELECTRON	MICROPROBE	ANALYSE	S OF DOLON	11TE-1470	ELECTRON	MICROPROBE	ANALYSE	S OF DOLOMI	TE-1470
CALCIUM	MAGNESIUM	IRON M	IANGANESE	TOTAL*	CALCIUM	MAGNESIUM	IRON	MANGANESE	TOTAL*
28.04	18.39	0.71	0.08	47.49	30.73	17.10	0.60	0.12	48.69
28.69	18.22	0.47	0.03	47.63	30.45	17.82	0.33	0.06	48.78
29.11	17.76	0.66	0.04	47.78	30.67	17.55	0.38	0.08	48.83
28.87	17.75	0.79	0.06	47.65	29.90	17.85	0.40	0.10	48.31
27.80	18.03	0.75	0.10	47.01	31.45	16.90	0.28	0.08	48.82
28.13	17.64	0.75	0.07	47.01	29.48	18.13	0.41	0.11	48.17
28.02	18.05	0.74	0.07	47.20	/ 29.50	17.86	0.39	0.09	47.91
27.93	18.21	0.77	0.06	47.25	29.08	17.94	0.37	0.09	47.58
28.30	17.82	0.69	0.06	47.20	. 29.75	18.03	0.35	0.04	48.27
28.08	18.44	0.59	0.06	47.37	29.22	17.50	0.42	0.06	47.67
28.39	18.17	0.54	0.06	47.28	29.45	17.57	0.38	0.04	47.52
27.67	18.18	0.57	0.03	46.75	29.97	17.43	0.44	0.05	48.02
27.77	18.33	0.62	0.02	46.93	29.24	17.87	0.59	0.03	47.91
28.15	17.86	0.62	0.05	46.84	28.77	18.05	0.65	0,02	47.56
27.94	18.42	0.65	0.05	47.14	28.69	18.31	0.62	0.04	47.71
27.84	18.56	0.51	0.05	47.10	28.48	18.08	0.70	0.03	47.39
29.51	17.42	0.37	0,02	47.54	28.23	18.34	0.69	0.04	47.46
27.82	18.58	0.59	0.04	47.17	28.25	18.17	0.66	0.03	47.23
27.92	18.18	0.39	0.07	46.78	28.23	17.93	0.62	0.03	46.93
27.85	18.55	0.43	0.05	47.00	27.88	18.29	0.57	0.03	46.88
27.80	18.51	0.41	0.05	46.87	28,23	18.23	0.58	0.04	47.19
27.77	18.38	0.40	0.04	46.69	28.64	18.17	0.51	0.05	47.43
27.45	18.20	0.53	0.08	46.56	28.71	17.80	0.69	0.06	47.47

