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I am submitting herewith a thesis written by Michael L. Ebers entitled "A Study of Gangue Dolomite Mineralization in the Mascot-Jefferson City Zinc District, Tennessee, Using Cathodoluminescence." I recommend that it be accepted in partial fulfillment of the requirements for the degree of Master of Science, with a major in Geology.

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Vice Chancellor
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Thesis
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A STUDY OF GANGUE DOLOMITE MINERALIZATION IN THE MASCOT-JEFFERSON CITY ZINC DISTRICT, TENNESSEE, USING CATHODOLUMINESCENCE

A Thesis

Presented for the

Master of Science

Degree

The University of Tennessee, Knoxville

Michael L. Ebers

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ABSTRACT

The purpose of this investigation was to study the nature of gangue dolomite associated with sphalerite mineralization in carbonate host rocks using cathodoluminescence. Preliminary observations of many thin sections from the Mascot-Jefferson City district revealed a number of textural details which were either not visible or only poorly visible with ordinary petrographic techniques.

Growth zonations were observed in gangue dolomite associated with sphalerite mineralization in the Mascot-Jefferson City district. A total of six zones were recognized. These zones luminesce from a bright to a dark red. The difference in color is thought to be due to variations in the iron and manganese content of the dolomite. A nearly perfect microstratigraphic correlation of the gangue dolomite was observed throughout the district. Sphalerite mineralization occurred in only a limited number of zones throughout the district (zones 3d through 5).

A number of other Mississippi Valley type districts were studied using cathodoluminescence. All the districts exhibited, to some degree, cathodoluminescent zonations in gangue dolomite. A nearly perfect microstratigraphic correlation was observed between the Mascot-Jefferson City district and the Copper Ridge district which is located about 48 km (30 miles) to the northeast.

The cathodoluminescent zonation microstratigraphy shows that both the sphalerite and gangue dolomite mineralization were time correlative throughout the Mascot-Jefferson City and Copper Ridge districts.

Brecciation and gangue dolomite mineralization both preceded and followed the main period of sphalerite mineralization. These observations suggest a common source for the mineralizing solutions for both the Mascot-Jefferson City and Copper Ridge districts. Preliminary studies suggest that cathodoluminescent petrography has possible exploration applications in East Tennessee. It may be possible to differentiate between brecciated and dolomitized areas adjacent to an ore body and similar areas unrelated to mineralization.

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CHAPTER I

INTRODUCTION

I. INTRODUCTION

The origin of Mississippi Valley Type[1] deposits is not well known for several reasons. A major problem is that often both the host rocks and the gangue minerals are carbonates; hence, characteristics, such as mineral zonation, which are discernible in other mineral deposits are difficult to detect. At the suggestion of Dr. Otto C. Kopp, Department of Geological Sciences, the University of Tennessee, Knoxville, it was decided to examine the relationship between gangue and ore mineralization in some of the Mississippi Valley type deposits using a technique called cathodoluminescence.

A preliminary cathodoluminescent examination was conducted using specimens from different Mississippi Valley type deposits which included the Powell River district, the Mascot-Jefferson City district and the Tri-State district. Mose specimens examined showed some degree of cathodoluminescence; however, due to the close proximity and availability of specimens from the Mascot-Jefferson City district, it was decided to concentrate on samples from this district. A number of samples were examined from the Copper Ridge, Powell River and Austinville-Ivanhoe districts for comparative purposes.

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[1]For a discussion of the features of Mississippi Valley Type deposits refer to Callahan (1964).

II. MASCOT-JEFFERSON CITY ZINC DISTRICT

The Mascot-Jefferson City district is located approximately 16 km (10 miles) northeast of Knoxville, Tennessee, in the Valley and Ridge province (Figure 1). The stratabound zinc deposits are restricted to the Lower Ordovician Kingsport and Mascot Formations. The Kingsport Formation, where unaltered, is a limestone with a few interbeds of fine crystalline dolostone. Within the district the Kingsport has been altered to a medium to coarsely crystalline dolostone (locally termed recrystalline). Dolomitization of these limestone beds is believed to be the result of laterally migrating mineralizing solutions (Hill et al., 1971).

Both crackle and rubble breccias are common in the Kingsport Formation within the district, but crackle breccias predominate in the overlying dolostones of the Mascot. Crackle (or mosaic) breccias are distinguished from rubble breccias by the degree of movement of the breccia fragments. Crackle breccias exhibit little rotation and/or vertical movement whereas rubble breccias show significant disorientation and vertical movement (Figure 2). The majority of the breccias were produced by dissolution and collapse and are not tectonic in origin (Maher, 1971).

The breccia fragments in rubble and crackle breccias are dolomitized limestone and/or fine grained dolostone. Dolomitized limestone breccia fragments predominate in the rubble breccias of the Kingsport and crackle breccias of the Mascot contain fine grained dolostone fragments. The matrix in both types of breccias is a white, coarsely crystalline

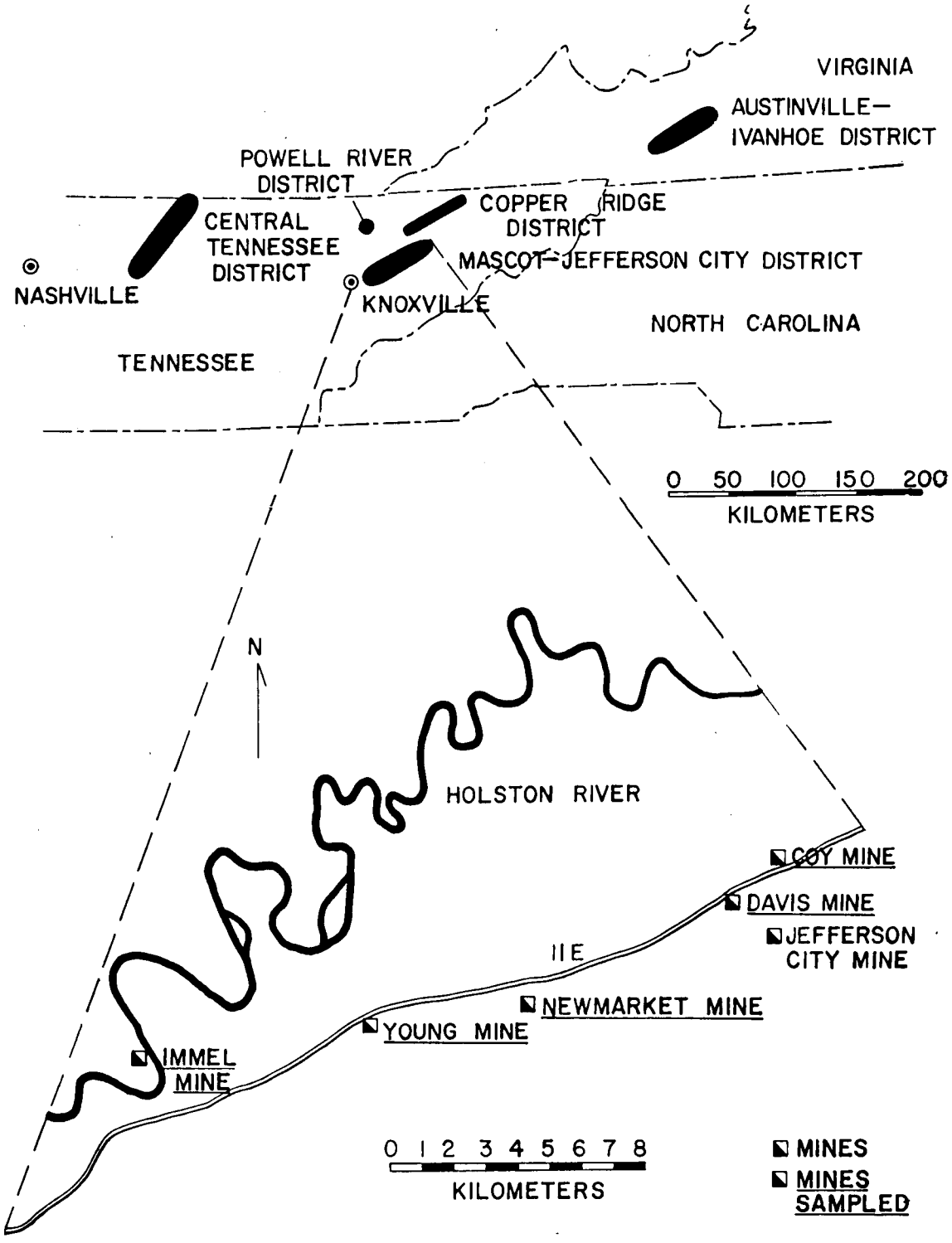


Figure 1. Map of the Mascot-Jefferson City zinc district, East Tennessee.

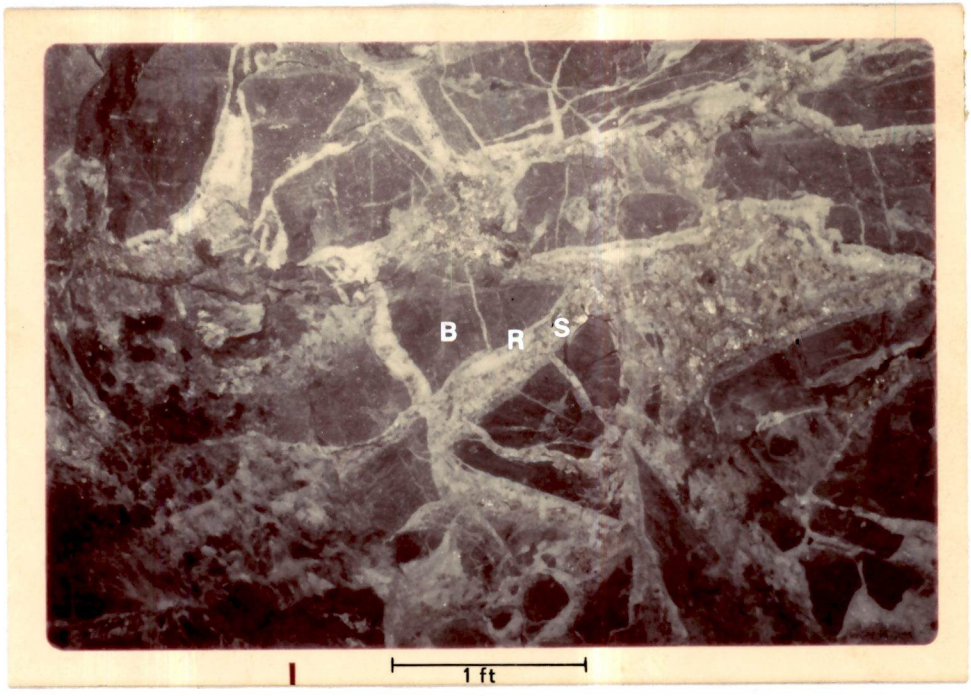


Figure 2. Rubble breccia exposed in a stope face at the Immel Mine.

Note the rind (R) of gangue dolomite between the breccia blocks (B) and the sphalerite(S).

dolostone with lesser quantities of sphalerite and pyrite. Strictly speaking, both the breccia fragments and the white, coarsely crystalline dolomite constitute the gangue, but all future references to gangue dolomite (vein dolomites of Snyder, 1975) in this text will refer only to the white, coarsely crystalline dolomite which forms the bulk of the breccia matrix.

Both white gangue dolomite and sphalerite were deposited as open space fillings rimming breccia fragments or along fractures. The deposition of gangue dolomite began before sphalerite mineralization and continued until after sphalerite mineralization was completed (Hoagland, 1967). Commonly, sphalerite was deposited as a crust on gangue dolomite. The thin rim of gangue dolomite between the host rock and sphalerite is referred to as "rind" (Figures 2, p. 4, and 3). This rind (or pre-sphalerite gangue dolomite) has been observed throughout the district (Greene, pers. comm.).

Cobb (1974), using an atomic absorpotion spectrophotometer, determined the quantities of Mn and Fe present in twenty different samples[2] from five mines in the Mascot-Jefferson City and Copper Ridge districts. Iron was present in amounts ranging from 2,404 to 9,423 ppm and manganese from 281 to 1,291 ppm. Cobb also examined seven samples from six different mines in the Mascot-Jefferson City and Copper Ridge districts using an electron microprobe. She found that the manganese

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[2]These samples were loaned to Cobb in 1973 by this investigator after the research for this paper had been completed. During the interim period between the research and preparation of this manuscript (1973-1976) the author has been employed by the New Jersey Zinc Co. at Austinville, Virginia.



Figure 3. A photograph of the slab from which thin section #117 was made.

Figure 38, p. 81, shows an infrared photograph of the thin section cut from this slab. Note the rind (R) of gangue dolomite between the breccia (B) fragments and the sphalerite (S).

concentrations appeared to be higher and the Fe/Mn ratios lower in the very bright luminescent areas. Conversely, the iron concentrations were found to be higher and the Fe/Mn ratios higher in the darker luminescent areas.

Hill et al. (1971) in a discussion of East Tennessee zinc deposits stated:

> The main problem in paragenesis is the correlation of the mineral sequences from district to district and even from mine to mine within a district . . . recent more detailed studies indicate that sequences from mines only a few miles apart cannot be matched readily . . . similar sphalerites as well as other distinctive minerals in the paragenetic sequences may not be time correlative . . . sizable information gaps produced by thrust faulting and subsequent erosion make the problem of mineralogic correlation even more difficult.

The cathodoluminescent study described here is an attempt to resolve the paragenetic and correlation problems (summarized by Hill) in the East Tennessee zinc deposits.

CHAPTER II

CATHODOLUMINESCENCE

I. DEFINITION

Luminescence is the emission of nonthermal radiation in response to some form of energy excitation. The radiation generated may be either visible light, ultraviolet or infrared and is a characteristic of the material itself. Cathodoluminescence refers to the emission of such nonthermal radiation produced by excitation using an electron beam.

II. HISTORY OF CATHODOLUMINESCENCE RESEARCH

Smith and Stenstrom (1965) were the first to describe in detail the cathodoluminescent properties of a number of minerals. The electron microprobe was used to produce the cathodoluminescence. They observed zoning of dolomite rhombs in dolomitized limestone, and noted that the same sequence of zoning was present throughout a single specimen.

Long and Agrell (1965) observed cathodoluminescence with an electronmicroprobe. They noted zonation in a calcite specimen from Strontian, Scotland. The electronmicroprobe showed a significant variation in the concentration of Mn and Fe between the light and dark zones. The light zones contained 1.0% Mn and 0.1% Fe while the dark zones contained only 0.1% Mn and 1.0% Fe. They concluded that iron concentrations in excess of 0.3% are sufficient to quench the Mn^{+2} induced cathodoluminescence of calcite.

Sippel and Glover (1965) built an instrument specifically for observing cathodoluminescence. They observed growth structures in both dolomite and calcite which recorded the complete growth history of the minerals.

Meyers (1974) observed five luminescent zonations in the calcarenite cement of the Lake Valley Formation (Mississippian) in New Mexico. He was able to correlate these zones within a 200-foot section and from section to section over a distance of 10 miles.

Medlin (1963) discussed the thermoluminescent properties of calcite, dolomite, magnesite, aragonite and anhydrite. He stated that Mn^{+2} is the most important activator in the thermoluminescence of calcite and dolomite. He also stated that the presence of Fe^{+2}, Co^{+2}, and Ni^{+2} quenches Mn^{+2} glow peaks in thermoluminescing dolomite. A synthetic sample of calcite was prepared by Medlin with approximately 500 ppm Mn^{+2} and 500 ppm Fe^{+2}, Co^{+2}, and Ni^{+2}. Both Co^{+2} and Ni^{+2} did not affect the Mn^{+2} spectrum but Fe^{+2} produced a new peak. Medlin also prepared synthetic samples of dolomite containing from 160 to 15,000 ppm Mn^{+2}. No change in the emission spectrum of the thermoluminescence was detected.

III. DESCRIPTION OF THE LUMINOSCOPE

A Nuclide Model ELM-2A LUMINOSCOPE was used for this study (Figure 4). This instrument consists of a variable high voltage power supply, a vacuum chamber and a horizontal electron gun. The vacuum chamber is mounted on the stage of a petrographic microscope. A focus coil mounted next to the electron gun makes it possible to vary the



Figure 4. The LUMINOSCOPE mounted on a petrographic microscope. The transformer and control box are on the right.

electron beam diameter from 5 centimeters down to $\frac{1}{2}$ mm. The specimen chamber accepts specimens up to 2 x 3 x $\frac{1}{2}$ inches and the specimens are traversed inside the vacuum chamber on a two-axis motion device.

IV. LUMINESCENT THEORY

The LUMINOSCOPE's electron gun generates an electron beam which is directed at a specimen placed in the vacuum chamber. The electron beam is generated by applying a high negative voltage to the cathode. Naturally occurring positive ions in the specimen chamber are attracted to the cathode. On impact these ions release electrons from the cathode which are repelled from the negatively charged cathode and attracted to the anode. Some of the electrons pass through the hollow anode and are deflected downward toward the specimen by a magnetic field. If the crystalline substance contains impurities or has an imperfect crystal lattice, a portion of the energy is re-emitted as visible light. This visible light is cathodoluminescence.

V. PETROGRAPHIC APPLICATIONS OF CATHODOLUMINESCENCE

Introduction

All thin sections prepared for this study were examined with ordinary light, with crossed nicols, and using cathodoluminescence. The use of cathodoluminescence was found to be advantageous both in mineral identification and the observation of textural details (Figures 5 and 6). Dolomite and calcite, the principal host rock and gangue minerals in the deposits studied both showed cathodoluminescence.

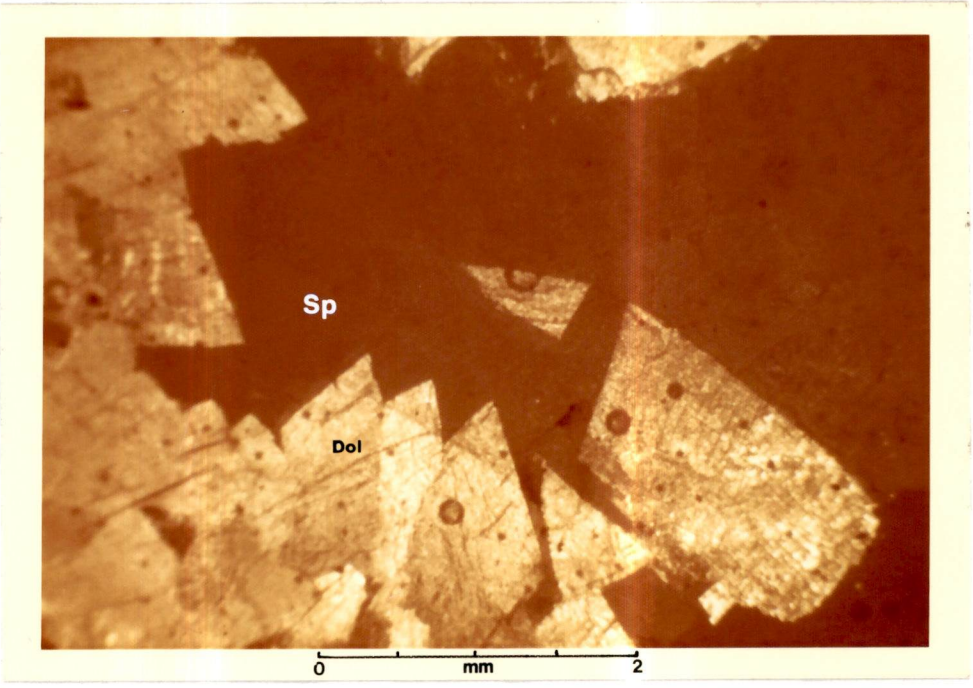


Figure 5. A photomicrograph showing gangue dolomite (Dol) and sphalerite (Sp) when observed with crossed-nicols in thin section.

This specimen is from the Young Mine.

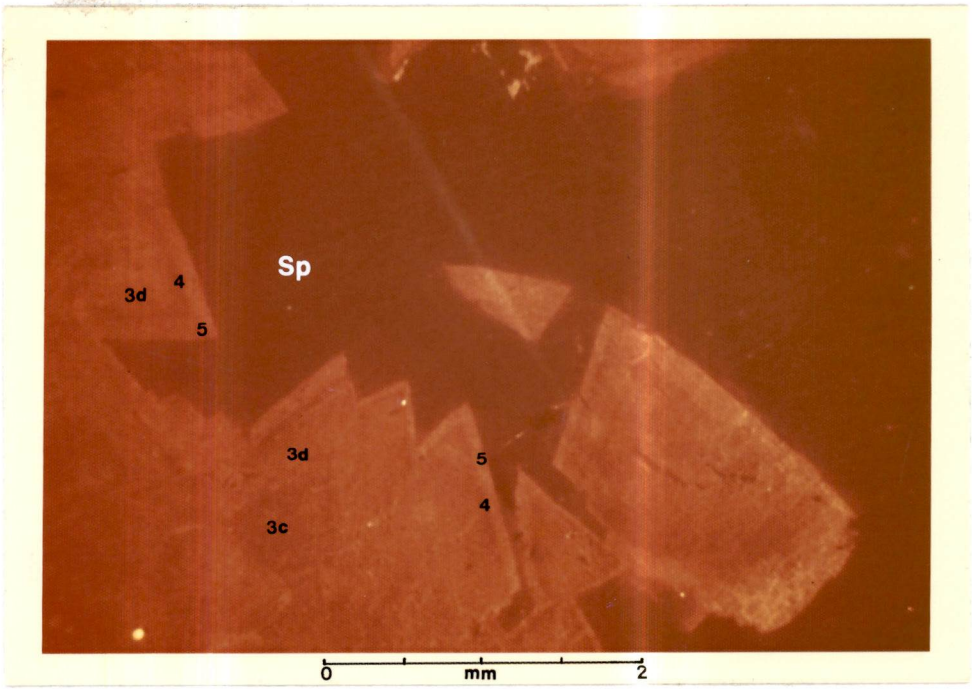


Figure 6. A photomicrograph showing the thin section shown in Figure 5 observed with cathodoluminescence.

Note zonation (zones 3c, 3d, 4 and 5).[1] Note that these zones are not visible with crossed-nicols (compare with Figure 5).

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[1]For a discussion of these zones refer to Chapter III, p. 18.

Textural Details

While examining thin sections from the Mascot-Jefferson City zinc district with cathodoluminescence, a number of textural details were observed. These details were either not visible or only poorly visible with ordinary light or crossed nicols (Figures 5 and 6). The improvement in detail with the LUMINOSCOPE is due to characteristic luminescent color(s) for each mineral species and variation in color intensity (from bright to dull in successive generations of growth within a single mineral grain as shown in Figures 7, 8 and 9).

Mineral Identification

All minerals which luminesce have characteristic luminescent color(s) depending on the type of activator and quenching ions present. These characteristic colors are useful in mineral identification in thin section. Dolomite from the Mascot-Jefferson City zinc district luminesces from a bright to a dull red. Calcite, which luminesces from yellow to orange, can be easily differentiated from dolomite in thin section (Figure 7). Quartz luminesces from dark to bright blue (Figures 8 and 9). The degree of silicification and dolomitization can easily be observed with luminescence (Figure 9). Sphalerite does not normally luminesce but locally it may luminesce bright yellow. The degree of luminescence of sphalerite appears to be related to the degree of idiomorphism. Most euhedral crystals of sphalerite lining vugs will luminesce a bright yellow. Only rarely will massive sphalerite luminesce and then it is usually confined to certain zones in the sphalerite.

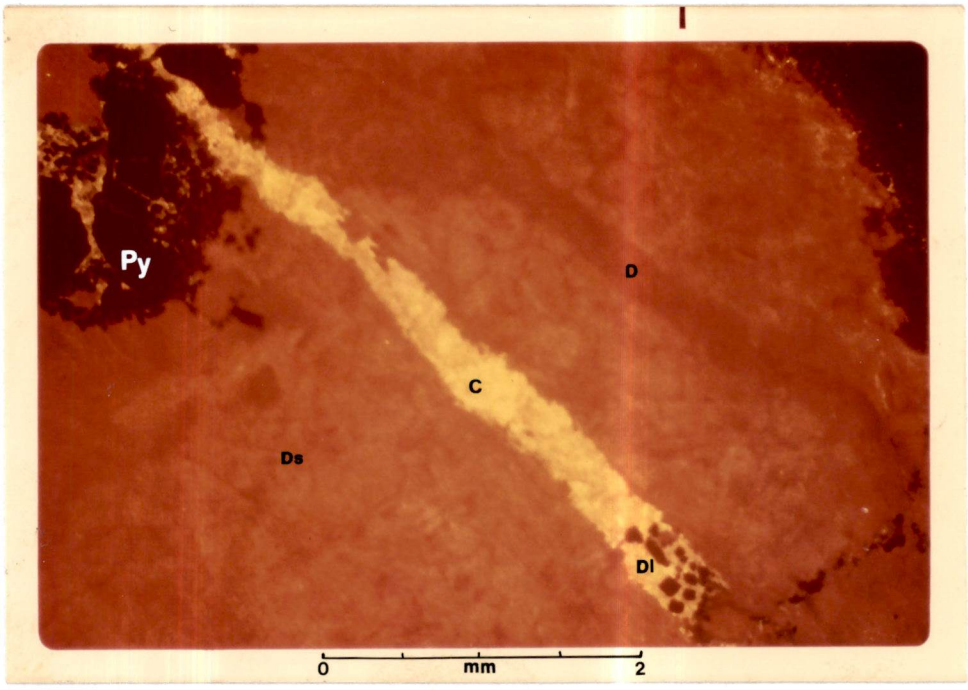


Figure 7. A photomicrograph showing two periods of fracture filling in dolostone (Ds) from the Immel Mine.

The earlier fracture is filled with dolomite (D) and the later fracture is filled with calcite (C) and dolomite (Dl). The black or nonluminescing mineral in the upper left is pyrite (Py).

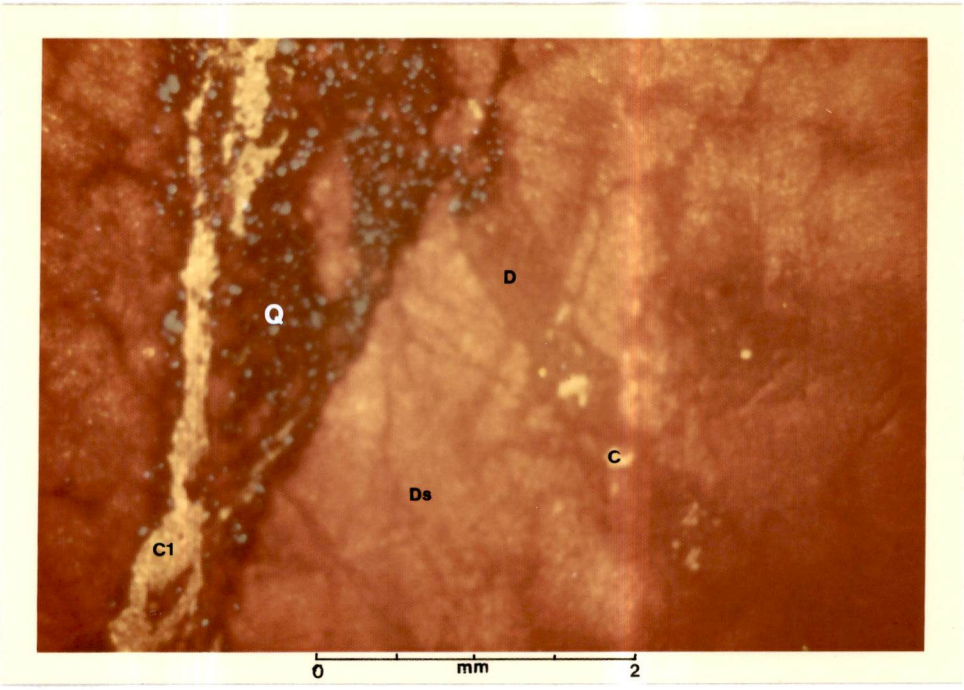


Figure 8. A photomicrograph showing fracture filling in dolostone (Ds) from the Young Mine.

Note the earlier fracture filled with dolomite (D) and calcite (C) and the later fracture filled with quartz (Q) and calcite (C1).

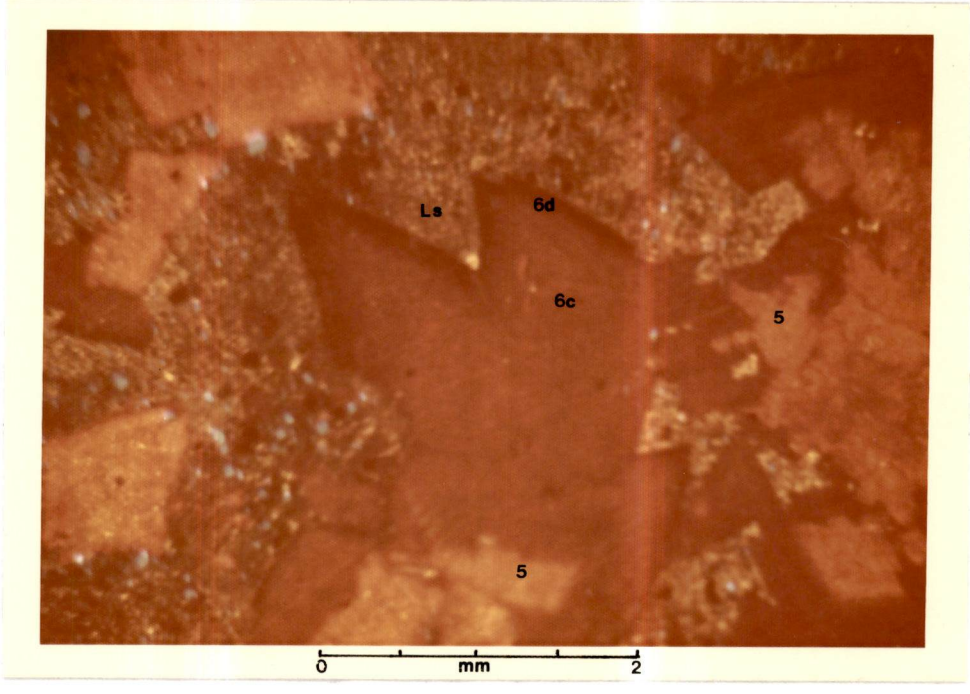


Figure 9. An example of dolomitization of limestone from the Coy Mine.

Unaltered limestone (Ls) is brown in color in this photomicrograph. Zones 5, 6c and 6d are visible in the dolomite.[2] (The percentage of blue luminescing quartz can easily be estimated with cathodoluminescence.)

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[2]For a discussion of these zones refer to Chapter III, p. 18.