*TOTALS ALSO INCLUDE LESSER AMOUNTS OF OTHER ELEMENTS

	ELECTRON	MICROPROBE	ANALYSE	S OF DOLOMI	TE-1470	ELECTRON	MICROPROBE	ANALYS	S OF DOLOMI	TE-1471A
	CALCIUM	MAGNESIUM	IRON	MANGANESE	TOTAL*	CALCIUM	MAGNESIUM	IRON	MANGANESE	TOTAL*
	27.73	18.29	0.47	0.07	46.66	31.86	17.28	0.33	0.12	49.62
	27.67	18.11	0.63	0.09	46.80	31.26	17.78	0.43	0.08	49.75
* F 0	TALS ALSO	INCLUDE LE	SSER AMO	OUNTS OF OTH	ER ELEMENTS	31.81	17.47	0.32	0.12	49.79
						30.36	18.67	0.37	0.13	49.63
	ELECTRON	MICROPROBE	ANALYSE	S OF DOLOMI	TE-1471B	30.97	18.25	0.34	0.11	49.70
	CALCIUM	MAGNESIUM	IRON	MANGANESE	TOTAL*	30.44	18.52	0.38	0.08	49.52
						30.70	18.27	0.41	0.06	49.55
	28.98	18.61	0.76	0.07	48.89	30.73	18.35	0.43	0.04	49.61
	29.76	18.04	0.40	0.09	48.63	30.43	18.52	0.41	0.02	49.48
	29.43	19.19	0.44	0.06	49.22	30.00	18.59	0.58	0.03	49.31
	31.41	17.29	0.36	0.14	49.47	29.62	18.84	0.59	0.04	49.19
*T0	TALS ALSO	INCLUDE LE	SSER AMO	OUNTS OF OTH	ER ELEMENTS	29.86	18.94	0.56	0.04	49.45
	EL COTOON				TE 41744	29.64	18.59	0.61	0.04	49.09
	ELECTRON	MICROPROBE	ANALYSE	S OF DOLOMI	TE-14/1A	29.48	19.05	0.57	0.02	49.14
	CALCIUM	MAGNESTUM	1 RON	MANGANESE	101AL#	30.16	18.65	0.59	0.04	49.51
	29.64	18.94	0.96	0.07	49.73	29.75	18.77	0.59	0.06	49.20
	29.75	18.93	0.77	0.06	49.61	29.95	19.04	0.61	0.05	49.70
	29.95	19.15	0.80	0.06	50.00	29.69	18.87	0.82	0.07	49.64
	29.97	19.15	0.71	0.08	49.92	29.49	18.54	0.77	0.04	48.90
	29.85	18.37	0.84	0.08	49.37	30.08	18.90	0.75	0.06	49.80
	29.90	18.95	0.82	0.07	49.82	29.63	18.98	0.73	0.06	49.46
	30.05	18.66	0.85	0.05	49.84	30.08	18.69	0.88	0.06	49.88
	30.00	18.73	0.87	0.06	49.94	29.96	18.77	0.89	0.06	49.82

*TOTALS ALSO INCLUDE LESSER AMOUNTS OF OTHER ELEMENTS

APPENDIX F: ELECTRON MICROPROBE TRAVERSES

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141



Fig. F-1. Electron Microprobe Traverse - Sphalerite



Fig. F-2. Electron Microprobe Traverse - Sphalerite



Fig. F-3. Electron Microprobe Traverse - Sphalerite



Fig. F-4. Electron Microprobe Traverse - Sphalerite



Fig. F-5. Electron Microprobe Traverse - Sphalerite



TRAVERSE THROUGH SPHALERITE ROSETTE - YOUNG 0142

Fig. F-6. Electron Microprobe Traverse - Sphalerite



Fig. F-7. Electron Microprobe Traverse - Sphalerite



Fig. F-8. Electron Microprobe Traverse - Sphalerite



TRAVERSE THROUGH GANGUE DOLOMITE - YOUNG 1470

APPENDIX G: GEOCHEMICAL MODELING OF ORE FLUIDS

In determining whether or not significant compositional trends existed in subsurface waters, analyses from 4 sources (White et al., 1963; White, 1965; Hitchon et al., 1971; Carpenter et al., 1974) were selected and compiled, all of which are listed in Table G-1. First, major element versus Cl⁻ concentrations were plotted by computer using SAS (Statistical Analysis System) Graphics with a Versatec plotter, which calculated best-fit lines through the data utilizing a linear regression equation. Positive, essentially linear relationships were observed for Ca-Cl and Mg-Cl pairs (Figures G-1 and G-2). Next, Mg^{2+} was plotted as a function of Ca^{2+} , which also resulted in a positive, near-linear relationship (Figure G-3). Potassium ion, when plotted as a function of Cl⁻, showed no definite correlation. Therefore, a K⁺ versus Cl⁻ plot in Hanor (1979, p. 161) was used as a substitute (Figure G-4). This diagram, based on data from Mississippi Valley-type main stage fluid inclusions, again showed a positive, essentially linear relationship between K⁺ and Cl⁻ concentrations of ore-forming brines.