CHAPTER III

CATHODOLUMINESCENT ZONATION MICROSTRATIGRAPHY

I. INTRODUCTION

Growth zones can be observed in all white gangue dolomite from the Mascot-Jefferson City zinc district using cathodoluminescence. The zones are visible due to variations in luminescent color and intensity which vary from a bright to a dull red. The variation in color and thickness of these zones has made it possible to construct a "micro-stratigraphic" sequence of luminescent zonation for each thin section studied. These luminescent sequences can be correlated both laterally and vertically.

II. COLOR AND INTENSITY OF CATHODOLUMINESCENT ZONES

Cathodoluminescent growth zones in gangue dolomite from the Mascot-Jefferson City district are visible with the LUMINOSCOPE due to variations in the color and intensity of adjacent zones. These color and intensity variations are presumed to be due to varying amounts of activator and quencher ions in the gangue dolomite. The observed colors and intensities of these zones are relative because of inherent variations in the techniques used for slide preparation and observation.

The most important factor which affects the observed colors and intensities of the cathodoluminescent zones is the voltage used in exciting cathodoluminescence. Colors get lighter and intensity becomes

brighter with increasing voltage. Figure 10 shows the cathodoluminescence observed using 6 kV. Compare this figure to Figure 11 which shows the cathodoluminescence of the same thin section observed using 12 kV. Both photographs were taken with four-minute exposures. Note that in both photographs the darkest and lightest zones are the same, only the relative color and intensity change. The color hues in Figure 10 vary from a very dark to a medium red, and in Figure 11 from a medium dark to a medium light red. The color intensity varies from dull to medium bright in Figure 10 and medium to very bright red in Figure 11. Color and intensity variations are mutually dependent. When the color hue becomes lighter due to variations in the techniques used, the intensity also becomes brighter and conversely when hue becomes darker the intensity becomes duller. The variables which affect both the color and intensity are listed in Figure 12. All observations were made within certain limits in order to standardize the color hue and intensity descriptions (Figure 12).

Photography introduces an additional set of variables which affect the color and intensity observed. When comparing the color and intensities of cathodoluminescent zones in different photographs the most important thing to remember is that all colors and intensities are relative. Colors are lighter and intensities are brighter with increasing exposure time and higher film speed. In order to minimize the apparent variation in color and intensity observed in photographs, all photographs were taken under similar conditions with identical types and speeds of film (see Appendix, p. 76).

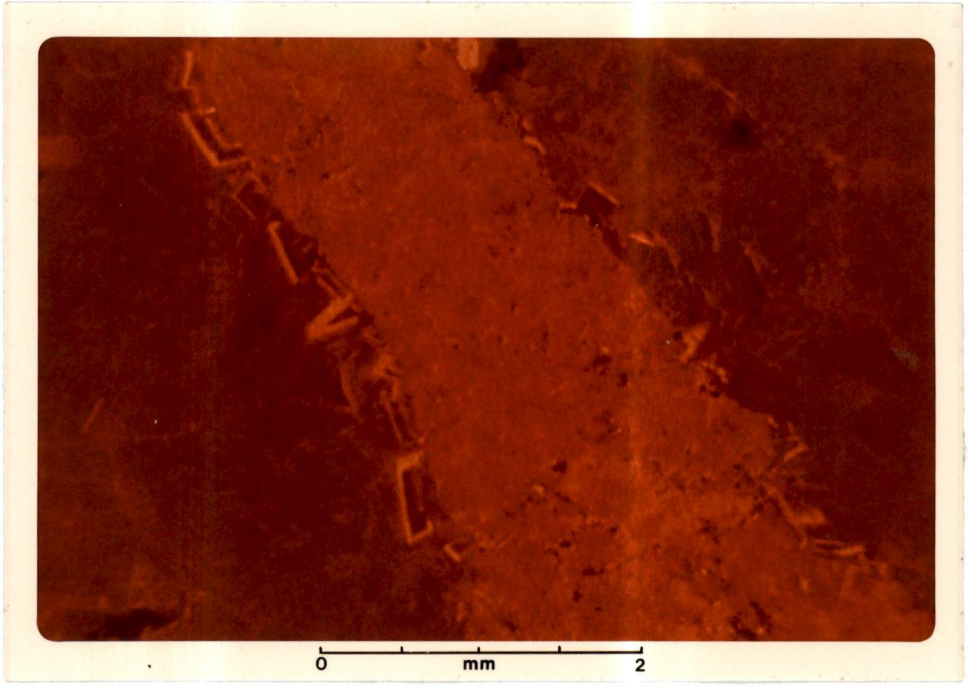


Figure 10. Cathodoluminescence observed with an applied voltage of 6 kV.

This thin section is from the Powell River district.

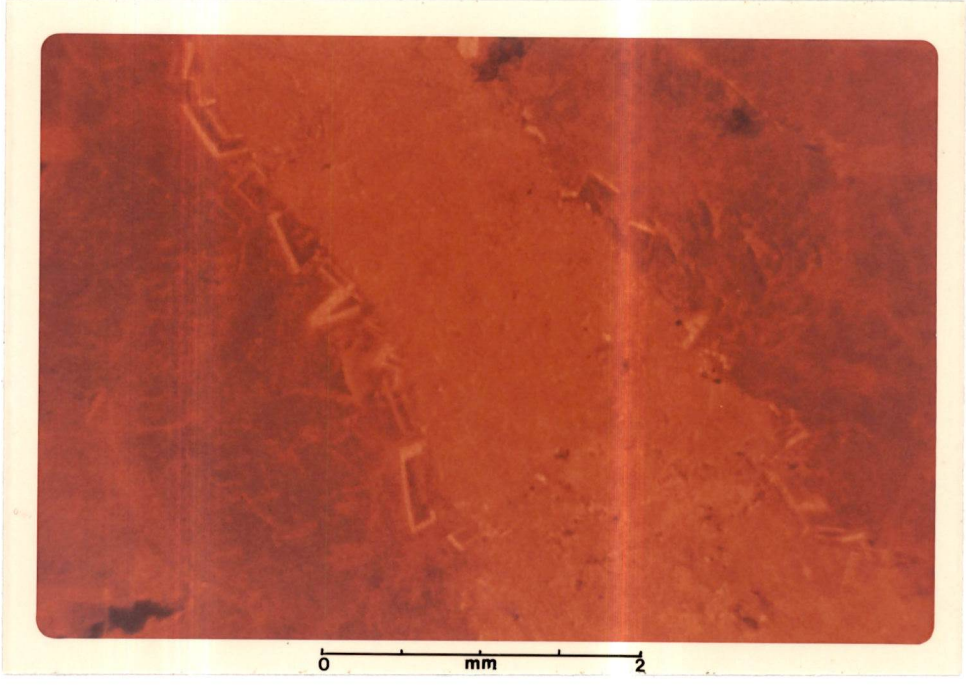


Figure 11. Cathodoluminescence observed with an applied voltage of 12 kV.

The intensity is brighter and the colors lighter than in Figure 10.

VARIABLES	LIMITS WITHIN WHICH ALL OBSERVATIONS WERE MADE
1. Applied kilovoltage of electron gun.	10 to 14 kilovolts.
2. Degree of polish of thin section.	400 grit finish.
3. Discoloration of vacuum chamber window.	Light to medium yellow.
4. Microscope characteristics.	Bausch & Lomb microscope, $3\frac{1}{2}$X objective, 5X ocular.
5. Diameter of electron beam.	5 to 10 mm.
6. Type and amount of gas.	Air.

Figure 12. The variables which affect both the color and intensity of cathodoluminescence and the variable limits observed in this study.

Figure 13 lists the color descriptions used in this study. All these descriptions are a combination of color hue and intensity. In the darker colors, the color hue makes the dominant visual impression and in the lighter colors, color intensity is dominant. Thus the lightest and brightest red is described as a very bright red and not a very light red.

COLOR DESCRIPTION	COLOR HUE	INTENSITY
Very bright red	Light	Bright
Bright red		
Medium bright red		
Bright medium red		
Dark medium red		
Medium dark red		
Dark red		
Very dark red	Dark	Dull

Figure 13. Colors of cathodoluminescent zones observed in white gangue dolomite from the Mascot-Jefferson City district.

III. THICKNESS OF CATHODOLUMINESCENT ZONES

The observed thickness of a cathodoluminescent zone may be either an apparent or true thickness depending on the orientation of the thin section. If the thin section is perpendicular to the intersected crystal faces all thicknesses are true thicknesses. However, if the thin section is at an angle to the crystal face the zonal thicknesses are apparent thicknesses and are always greater than true thickness (Figure 14). These zonal thicknesses are also dependent on the size of the open space which was filled. All the zones developed are proportionally thinner in

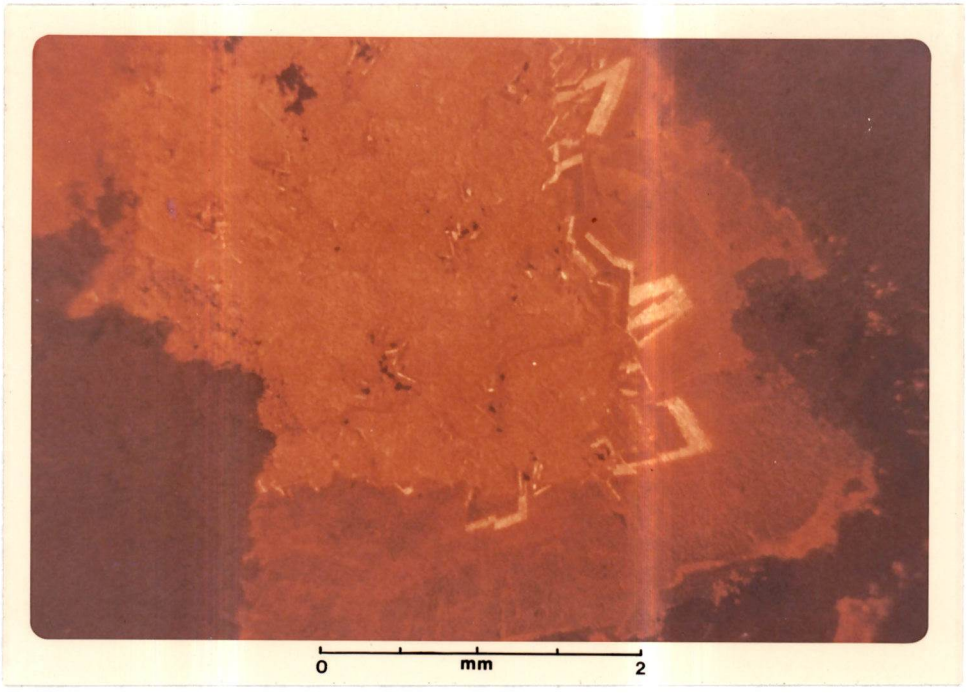


Figure 14. A photomicrograph showing variations in thickness of cathodoluminescent zones in gangue dolomite due to varying angles between the crystal faces and the plane of the thin section.

This thin section is from the Powell River district.

a narrower fracture than in a wider fracture. A possible explanation is that the thickness of the zones are dependent on the volume of the fluid passing through a given size opening. Any correlation between zonal sequences from sample to sample must compare only the relative thicknesses and not the absolute thicknesses. In describing a zonal sequence all comparative thicknesses should be observed from a single crystal cross section. This assures that all described thicknesses of a zonal sequence will be proportionally correct. The six relative thickness terms used in describing zone widths are shown in Figure 15.

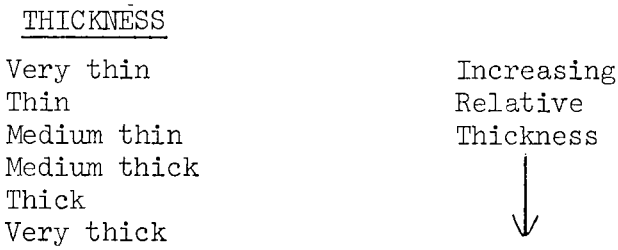


Figure 15. Descriptive terms for the relative thicknesses of cathodoluminescent zones.

IV. MICROSTRATIGRAPHIC CORRELATION

All attempts at microstratigraphic correlation of cathodoluminescent zones must consider the relative differences in thicknesses, color hue and color intensity of different zonal sequences. The thicknesses and colors of the zonal sequences seen in Figures 16 and 17 are described in Figure 18. Note the relative thicknesses of the various zones in each sequence in both photographs are almost the same but the colors are not.

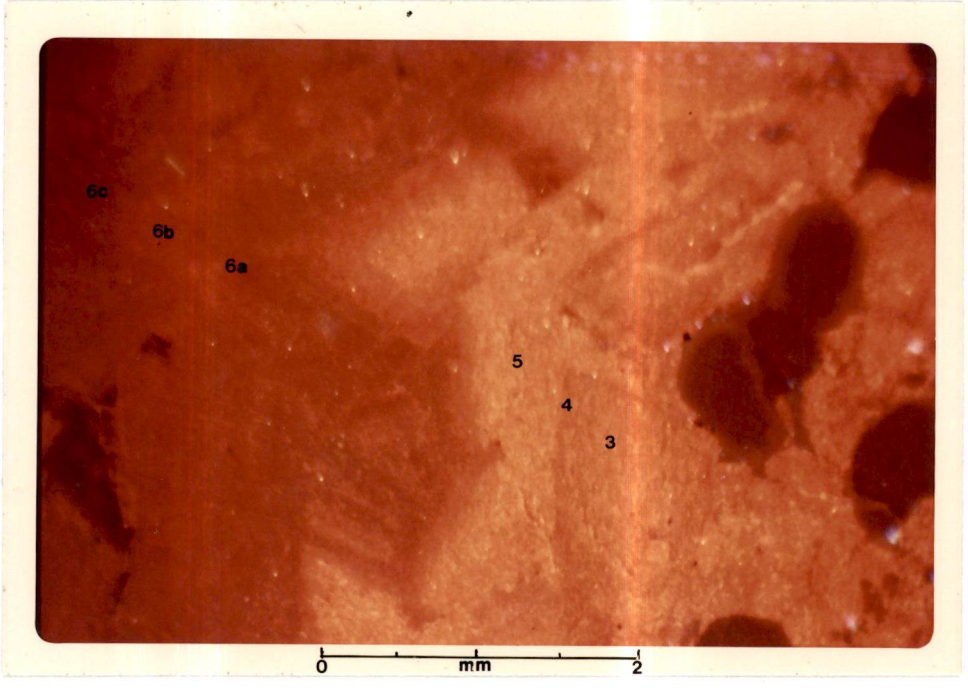


Figure 16. The cathodoluminescent growth zones in gangue dolomite from the Immel Mine.

Note the four distinct zones. Zone 3 is the earliest and zone 6 the latest zone present. This zone sequence is described in Figure 18.

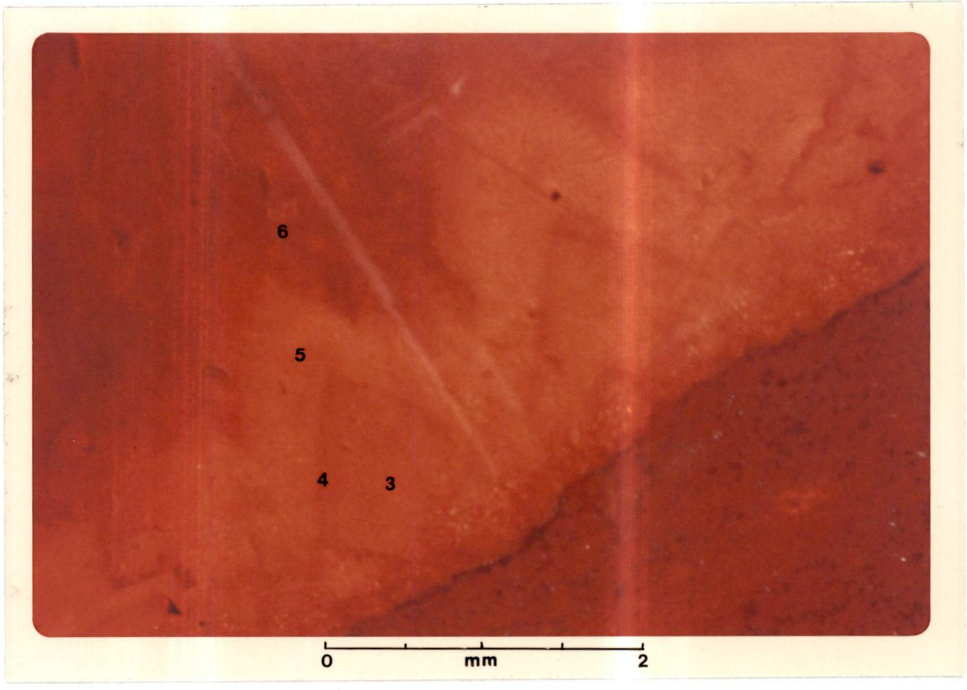


Figure 17. The cathodoluminescent growth zones in gangue dolomite from the New Market Mine.

Note the four distinct zones, zone 3 the earliest and zone 6 the latest. This zone sequence is described in Figure 18. Compare this zone sequence to that in Figure 16 from the Immel Mine.

ZONE	IMMEL	IMMEL (ADJUSTED)	NEW MARKET	
6	Thick medium dark red	Thick dark red	Thick dark red	LATE
5	Thick bright red	Thick medium bright red	Thick medium bright red	
4	Thin medium dark red	Thin dark red	Thin dark red	
3	Thick medium bright red	Thick medium dark red	Thick medium dark red	EARLY

Figure 18. This chart shows the cathodoluminescent zonation microstratigraphic correlation between Immel (adjusted) and New Market.

The Immel color descriptions have been adjusted (one color term darker) to nullify any relative differences in observed color between samples caused by variations in conditions of observation.

Now if the color terms of the Immel photograph (Figure 16) are all assigned the next darker color term (Immel Adjusted, Figure 18) the color sequence is the same as in the New Market photograph (Figure 17). This is the only valid method of microstratigraphic correlation of cathodoluminescent zonal sequences which show relative differences in thicknesses and colors.

Zonal correlation should only be attempted when three or more distinct zones are present in each zonal sequence. Zone recognition is possible when two or more zones are present in an area where the zonal sequence is known. Zone recognition is tenuous when only one zone is present but in some cases it may be attempted.

Zonal sequences should be described in a filled fracture where both sides of the fracture are visible. If the mineral(s) in the fracture were deposited as open space filling and not as replacement, the zonal sequence would show a growth pattern from the edges of the fracture to the center--the honeycomb (sawtooth) texture typical of open-space filling. Figure 19 is an example of cathodoluminescent zones clearly outlining the fracture infilling as open space filling. Zonal sequence determination is easier in such a small fracture filling than in a rubble breccia matrix. It is more difficult to determine the correct zonal sequence in dolomite rhombs in dolomitized limestone. Dolomite crystals may have either grown from the center outward or rhomb shaped voids may have filled from the edges inward (Figure 20). Locally, fracture crosscutting relationships may help to confirm zonal sequences already established from filled fractures (Figures 7 and 8, pp. 15 and 16, respectively).

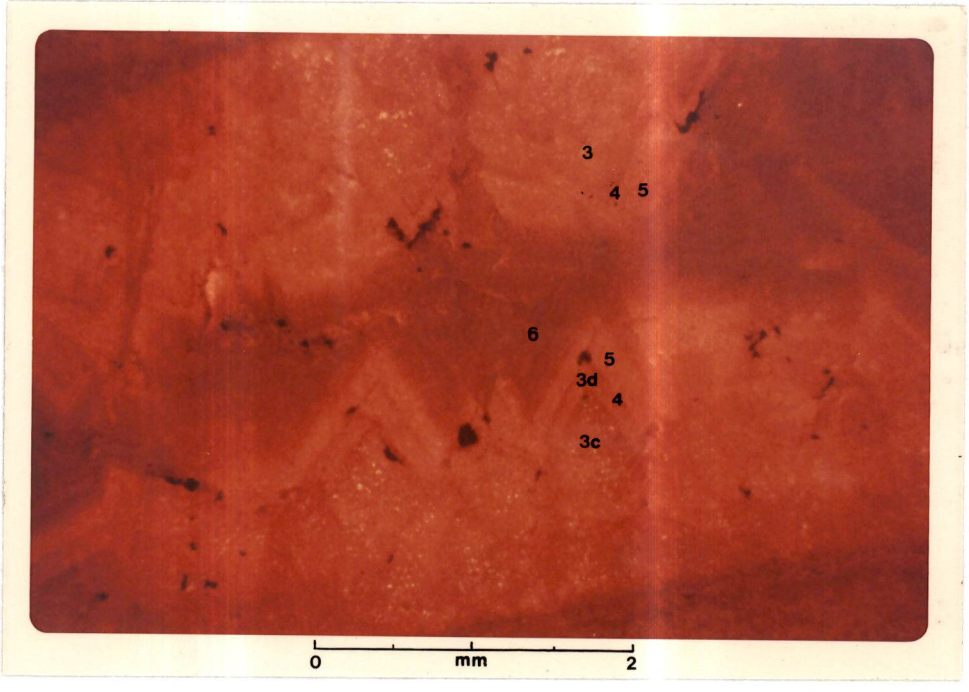


Figure 19. An example of cathodoluminescent growth zones outlining the filling in a fracture as an open space filling.

This specimen is from the Mascot-Jefferson City district.

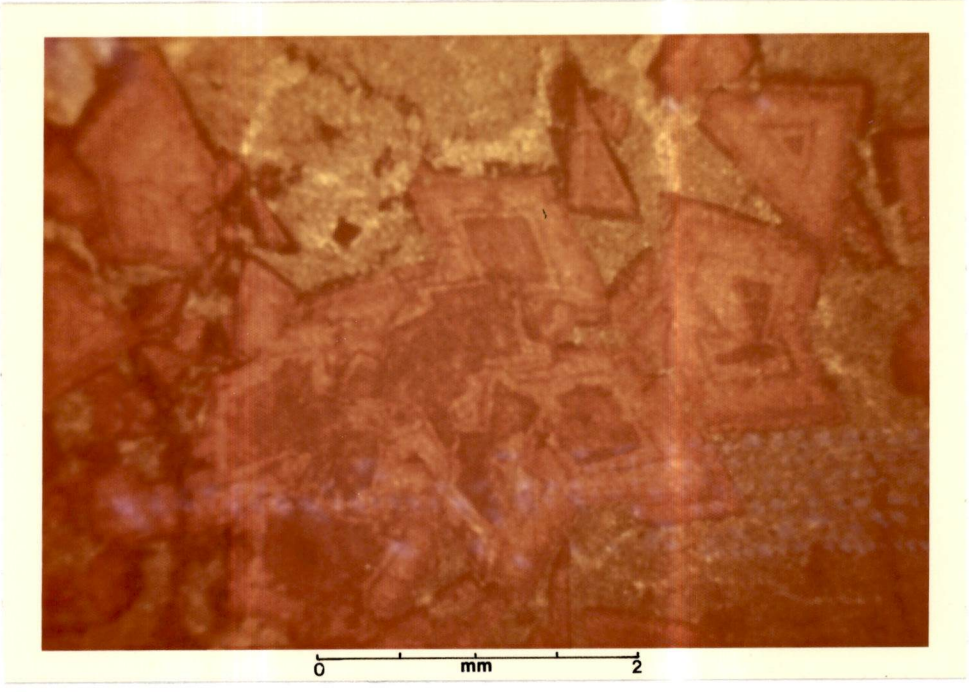


Figure 20. An example of dolomitization (red) of limestone (yellow) from the Young Mine.

The cathodoluminescent zonation in these dolomite rhombs does not fit the normal zonation sequence as seen in Figure 22, p. 35.

V. PRELIMINARY INVESTIGATION

During the preliminary phase of this study approximately 100 thin sections of varying lithologies from the Mascot-Jefferson City zinc district were examined with the LUMINOSCOPE. These thin sections had been collected and prepared by Snyder (1975) as part of his dissertation research.

In thin sections limestone luminesced from a medium to a dark yellow and dolomite from a medium to a dark red (Figure 8, p. 16). Recrystalline dolostone consisting of subhedral to euhedral rhombs of dolomite, luminesced bright red along the edge of each rhomb while the centers luminesced dark red (Figure 21).

A wide range of luminescent colors and intensities were observed in the white gangue dolomite. The range was from very bright red to very dark red or even black. These changes in color and intensity made visible growth zones outlining the complete growth history of the white gangue dolomite as open space filling. It was observed that the individual luminescent zones could be traced across a single slide. However, very few of Snyder's thin sections contained white gangue dolomite. As a result of this initial investigation, it was decided to examine white gangue dolomite in greater detail. Permission was requested to collect specimens from the mines and dumps of the American Smelting and Refining Company in the Mascot-Jefferson City zinc district in East Tennessee.

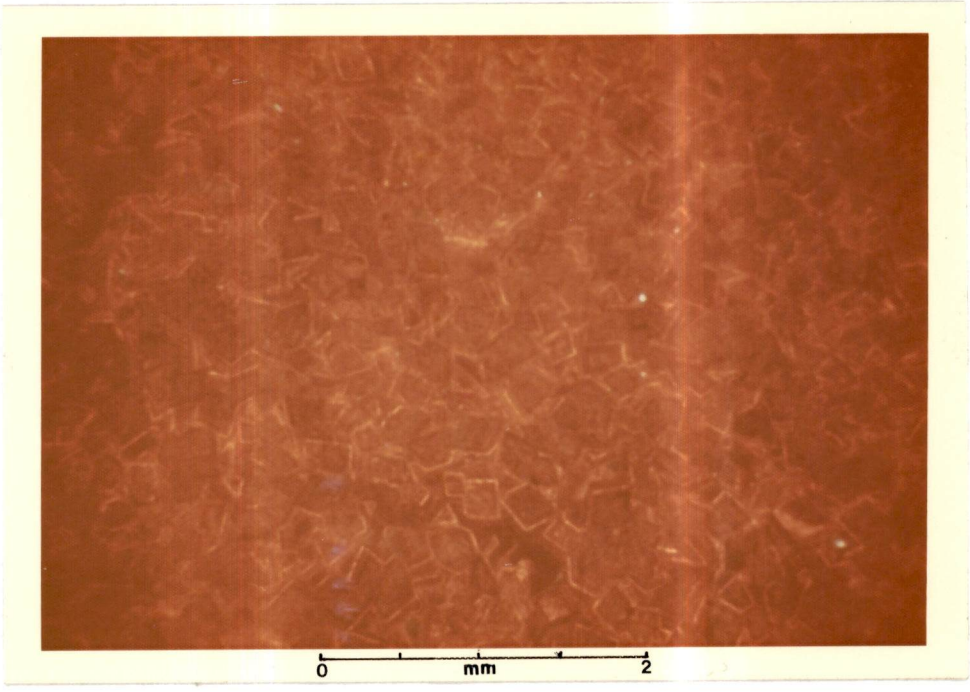


Figure 21. A good example of dolostone (from the Coy Mine) recrystallization as observed with cathodoluminescence.

VI. LATERAL CORRELATION OF LUMINESCENT ZONATION

A number of thin sections prepared from grab samples from the surface ore pile at the Immel Mine were examined with the LUMINOSCOPE. From these thin sections it was possible to work out a complete sequence of luminescent zonation in the white gangue dolomite. This micro-stratigraphic luminescent zonation sequence in shown in Figures 22 and 23.

Six major luminescent zones have been established (here numbered from 1 to 6, 1 being the earliest in the sequence). Zones 3 and 6 have been divided into four subzones (lettered a, b, c and d). The subzones of 3 and 6 could be observed only when these zones were thick (Figures 24 and 25). The earliest zones (1 and/or 2) were observed only in 24% of the thin sections examined. The initial zone in most thin sections was zone 3 (Figure 26).

Having established the luminescent zonation scheme for the samples from the Immel Mine, it was decided to examine white gangue dolomite throughout the district in order to determine whether lateral and/or vertical correlation of the luminescent zonations was possible. The following samples were collected: 27 from 5 stopes in the Immel Mine in the western portion of the district; 28 from 9 stopes in the New Market Mine in the central portion of the district; and 14 specimens from 6 stopes in the Coy Mine in the eastern portion of the district. Also included were eight specimens from the Davis Mine in the eastern portion of the district and twelve specimens from the Young Mine in the central portion of the district. The samples from the Davis Mine were from the

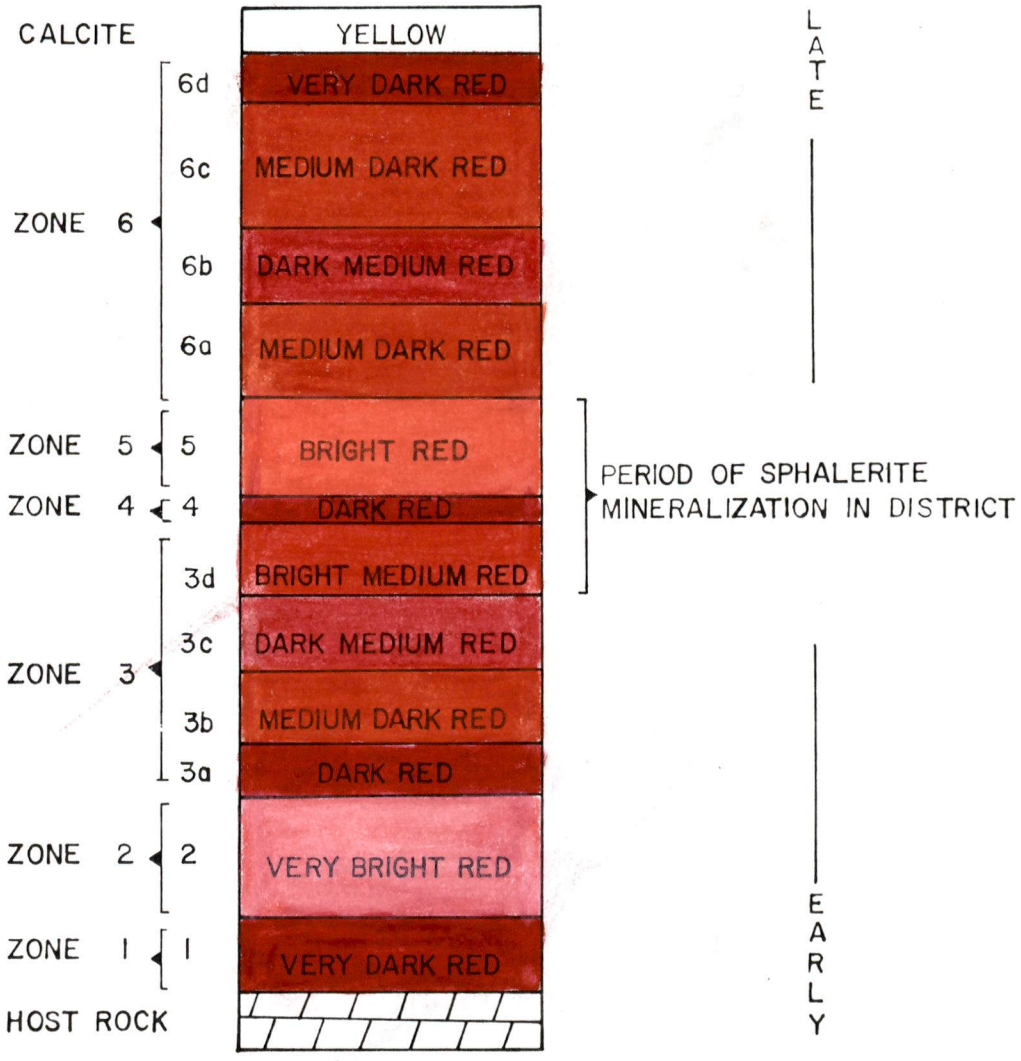


Figure 22. Luminescent zones in white gangue dolomite in the Mascot-Jefferson City district.