Concentrations of all elements plotted by computer were listed in parts per million (ppm). NaCl concentrations of fluid inclusions, determined by freezing, were given in wt.% NaCl. Concentrations of the major ions are obtained from the plots by applying wt.% NaCl values (obtained from fluid

151

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inclusions) directly to the ppm Cl⁻ abscissa (i.e. 25 wt.% NaCl = 250,000 ppm NaCl) and reading off the corresponding Mg^{2+} or Ca^{2+} value from the ordinate. A similar procedure is followed for the K-Cl plot, where Cl⁻ values were listed in parts per thousand.

No	Temp	pH	Na	ĸ	Са	Mg	CI	S04	HCO3	Zn	Pb	Ref
1	132		79000	7080	34000	3920	198700	176		6	1	1
2	144		31000	5770	25300	1860	104000			5	1	1
3	141		53800	4430	39200	3610	166200	232		6	-	1
4	137		58300	2030	55600	3740	203300	121		43	1	1
5	133		69500	9520	32600	2720	184200			1	1	1
6	133		69000	10100	32800	2620	184400	100		10	2	1
1	143		63000	6150	44600	2770	200400	1/20		10	3 11	1
8	143		62000	6080	47300	2060	197700	145		10	7	i
10	143		5200	551	16800	1360	115300			43	1	i
11	102		52100	636	17700	1460	116400			46	i	1
12	102		53000	243	20000	1530	126300			87	11	1
13	109		52100	519	22200	1660	124600	310		79	15	1
14	114		53300		25800	1780	140800			141	32	1
15	114		54200	485	27600	1770	143600	248		143	28	1
16	123		59500	538	36400	1730	158200	310		300	80	1
18	129		54200	863	41200	2550	169000			108	23	1
19	98		47300	595	13200	1150	103200			575	10	1
20	116		49900	461	29500	2290	138400	53		34	2	
21	116		50100	474	30700	2510	140100			28	16	1
22	120		48800	625	37200	2000	190500			110	24	1
23	131		59700	1340	45000	5230	71520			04	24	1
24	80		40100	343	2000	582	71920	301		ц Ц	i	i
20	100		53700	750	16800	1640	118500	501		12	1	i
27	109		54200	727	16700	1650	122000			12	1	1
28	125		54400	708	25800	2250	138900			26	1	1
29	125		53900	888	28900	2150	141600			126	26	1
30	127		53600	649	19300	2200	123100			26		1
31	154		46500	6800	30600	2970	141700			5	1	1
32	154		52400	5980	37400	3010	159700			7	1	1
33	154		29200	3830	25700	2480	103300	276		5	1	1
34	154		52000	6080	37700	3410	156900			(1	. 1
36	135		57200	545	26800	1840	140800			100	22	1
37	124		58200	916	29900	2220	120300	20		100	22	1
38	127		54000	979	20200	1920	159300	249		217	20	1
39	1129		57100	851	10000	1570	125600	182		61	11	i
40	128		59900	704	32100	2230	154700	168		173	79	1
42	158		29000	3030	25000	1470	99100			48	1	1
43	114		53200	635	27300	1880	144900			167	35	1
44	135		79100	860	37700	2680	194600			357	111	1
45	119		45000	435	23200	1380	122500			152	35	1
46	107		55700	735	19600	1660	126200			80	12	1
47	107		57400	116	19500	1630	128400			205	11	1
48	121		62500	1140	20100	2240	156700			11	40	i
49	121		60900	1610	31800	3510	161600			8	i	1
51	123		62300	2080	31800	3560	167700			12	1	1
52	124		64000	2850	31800	3700	173800	362		7	1	1
53	124		65400	3000	32600	3700	175400			5	1	1
54	124		65300	2720	33000	3780	177000	266		4	1	1
55	127		60600	2610	31800	3520	167300				1	1
56	127		64300	5600	32600	3650	174200			057	E 1	1
57	130		65000	970	30500	2180	163900	1		221	21	1
58	130		63500	815	34800	2310	166000			200	26	1
59	130		50300	950	30800	2100	191000			217	57	1
60	120		67700	1000	32800	2200	16/1200			257	62	1
61	130		63000	1410	L1200	3220	181100			290	40	i
61	122		68500	970	33900	2650	167900			271	68	1
60	133		64500	1020	33700	2430	171400			296	68	1
65	135		77800		30800	2760	193800	26		320	106	1
66	135		76200	979	36500	2400	193400	3		342	96	1