A proposed model for the development of this sequence, including sphalerite mineralization, is shown in Figure 23.

Figure 23. A graphic model depicting five stages in the mineralization of a fracture in the Mascot-Jefferson City district.

The growth history is clearly outlined by variations in the color and intensity of the cathodoluminescence of the white gangue dolomite infilling. All drawings are approximately 5x actual size.

A. Initial dolomite mineralization along both sides of the fracture is in the form of a crystal druse. This is zone 1. An abrupt variation in luminescent color from dark to bright red marks the boundary between zone 1 and 2.

B. A distinct change in luminescent color from bright to dark red marks the boundary between zones 2 and 3. The color of zone 3 varies from a bright medium to a dark red. When this zone is thick four subzones can be detected. This drawing shows zones 3a, 3b and 3c.

C. The end of zone 3c marks the beginning of sphalerite mineralization. Note in this drawing that sphalerite mineralization began at two points (X). At these points dolomite mineralization was interrupted. As the sphalerite rosettes (Sp) grew they covered and interrupted dolomite mineralization. When the sphalerite rosettes reached points Y the deposition of zone 3d in the dolomite was nearly complete. Note the increase in thickness of zone 3d from X to Y.

D. This drawing shows sphalerite mineralization which has intersected the other side of the fracture. Here it smothered and interrupted dolomite mineralization during zone 5 deposition. A thin dark zone (4) separates zones 3d and 5. Two yellow luminescing zones in the sphalerite rosettes are marked by white bands in this drawing.

E. This drawing shows the deposition of zone 6. Sphalerite mineralization ended before initial zone 6. This zone, when thick, can be subdivided into four subzones 6a, 6b, 6c and 6d. They vary from medium to very dark red. Zone 6d will either completely or nearly completely fill the remaining voids. Any remaining open spaces may be filled with calcite (C) or remain open (O).

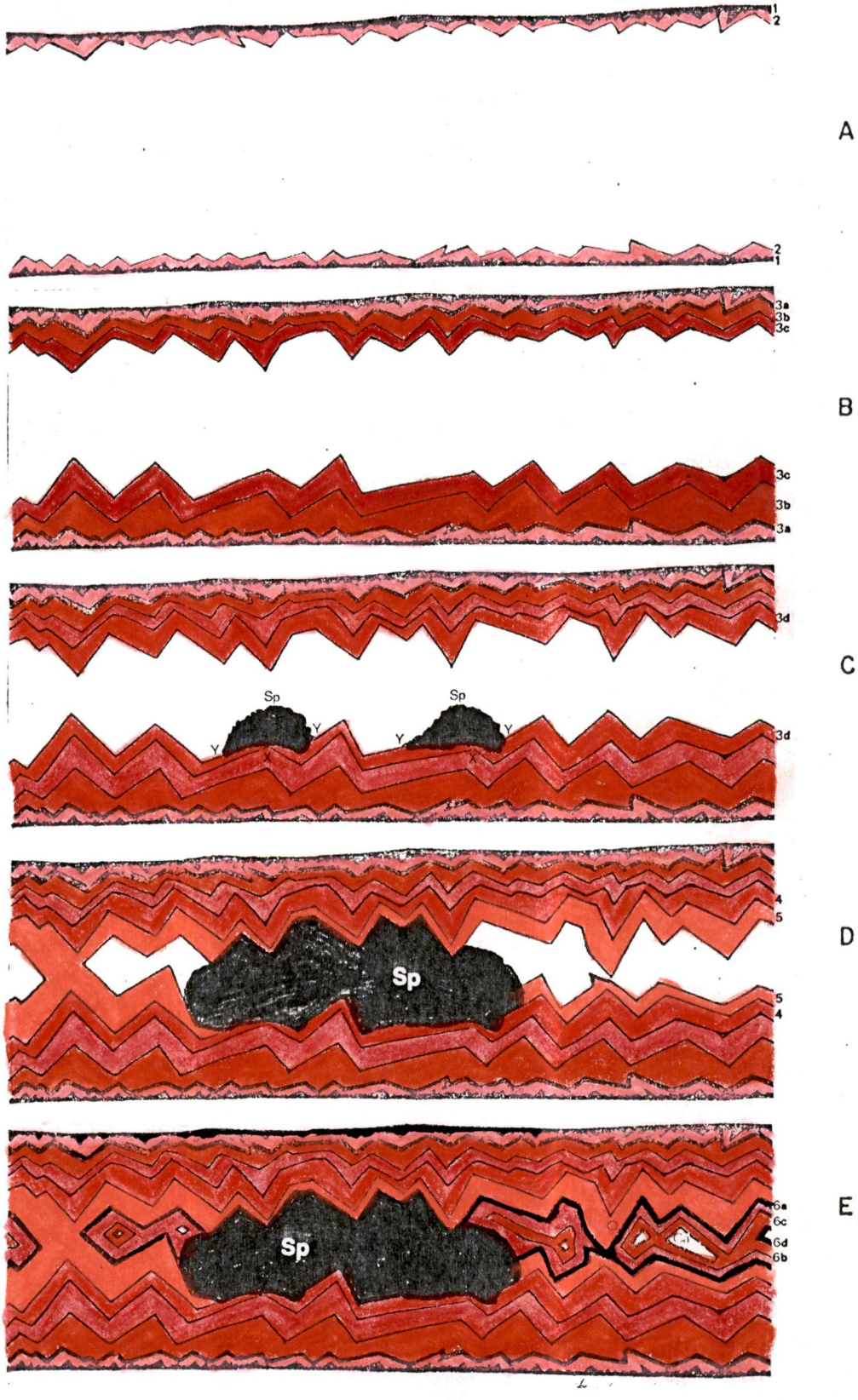


Figure 23

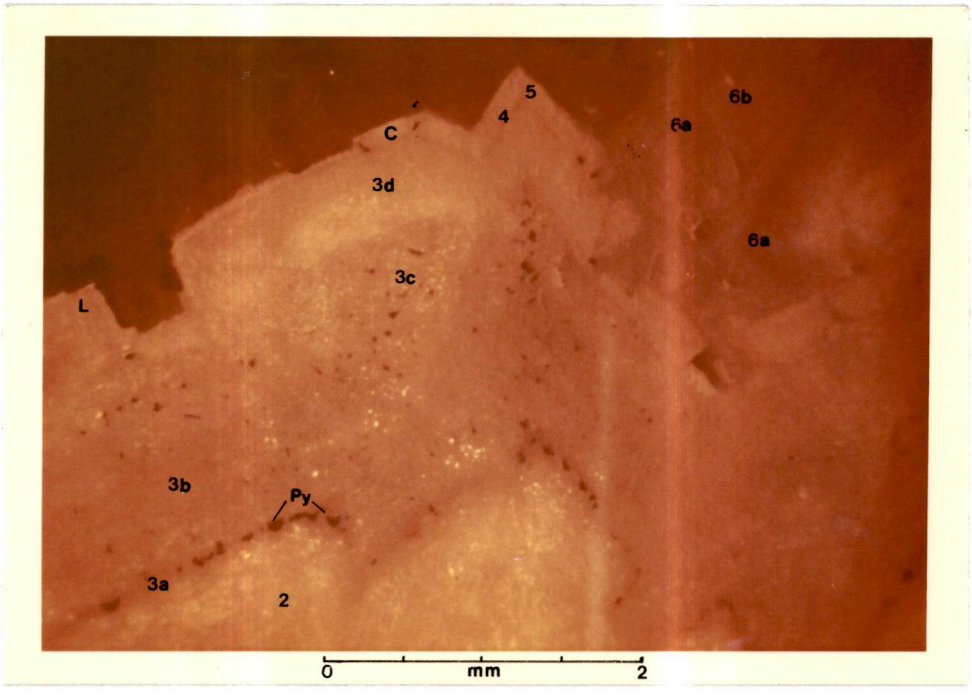


Figure 24. A photomicrograph showing zones 2 through 6 and sphalerite overgrowths on white gangue dolomite from the Coy Mine.

Note zones 4 and 5 are not present at the left (L) but are in the center (C) of the thin section. Sphalerite crusted the dolomite from the left to the right (L to C). Note the black, nonluminescing pyrite (Py) associated with zone 3a and disseminated in zones 3b and 3c.

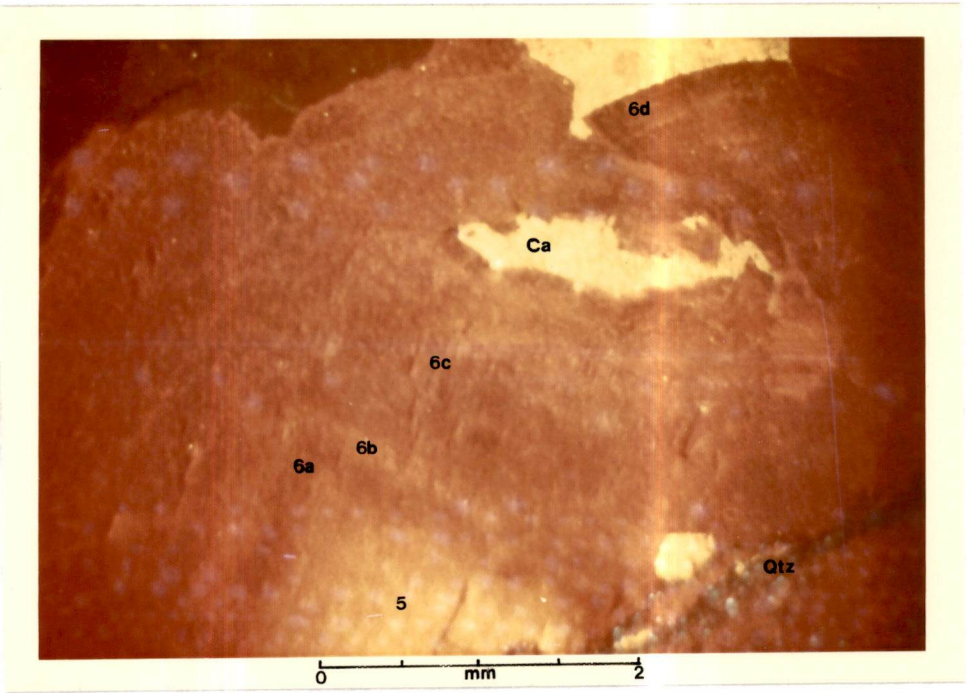


Figure 25. Zones 5, 6a, 6b, 6c and 6d are present in this photomicrograph of white gangue dolomite from the Immel Mine.

Note the quartz (Qtz) in the lower right (blue) and the calcite (Ca) in the upper right (yellow).

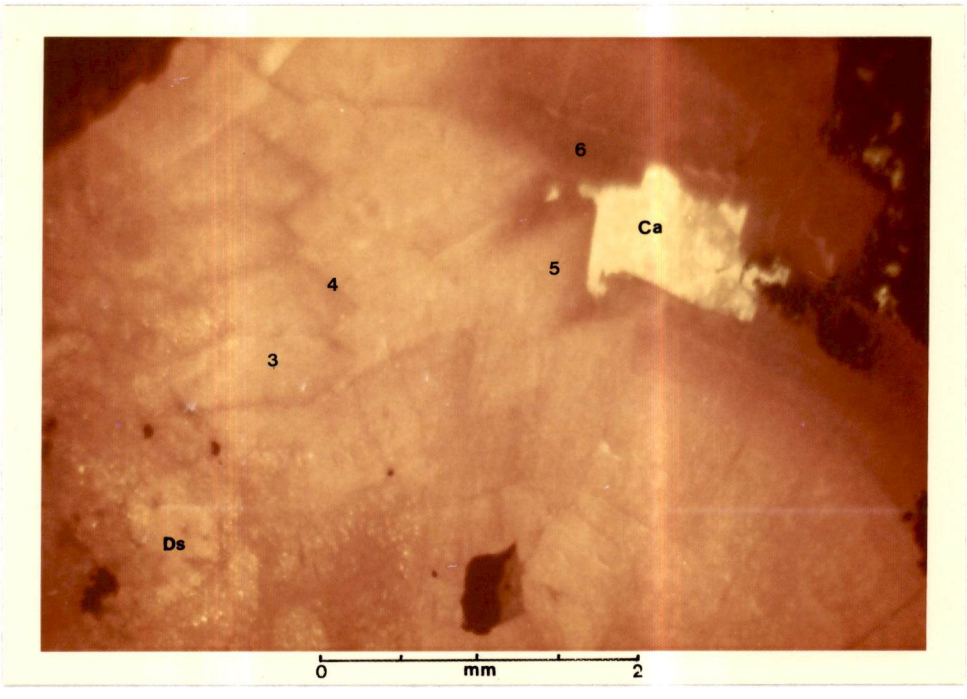


Figure 26. A photomicrograph showing zones 3, 4, 5 and 6 from the Immel Mine.

Note the dolostone (Ds) in the lower left corner.

University of Tennessee's reference collection and the samples from the Young Mine were supplied by Robert Greene. (See Appendix, Sample Collection, p. 77).

Each thin section was examined with the LUMINOSCOPE and the luminescent zonation sequence in the gangue dolomite was recorded. Of the 89 thin sections examined, the luminescent zonation sequence in 83 or 93% showed no irregularity when compared to the luminescent zonation sequence shown in Figure 22 or Figure 23 (pp. 35, 36). Only six thin sections exhibited luminescent zonation (Figure 27) which did not conform to the luminescent zonation sequence (Figure 22, p. 35). The lack of correlation of these six thin sections may be due to the fact that some open space fillings (and its resultant luminescent zonation) may have occurred either before or after the main period of dolomite mineralization or the flow of mineralizing fluid(s) might have been locally interrupted.

VII. DESCRIPTIONS OF INDIVIDUAL ZONES

Zone 1

Zone 1, the first zone recognized in white gangue dolomite, is a medium to thick, very dark red zone and is relatively rare, being more common in the eastern portion of the district. It was observed in only one thin section in the western portion of the district, in one thin section of the central portion of the district and in eight thin sections in the eastern portion of the district (Table I).

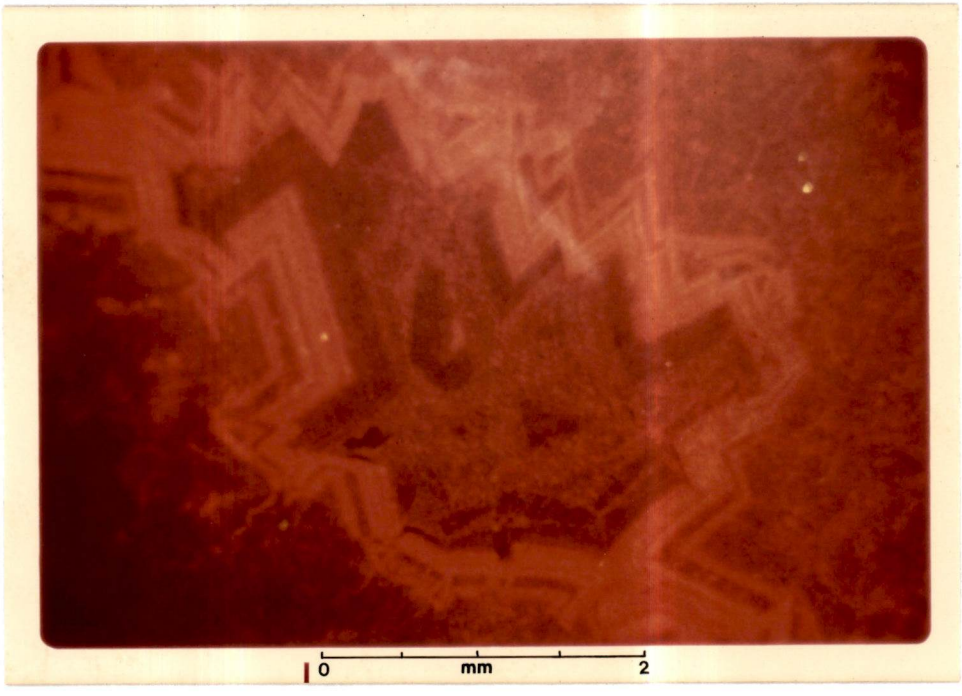


Figure 27. Cathodoluminescent zonation in a vug in dolomite from the Immel Mine.

Note that the zones do not fit the normal zonation sequence as shown in Figure 22, p. 35.

TABLE I

FREQUENCY OF OCCURRENCE OF LUMINESCENT ZONES
IN THE MASCOT-JEFFERSON CITY DISTRICT

Mine	Location in District	Specimens Examined	Luminescent Zones Present					
			1	2	3	4	5	6
Immel	Western	27	1	4	24	22	23	22
Young	Central	12	1	1	11	10	10	7
New Market	Central	28	0	2	24	24	25	26
Davis	Eastern	8	2	6	8	5	7	7
Coy	Eastern	14	6	8	13	11	12	11
	TOTAL	89	10	21	80	72	77	73
	PERCENTAGE		11	24	90	81	87	82

Zone 2

Zone 2 is a thick, very bright red zone which is more common than zone 1. It was observed in 24% (Table I) of the thin sections examined (Figure 24, p. 38). This zone is also more common in the eastern portion of the district. When present, zone 2 is as thick in the western and central portions of the district as in the eastern portion.

Zone 3

This zone is present in 90% of the thin sections examined (Table I). It is very thick in relation to the other zones. In many thin sections this zone can be divided into four subzones, 3a, 3b, 3c and 3d (Figures 6 and 24, pp. 13 and 38, respectively). The subzones vary in color from dark red (3a) to medium bright red (3d). The boundary between zones 2 and 3 is distinct even where the division between the subzones of 3 are gradational. Small pyrite crystals, when present, are associated with 3a which is the darkest subzone of 3 (Figure 24, p. 37). Sphalerite mineralization is associated with zone 3d.

Zone 4

This zone is the most distinct zone. It is a thin, dark red zone between the brighter zones 3 and 5 (Figures 6, 17, and 19, pp. 13, 27, and 30, respectively). The contact between zone 3 and 4 is gradational but, the contact between zone 4 and 5 is sharp (Figure 26, p. 40). This zone's thinness, dark color and its position between two thick bright red zones allowed it to be easily recognized. Thus this zone helped to serve as a marker in interpreting the other zones present in a thin

section. This marker zone was observed in 72 or 82% of the thin sections examined (Table I, p. 43). Both sphalerite and pyrite, when present, are associated with this zone.

Zone 5

This zone is bright red and is medium thick where sphalerite mineralization has not interrupted its deposition (Figures 6, 17, 19 and 24, pp. 13, 27, 30 and 38, respectively). The end of this zone also marks the end of sphalerite deposition, for sphalerite is not associated with any later zones. This zone was observed in 77 of the 89 thin sections examined (Table I, p. 43).

Zone 6

Zone 6 is a very thick, medium dark to very dark red zone which was deposited after sphalerite mineralization. Zone 6 was observed in 73 or 82% of the thin sections examined (Table I, p. 43). In some thin sections the last subzone, 6d, consists of a number of medium dark to dark red zones (Figure 28).

A rare post 6d bright and dark red zonal sequence has been observed in one thin section from the Mascot-Jefferson City district (Figure 28). This post 6d (p6d) sequence is more common in the Copper Ridge district located about 48 km to the northeast. This is the last luminescent zone present in white gangue dolomite. Any open spaces that remained after zone 6 are filled with calcite (Figures 25 and 26, pp. 39 and 40), or remain open as small vugs (Figure 28). The late calcite luminesces bright yellow. Thus most of the channels through which the solutions passed were still open after the end of sphalerite mineralization.

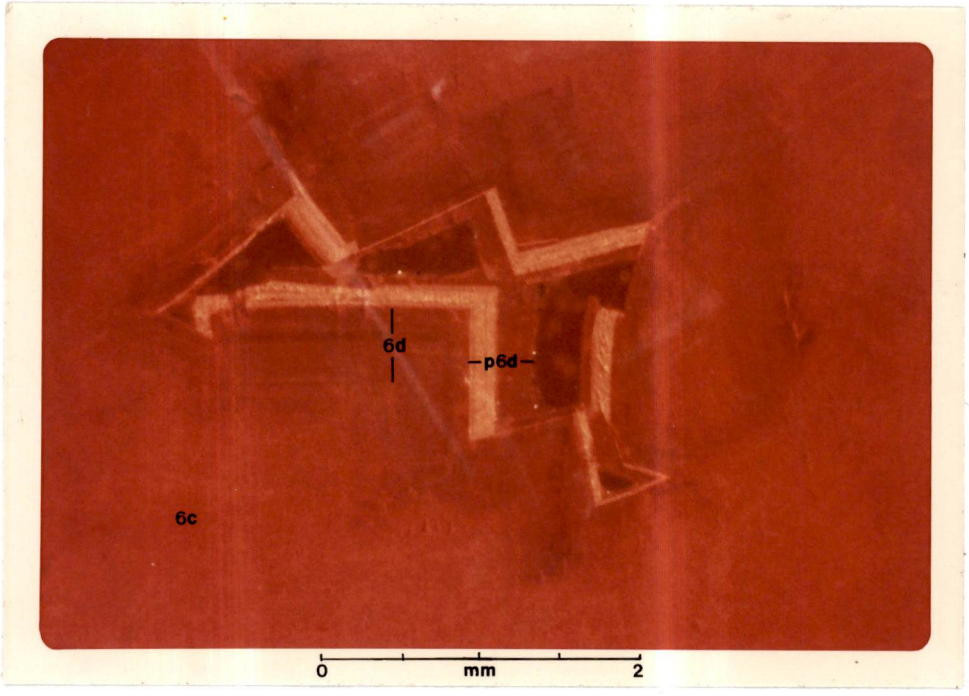


Figure 28. A thin, alternating bright and dark red post 6d (p6d) zone rims an incompletely filled vug in this photomicrograph from the New Market Mine.

This was the only example of this zone observed in the Mascot-Jefferson City district. Note also that subzone 6d consists of a number of medium dark to dark red zones.

Frequency of Occurrence

The frequency of occurrence of the individual zones was shown in Table I (p. 43). Note that zones 3 through 6 are more common than zones 1 and 2. Table II shows the frequency of occurrence of zonal sequences in the thin sections examined. Zones 3 through 6 were observed in 55 (62%) of the specimens examined. Two thin sections exhibited only zones 5 and 6. The absence of zones 1 through 4 in these thin sections is due to either: (1) the solutions did not have access to the open spaces until zone 5, or (2) the open spaces were not present until zone 5. Zone 6 was absent in 11 thin sections (excluding the six nonconforming thin sections). In these thin sections the open spaces were filled before zone 6 was deposited.

In only four thin sections were one or more intermediate zones not observed in the usual zonal sequence present. These thin sections were from the eastern portion of the district. The zones in these four thin sections were not distinct and recognition of zones 4 and/or 5 was not possible.

Table III summarizes the number of zones (regardless of which zones) present in various thin sections. It is important to note that 77 or 93% of the thin sections exhibited three or more recognizable zones (excluding the six nonconforming thin sections). The relative nature of the color, intensity and thickness properties of each zone makes it essential to have three or more zones present for zone recognition. Zonal recognition is tenuous in the six thin sections where only one or two zones were present.

TABLE II

FREQUENCY OF OCCURRENCE OF LUMINESCENT ZONAL SEQUENCES IN THIN SECTIONS FROM THE MASCOT-JEFFERSON CITY DISTRICT

Mine	Specimens Examined	Luminescent Zonal Sequences Present												
		1,2,3 4,5,6	2,3,4 5,6	3,4 5,6	5,6	6	1,2 3	1,2,3 4,5	2,3	2,3 4,5	3,4 5	1,2,3 5,6	2,3 6	None
Immel	27	1	1	19	1				2		1			2
Young	12			7					1		3			1
New Market	28	1	1	22	1	1								2
Davis	8		2	2						1		2	1	
Coy	14	3	2	5			1	1				1		1
TOTAL	89	5	6	55	2	1	1	1	3	1	4	3	1	6
PERCENTAGE	100	6	7	63	2	1	1	1	3	1	4	3	1	7

TABLE III

SUMMARY OF THE ZONAL SEQUENCES AND THEIR FREQUENCY OF OCCURRENCE*

Total Number of Zones Present	Number of Specimens	Percentage	
1 zone present	1	1	
2 zones present	5	6	
3 zones present	6	7	93% 3 or more zones present
4 zones present	56	68	
5 zones present	10	12	
6 zones present	5	6	
TOTAL	83	100	

*Excluding six specimens which did not conform to the established zonal sequence.

VIII. VERTICAL CORRELATION

Twenty-three samples were taken at ten-foot intervals through a 220-foot section of drill core to determine what, if any, variation in zonation occurs vertically in white gangue dolomite. The vertical core sampled was drilled from the surface through the Mascot and Kingsport formations in the western portion of the district. It penetrated a typical solution collapse structure with rubble breccia in the Kingsport grading up to a crackle breccia in the Mascot. The portion sampled was from the U bed of the Kingsport Formation through the Kingsport and into the lower 100 feet of the Mascot (Post R bed, Figure 29). Samples were taken from fractures containing white gangue dolomite. Thin sections were prepared from these samples and examined with the LUMINOSCOPE.

Figure 29 illustrates the luminescent zones present in each thin section. Note that zones 3 and 4 are largely restricted to dolomitized limestone. These fractures must have been present prior to the deposition of zone 3 in order for the mineralizing solutions to deposit zones 3 through 6 in these fractures.

Those beds in the Kingsport and Mascot which are penecontemporaneous dolomites normally contain only zones 5 and 6 in fractures. These fractures must be either younger than fractures in dolomitized limestone or they were not accessible to solutions until zone 5 was being deposited. The upper 50 feet sampled contained only zone 6 in fractures. The next 40 feet below this contained zones 5 and 6. Samples containing only zone 6 were filled after sphalerite mineralization and hence would be expected to be barren.

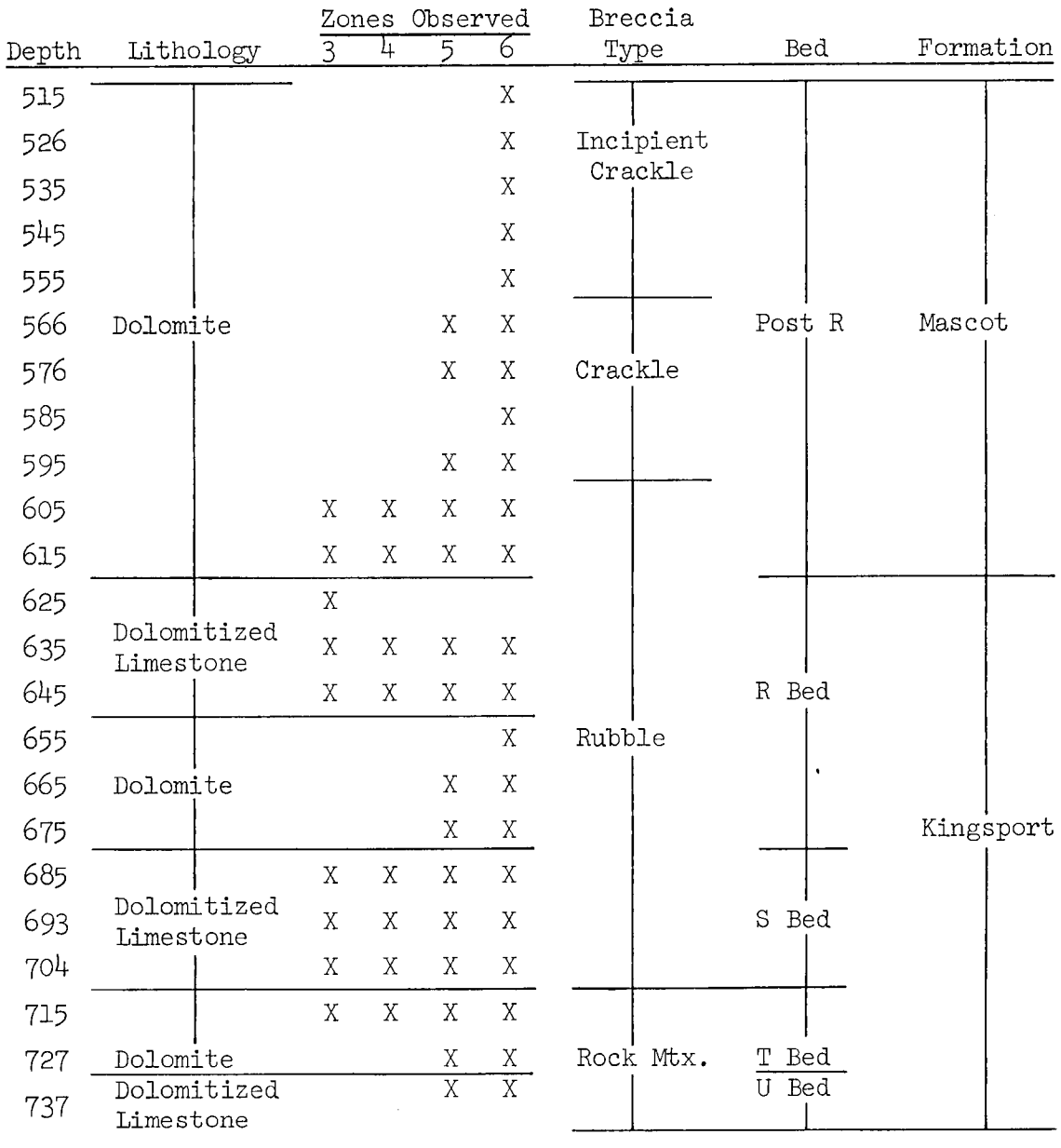


Figure 29. Luminescent zones observed in a core intersecting a typical breccia structure.

Zones 1 and 2 were not observed in this core.