Table G-1: Oil Field Brine Analyses

No	Temp	рН	Na	к	Са	Mg	CI	S04	HCO3	Zn	Pb	Ref
67	135		76200	905	37700	2410	190100	64		367	101	1
68	126		58300	1040	51100	3510	185900	42		216	69	1
70	116		55800	830	26000	2180	139700	•		154	27	1
1/1	120		56000	013	34700	2380	158100			120	28	1
73	120		56400	882	36100	2460	161300			204	49	i
74	129		55200	960	35600	2490	161800			184	40	1
75	133		55600	1030	33000	2330	156100			194	43	1
76	135		56900	1170	34700	2370	156100			157	20	1
77	136		56100	1320	35200	2380	159100			107	28	1
70	153		65100	7640	45600	2650	195700	94		19	20	i
80	151		66700	7860	47200	2840	207400	36		19	3	1
81	154		55400	9000	46100	3070	188300	143				1
82	49	6.80	31500	585	5750	1070	60400	180	140	06	0	2
83	49	7.10	5820	130	325	123	9940 0840	4.1	535	.00	0	2
85	81	7.20	6710	113	3040	49	15300	31	287	.40	.02	2
86	89	6.48	4310	80	3400	43	11100	1030	795			2
87	104	5.70	13600	404	12200	275	44000	16	80			2
88		7.60	6300	11	57	23	9690	1.1	1010		0	2
90		7.00	33000	101	2260	547	58700	1.5	314	0	ő	2
92		6.50	41200	141	4040	901	74800	214	243	ŏ	ŏ	2
<u>93</u>		6.80	3700	50	485	140	5410	1230	600	.05	.20	3
94		7.10	9800	68	1315	420	17330	1010	660	.22	. 30	3
95	19	6.20	2.6	2.0	2.4	.5	2.5	1.4	10	0		3 3
90 07	13	7 80	23	2.2	27	10	5.6	31	80	ŏ		3
98	17	7.40	2.4	3.0	50	Ğ	1.8	2.1	184	•		3
99		8.00	12	3.9	44	7.6	6.4	28	163			3
100		5.60	36	36	14	21	61	12	122			3 2
101	14	9.20	60	.0 1 1	.0 111	.9	4.4	22	327	0		3
103		7.60	12	- 4	60	31	12	111	285	•		3
104	11	8.00	26	3.4	78	51	1.5	60	490			3
105	11	7.30	14	4.6	157	21	8	330	241	0		3
106	11	7.60	24	3.8	153	63 87	30	302	330 774	0		3
108	26	7.60	374	20	65	6.8	442	85	378			3
109		8.39	4400	22	65	21	6730	3	661	.08		4
110		8.24	6360	25	55	87	8650	4	1220	3.05		4
111		7.13	16/0	8	22	113	5370	1	413	.09		- 4 Ц
113		8.30	1990	5.6	208	45	798	24	3560	.09		4
114		7.76	8290	50	249	79	13100	5	1030	.49		4
115		8.12	1510	_10	17	8	994	5	1870	.07		4
116		9.50	3290	1.6	14	10	1530	5	2330	.06		4
118		8.00	9340	36	197	69	14600	218	357	.04		4
119		7.94	10300	36	274	94	16000	2	258	. 05		4
120		7.92	7260	40	71	32	11400	6	437	.05		4
121		6.97	22800	98	1230	409	38200	11	176	. 44		4
122		8 19	10800	25	409	36	14900	4	2450	.06		4
124		7.25	6340	54	209	68	9780	8	1560	.47		4
125		7.34	11500	60	562	296	18400	4	379	.40		4
126		6.77	16800	440	489	104	25400	901	2080	.06		4
12/		6 01	33800	000 8110	2110 4540	1000	61100	45 41	432 509	. 10		4 L
129		8.03	3130	36	12	18	2790	46	3660	. 05		4
130		8.10	2260	74	38	15	1600	11	2280	. 11		4
131		7.95	2710	70	32	4	1210	265	1460	. 05		4
132		8.60	8/10	132	39	52	/540	/	1150	.03		4
		1 Ca	rpenter	et a	1., 197	4 3	White e	et al	., 196	53		
		2 Wh	ite, 19	65		4	Hitchor	n et a	al., 1	971		