Brecciation was a continuing process involving dolomitization, dissolution and mineralization. These processes were initially restricted to the more favorable limestone beds. Fracturing of the overlying dolomite beds occurred later, after the initial dissolution and dolomitization of the underlying limestone beds and continued until after sphalerite mineralization.

Unfortunately, only a trace of sphalerite was present in this surface diamond drill core, so no study of the vertical relationship of sphalerite and gangue dolomite could be conducted.

IX. SPHALERITE MINERALIZATION

Sphalerite mineralization began during the deposition of zone 3d and continued until the end of zone 5. No sphalerite mineralization was observed before 3d and only a trace of sphalerite mineralization was observed after zone 5. During the period of sphalerite mineralization, dolomite gangue was deposited without interruption. Late sphalerite mineralization, in the form of small crystals in vugs, accounts for only a trace of the total sphalerite present.

The period of sphalerite mineralization in relation to dolomite zonation can be determined by observing their paragenetic relationship in thin section with the LUMINOSCOPE. Sphalerite mineralization occurred in fractures largely as open space filling. The gangue dolomite or "rind" (Figure 3, p. 6) between the host rock and sphalerite has been observed previously throughout the district (Greene, pers. comm.). Where sphalerite was not present, gangue dolomite mineralization

continued through zone 6 or until the fracture was filled, whichever came first.

By examining luminescent zonation in gangue dolomite (rind) which has been crusted over by sphalerite, it was possible to correlate sphalerite mineralization with the time of development of the luminescent zones. In 44 thin sections examined (from all parts of the district) the following relationship between dolomite zonation and sphalerite mineralization was observed: in every case sphalerite was introduced during zone 3d and continued through zone 5. Twelve additional thin sections contained sphalerite but due to poor thin section orientation the relationship between dolomite and sphalerite was obscured.

A late, dark sphalerite has been found in the Jefferson City Mine, owned by the New Jersey Zinc Co. At the time of this study no samples containing this dark sphalerite were available for study. Therefore, it is not known during which zone(s) this dark sphalerite was deposited.

X. RELATIONSHIP BETWEEN CATHODOLUMINESCENT ZONATION AND FERROUS IRON CONTENT OF DOLOMITE

In order to test for Fe as an impurity in white gangue dolomite four representative slabs were etched with 1 $HCl/4H_2O$ and stained with a potassium ferricyanide solution (Dickson, 1966). The ferricyanide solution reacts with the ferrous iron in the dolomite and forms a blue stain (Figure 30). The darker red luminescent zones stain a darker blue color due to the greater quantity of Fe^{+2} present. The presence of pyrite associated with the darker zones also suggest that the darker red



Figure 30. A thin section stained with potassium ferricyanide from the Davis Mine.

The darker blue ferricyanide stain indicates a higher Fe^{+2} content in the dolomite than the lighter stain. Note zones 2, 3a, 3(b, c, d), 4 and 5 are easily recognizable. Also note the darker blue zones (zones 3a and 4) correspond to the darker red luminescing zones (compare to Figure 24, p. 38). The lighter blue zones (zones 2 and 5) luminesce a bright red due to the lesser quantities of Fe^{+2} (which quenches the luminescence) present.

luminescent dolomite contains more iron than the brighter luminescent dolomite zones. The variation in the concentrations of the activator and quenching ions in the gangue may be the result of variations in the chemical makeup of the mineralizing solutions or the temperature-pressure conditions in effect during crystallization. Hence, the growth zonations in the gangue dolomite are believed to reflect the physico-chemical history of the mineralizing solutions.

The luminescent zonation sequence observed throughout the district in gangue dolomite must be either nearly time correlative or a zoned facies resulting from a migrating geochemical environment. The correlation (in 93% of the slides examined) of up to 12 luminescent zonations in gangue dolomite suggests a common source for the mineralizing solutions. If the zone sequence is time correlative then sphalerite mineralization began and ended at virtually the same time throughout the district. Any theory which attempts to explain the origin and deposition of sphalerite and gangue dolomite must take into account: (1) the variation in iron and manganese in gangue dolomite which can be traced throughout the district; and (2) the well-defined interval of sphalerite deposition which can be correlated to gangue dolomite deposition throughout the district.

CHAPTER IV

COMPARISONS TO OTHER MISSISSIPPI VALLEY TYPE DEPOSITS

I. INTRODUCTION

Thin sections from three other Mississippi Valley type deposits in Tennessee and Virginia were observed with cathodoluminescence. These three districts were the Copper Ridge district, the Powell River district and the Austinville-Ivanhoe district. Samples were collected from the New Prospect Mine in the Powell River district and from the Austinville and Ivanhoe Mines in the Austinville-Ivanhoe district. Samples from the Copper Ridge district were borrowed from the University of Tennessee's reference collection.

All three of these districts are considered to be Mississippi Valley type, strataform deposits. Sphalerite and galena are the primary economic minerals found in these deposits, all of which are found in Cambro-Ordovician limestone-dolostone sequences.

II. COPPER RIDGE DISTRICT

The Copper Ridge district is located approximately 48 km (30 miles) northeast of the Mascot-Jefferson City district. There are two mines in this district, the Flat Gap Mine and the Idol Mine. Both are owned by the New Jersey Zinc Company and the Flat Gap Mine is presently inactive. As in the Mascot-Jefferson City district, the ore occurs in stratabound deposits within the Kingsport and Mascot Formations of the Knox Group

(Hill et al., 1971). The Mascot-Jefferson City district and the Copper Ridge district are in separate strike belts.

Only four specimens from the Flat Gap Mine were available from this district. These came from the departmental reference collection. The zonal sequence observed in the white gangue dolomite was quite similar to that observed in the Mascot-Jefferson City district (Figures 31, 32 and 33).

There is a good correlation between the luminescent zones seen in white gangue dolomite from the Flat Gap Mine and the luminescent zonal sequence in the Mascot-Jefferson City district (Figure 34). The relative thicknesses are similar in both districts. Zones 2 and 5 at the Flat Gap Mine are not as bright as in the Mascot-Jefferson City district and Flat Gap's post 6 zone is rare in the Mascot-Jefferson City district. Only one of the four thin sections studied contained sphalerite. In this thin section the sphalerite mineralization is clearly post zone five. If the mineralization in the Flat Gap Mine is related to the mineralization in the Mascot-Jefferson City district, it would appear that the sphalerite was introduced a little later (relatively) in the Flat Gap deposit.

III. POWELL RIVER DISTRICT

Samples were collected from the abandoned New Prospect Mine in the Powell River district located about 42 km (26 miles) northwest of the Mascot-Jefferson City district. The majority of the ore mined from this district came from the New Prospect Mine. The New Prospect Mine is in

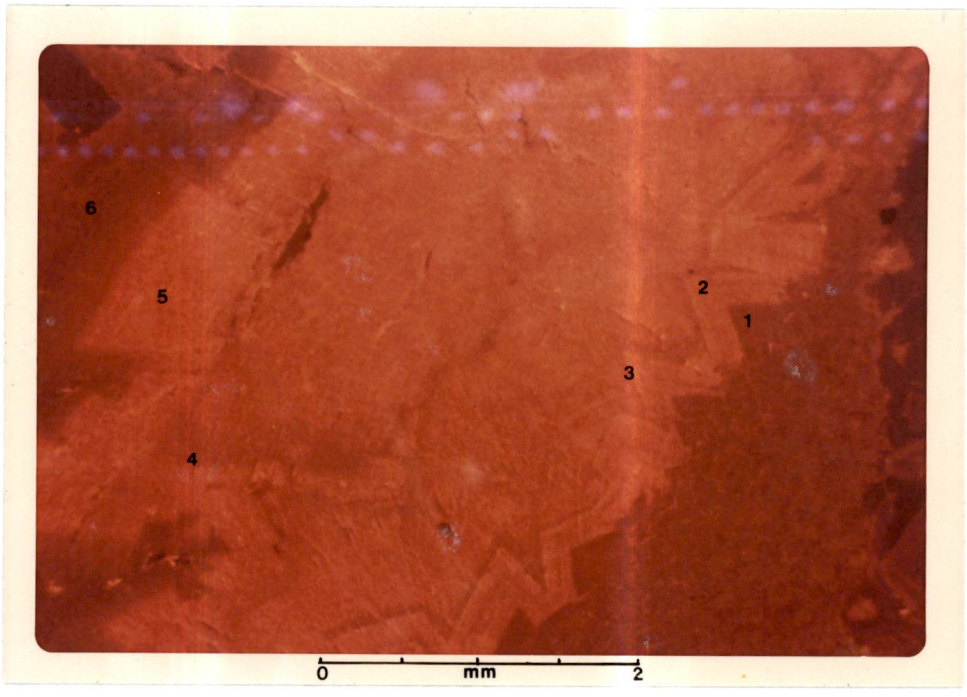


Figure 31. Cathodoluminescent zonation in gangue dolomite from the Flat Gap Mine, Copper Ridge district.

A nearly perfect correlation is possible between the zonation sequence seen here and that in the Mascot-Jefferson City district.

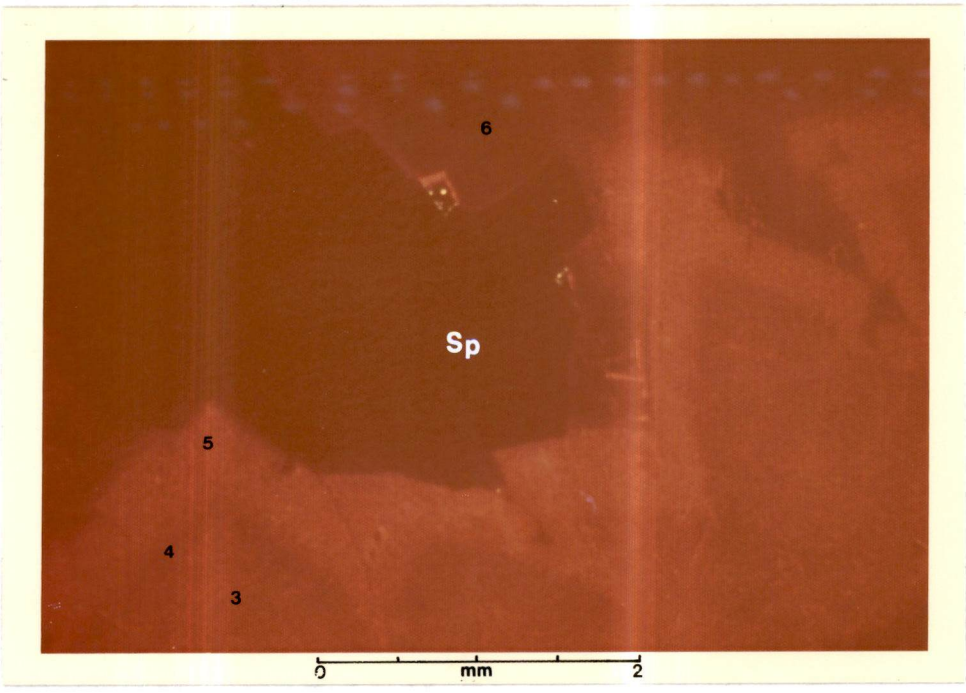


Figure 32. A photomicrograph showing zones 3 through 6 from the Flat Gap Mine.

Note that sphalerite covers sharp terminations in dolomite near the end of zone 5 deposition. Zone 6 filled the remaining open spaces after sphalerite mineralization.

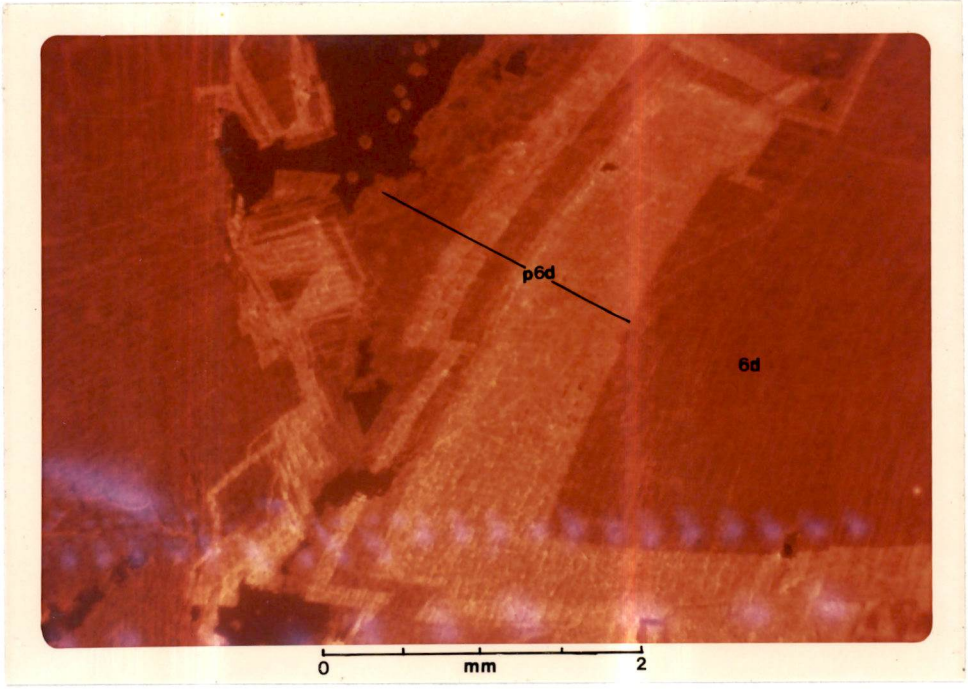


Figure 33. Alternating bright and dark red post 6d zones (p6d) in gangue dolomite from the Flat Gap Mine.

This zone was observed in only one thin section from the Mascot-Jefferson City district (Figure 28, p. 46).

RELATIVE THICKNESS	COLOR	MASCOT-JEFFERSON CITY EQUIVALENT	
Medium thin	Alternating bright and dark red	Post zone 6	Late
Thick	Dark red	Zone 6	
Medium thick	Medium bright red	Zone 5	
Medium thin	Dark red	Zone 4	
Thick	Medium dark red	Zone 3b, c and d	
Thin	Dark red	Zone 3a	
Medium thin	Medium bright red	Zone 2	
Medium thin	Dark red	Zone 1	Early

Figure 34. Cathodoluminescent zonation in white gangue dolomite from the Flat Gap Mine.

Union County in northeastern Tennessee (Figure 1, p. 3). The ore body is in the upper Cambrian Maynardville Limestone (Brokaw et al., 1966). Mineralization occurs as replacement bodies and fracture fillings in a shear zone approximately 20 to 25 feet in height between two horizontal shear planes. Sphalerite and galena are the principal ore minerals with white crystalline dolomite as a minor gangue mineral.

Six thin sections were prepared and examined with cathodoluminescence. When present, the white gangue dolomite exhibited zoning visible due to variations in luminescent color. The observed sequence of zonation is shown in Figure 10 (p. 20) and listed below:

Relative Thickness	Color	
Very thick	Dark red	Latest
Medium thin	Bright red	
Medium thin	Very dark red	Earliest

Due to the limited number of slides available the relationship between sphalerite and the luminescent zonations in gangue dolomite could not be established. The incipient sphalerite luminesced bright yellow, but most of the sphalerite did not luminesce.