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154

PLOT OF CALCIUM VERSUS CHLORIDE ION



SOURCES OF DATA: WHITE ET AL., 1963 WHITE, 1965 HITCHON ET AL., 1971 CARPENTER ET AL., 1974

Fig. G-1



PLOT OF MAGNESIUM VERSUS CHLORIDE ION

SOURCES OF DATA: WHITE, 1965 WHITE ET AL., 1963 HITCHON ET AL., 1971 CARPENTER ET AL., 1974

Fig. G-2

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PLOT OF MAGNESIUM VERSUS CALCIUM ION

SOURCES OF DATA: WHITE ET AL., 1963 WHITE, 1965 HITCHON ET AL., 1971 CARPENTER ET AL., 1974

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Fig. G-3



158

Fig. G-4



Appendix I: Temperature Gradients in Thermal Areas of Yellowstone Park, Wyoming (after White et al., 1975)

Temp. Range (°C)	Temperature Variation	Depth Range (m)	Calculated Gradient (°C/km)
25 - 165	140	0-65.53	2136.5
25 - 141	116	0-73.76	1572.7
51-170	119	0-153.31	776.2
50-244	194	0-153.31	1265.4
125-181	56	30.48- 123.75	600.4
20-180	160	6.10- 152.40	1093.6
42-200	158	4.57 - 157.28	1034.6
53-196	143	6.10- 156.67	949.7
43-215	172	0-156.67	1097.9
Range: 600.4	to 2136.5°C/	'km Average	: 1169.7°C/km

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GEOLOGY, PARAGENESIS, AND GEOCHEMISTRY OF SPHALERITE MINERALIZATION AT THE YOUNG MINE, MASCOT-JEFFERSON

ZINC DISTRICT, EAST TENNESSEE

by

Jonathan R. Caless

(ABSTRACT)

The Mascot-Jefferson City zinc district of East Tennessee is the major source of zinc in the United States. Sphalerite mineralization which occurs as a breccia infilling in the Lower Ordovician Knox Group carbonates has been studied in detail at the Young Mine, located in the central portion of the district. The sphalerite occurs as fracture fillings and as rosettes between carbonate breccia blocks and displays well developed growth zoning characterized by variations in color, opacity, inclusions, and composition.

Ore emplacement was preceded by two periods of solution brecciation. The first episode was related to a paleokarst terrain developed atop the Knox unconformity. The second episode was probably related to tectonic activity and expulsion of fluids from a sedimentary basin to the southeast. Episodic dolomitization in the vicinity of the ore bodies both predated and accompanied sphalerite deposition. Dolomite and other minor gangue phases deposited concurrently with sphalerite. Fluorite, calcite and quartz grew as postore, vug-filling phases. Sphalerite fluid inclusions reveal wide ranges in homogenization and freezing temperatures (81° to 199° C; -11.2° to -37.0° C) which may represent the mixing of two fluids--a hypersaline metal-rich brine with a less saline fluid resident in the host rocks. A geochemical model shows that Mg/Ca ratios and temperatures were such that dolomite was stable during ore deposition. Inclusions in post-ore gangue phases display an overall decrease in homogenization temperatures, are less saline, and show a narrower range of salinities.