IV. AUSTINVILLE-IVANHOE DISTRICT

The Austinville-Ivanhoe district is in the Valley and Ridge province in Southwestern Virginia, approximately 323 km (200 miles) northeast from the Mascot-Jefferson City and Copper Ridge districts. This strataform Mississippi Valley type ore deposit occurs both in the Austinville and Ribbon members of the Shady Formation. The Shady Formation is Lower Cambrian and thus older than the Mascot and Kingsport

Formations (Lower Ordovician) of the Mascot-Jefferson City district. The New Jersey Zinc Company presently operates both the Austinville and Ivanhoe Mines.

Samples were collected from all the major ore bodies at both the Austinville and Ivanhoe Mines. From these samples 50 thin sections were prepared and examined with cathodoluminescence. White gangue dolomite, locally referred to as "met," luminesced from bright to dark red. Calcite luminesced dull yellow and some sphalerite luminesced a bright lemon yellow. However, luminescent zonations in the white gangue dolomite were not well defined. The zones were vague and their boundaries gradational. When present, the pre-sphalerite gangue dolomite (rind) luminesced dark red with a thin, bright red zone immediately preceding initial sphalerite mineralization. Luminescent zonation in most post-sphalerite gangue dolomite varied from a bright to a dark red without any definite, correlatable zones.

VI. CORRELATION BETWEEN DISTRICTS

Luminescent data are limited for the Copper Ridge and the Powell River districts due to the small number of thin sections observed from each locality. However, correlation seems to exist between the Copper Ridge district and the nearby Mascot-Jefferson City district.

Each district has its own characteristic cathodoluminescent properties. White gangue dolomite was present to some degree before sphalerite mineralization began in each district. Luminescent zonation in this pre-sphalerite white gangue dolomite grades from an initial dark red to a bright red in each district.

In all districts examined, post-sphalerite dolomite luminesces from medium dark to a very dark red. The only exception to this is the post 6 zone at the Flat Gap Mine. Beyond these two generalizations, the only correlation observed was between the Copper Ridge district and the Mascot-Jefferson City district. However, it must be kept in mind that the distances to the other districts examined are quite large.

CHAPTER V

CONCLUSIONS, APPLICATIONS AND RECOMMENDATIONS

I. CONCLUSIONS

This study has shown that the white gangue dolomite in the Mascot-Jefferson City district cathodoluminescesces from bright to dark red along definite zones or bands which outline the growth history of the gangue dolomite as an open space filling.

A detailed examination of the zones in gangue dolomite has revealed a nearly perfect microstratigraphic correlation throughout the district. The relationship between the first appearance of sphalerite and the cathodoluminescent zones in gangue dolomite has shown that sphalerite mineralization was essentially time correlative throughout the district and that sphalerite and gangue dolomite coprecipitated. A good microstratigraphic cathodoluminescent correlation was observed between the Mascot-Jefferson City and the Copper Ridge district (Figure 34, p. 61).

It has been shown by Cobb (1974) that both iron and manganese vary in concentration in the gangue dolomite (iron ranges from 2,404 to 9,423 ppm; manganese ranges from 281 to 1,291 ppm). The number of zones and their microstratigraphic correlation within the district support the conclusion that the zones were essentially time correlative. Even if the zones were the result of a migrating geochemical environment, the difference in time between deposition of one zone in the western portion

of the district and its deposition in the eastern portion of the district would be insignificant geologically and the zones can be considered essentially time correlative. It is also concluded that the variation in color and intensity of the luminescent zones was a result of variation of the Mn and Fe content of the mineralizing solutions. The mineralizing solutions migrated through the network of solution cavities within the ore horizon depositing gangue dolomite as crusts on fractures and breccia fragments. After this initial precipitation of gangue dolomite all subsequent zones in dolomite followed in sequence until zone 6. During mineralization, the channels through which the solutions passed generally remained open. Examination of numerous thin sections revealed the presence of vugs which were still open at the time of sampling or had filled with late stage calcite.

The distinct variations in the Fe, Mn and Zn concentrations of the mineralizing solutions in the Mascot-Jefferson City district suggests that the source of the solutions was capable of producing variations in composition on a regional scale.

II. APPLICATION

A number of host rock characteristics have been noted within and adjacent to ore bodies in the Mascot-Jefferson City district. They are dolomitization, brecciation and the presence of gangue dolomite. A major problem in regional exploration is that sphalerite need not be present in an area which exhibits the above characteristics. Dolomitized and brecciated areas are common within the Kingsport (Harris, 1971) but

the presence of sphalerite in other than trace amounts is more the exception than the rule.

Fifty-six of the eighty-nine thin sections examined contained some sphalerite. Of these, zones 3, 4 and 5 were present in 52 (zones 4 and/or 5 were not recognized in four thin sections from the eastern portion of the district). The period of sphalerite mineralization in the district was during the deposition of zones 3, 4 and 5. Thirty-three thin sections did not contain sphalerite. Of these, 20 exhibited zones 3, 4 and 5. The presence of zones 3, 4 and 5 is a characteristic of gangue dolomite within or adjacent to an ore body. The absence of these zones in white dolomite in fractures or breccias is indicative of barren or unmineralized areas (Figures 35 and 36). Note in Figure 29 (p. 51) that only zone 6 is observed in white dolomite in fractures in the Mascot above the Post R bed. Sphalerite mineralization is almost totally absent in this stratigraphic interval. It may be possible to differentiate between brecciated and dolomitized areas adjacent to an ore body and similar areas unrelated to sphalerite mineralization.

This study has shown that a cathodoluminescent microstratigraphic interval as shown in Figure 22 (p. 35) exists in white dolomite which occurs as open space fillings in fractures and as breccia matrix (more properly, a cement) in both the Mascot-Jefferson City district and the Copper Ridge district. If through further research it can be shown that this cathodoluminescent microstratigraphic interval (Figure 22) is present only in white dolomite associated with ore grade mineralization in the Kingsport Formation in East Tennessee the geologist will possess an extremely valuable exploration tool (Figure 37).

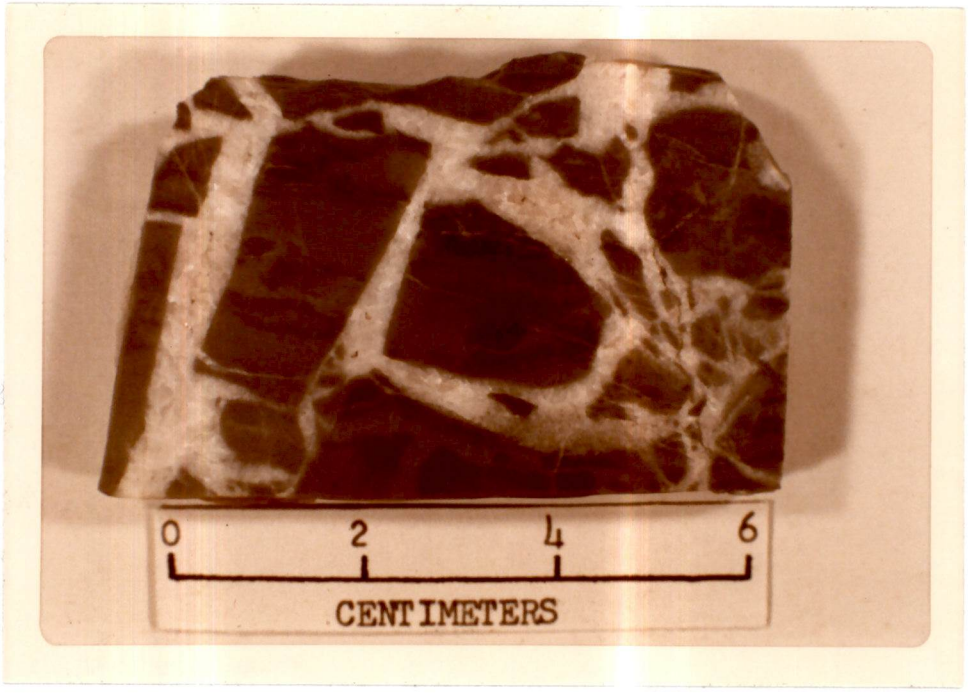


Figure 35. A photograph of a barren or dry breccia (without sphalerite) from the New Market Mine.

The cathodoluminescent zonation pattern (see Figure 36) of this breccia matrix differs from the normal pattern and may either pre- or postdate the main period of sphalerite and gangue dolomite mineralization.

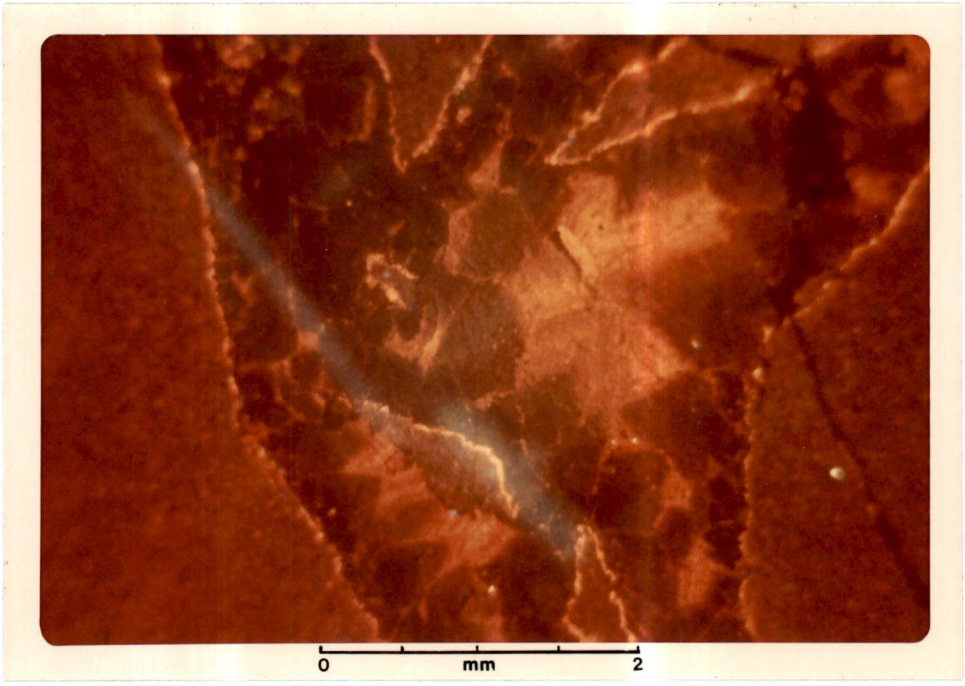


Figure 36. Cathodoluminescence of a barren breccia (Figure 35) from the New Market Mine.

Note the dissimilarity of the cathodoluminescent zonation sequence in this slide and the normal sequence observed in the Mascot-Jefferson City district (for example, Figure 19, p. 30).

Zones Present in Gangue Dolomite	Potential for Sphalerite Mineralization		Comments
	Close Vicinity	Regionally	
None	Negative	Negative	Brecciation and gangue dolomite absent.
Zones not correlating with normal zonal sequence	Negative	Negative	Open spaces developed and/or filled either before zone 1 or after zone 6.
Pre-sphalerite zonations only (zones 1-3c)	Negative	Possible	Open spaces filled before sphalerite mineralization (3d).
Post-sphalerite zonations only (zone 6)	Negative	Possible	Open spaces inaccessible or were not present until after sphalerite mineralization.
Both pre- and post-sphalerite zonations (1-6)	Positive	Positive	Open spaces present and accessible during sphalerite mineralization.

Figure 37. Cathodoluminescent zonation in gangue dolomite as an aid to exploration in the Mascot-Jefferson City district.

III. RECOMMENDATIONS

This study has shown that cathodoluminescence is an important new petrographic tool which can be employed in examination of thin sections from Mississippi Valley type deposits. Its potential (especially as a possible exploration tool) warrants further research in the Mascot-Jefferson City district. This research should include:

1. Study of gangue dolomite in the R, S, and U beds at increasing distances from known ore bodies in the Mascot-Jefferson City district to determine whether any variation in luminescent zonation exists.

2. Study of dolomitization in the Kingsport and Mascot Formations to determine its age relationship to the luminescent zonation in gangue dolomite.

3. Study of the vertical changes in luminescent zonation in gangue dolomite throughout the district to better understand the relationship between mineralization and continued development of breccia bodies.

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APPENDIX

APPENDIX

PROCEDURES AND APPARATUS

Sample Collection

Samples were collected from three mines in the Mascot-Jefferson City zinc district, one mine in the western portion of the district, one in the central and one in the eastern portion of the district. L. T. Larson and R. Greene supplied samples from two additional mines in the district for this study. Selected samples were collected from at least five different stopes in each mine. The collection sites were chosen to insure a good geographic coverage of each mine and all beds where significant mineralization was present.

Two or three samples were collected in each stope. The samples were collected from the muck pile or at the face, and contained all of the following:

1. Fine- to coarse-grained dolomite host rock.
2. White gangue dolomite rind between the host rock and sphalerite (pre-ore).
3. Sphalerite as crusts and rosettes.
4. White gangue dolomite (post-ore).

Sample Preparation

Two by three inch (5.1 x 7.6 cm) thin sections were cut and ground from each sample collected. A number of mounting media were tried including Naphrax, Canada Balsam, Lakeside-70 and Epoxy (Shell Epon 828).

All the mounting media but the epoxy were found to vaporize when subjected to a concentrated electron beam in the LUMINOSCOPE. The need to have a mounting media which would not vaporize under prolonged observation or long time exposures required the use of an epoxy. Epoxy cements are subject to discoloration due to radiation and/or heat damage, but this did not affect the luminescent properties of the thin section itself.

No significant difference in luminescent clarity was observed for thin sections finished only with 220 grit and a polished thin section. The thickness of the thin sections was not critical, since cathodoluminescence is a surface phenomenon. However, the thinner the thin section, the less pump down time before an operational vacuum is achieved and the less degassing that can be expected during observation with the LUMINOSCOPE.

Photographic Techniques

Photography is the best way to record cathodoluminescence. It is superior to color drawings both in the time involved and the results obtained. Since at least ten minutes is required to examine one thin section with the LUMINOSCOPE, quick comparisons between a number of thin sections is impossible unless photography is employed. In microstratigraphic cathodoluminescent zonation correlation the need for direct comparisons is essential.

Color slides have a number of advantages over other types of photographs:

1. More accurate record of colors observed than black and white photographs.

2. Less expensive than color prints.

3. Variety of types of films available.

4. Can be projected on a screen, thus increasing magnification.

5. Easy, compact storage.

All photographs were taken with a Zeiss Ikon camera mounted on the petrographic microscope using a 5X ocular and a $3\frac{1}{2}$X objective. The LUMINOSCOPE was mounted directly on the microscope stage. A shutter extension was used to eliminate vibrations. During photography the room was made as dark as possible.

The exposure time is dependent on a number of variables. These are:

1. Magnification, numerical aperture of the objective and other characteristics of the microscope.

2. Camera characteristics.

3. Film type and speed.

4. Intensity of luminescence.

5. Degree of discoloration of specimen chamber window.

With the camera and microscope setup as described above, one to four minute exposure times were required using Ektachrome 125 ASA color slide film. (Note that the specimen chamber window was discolored due to radiation damage at the time the specimens were photographed. With a transparent window the exposure times could be decreased considerably.)

A number of different types of color slide film were tried. These included GAF (ASA 500), Ektachrome (ASA 125), Ektachrome (ASA 160) and

Kodachrome (ASA 64). GAF and Ektachrome (ASA 160) were found to be acceptable if a blue-filtered light source was used when photographing with ordinary light. The exposure time of Ektachrome (ASA 160) can be cut in half by developing it at ASA 400. This type of processing is more expensive than ordinary processing. Kodachrome X was the only unsatisfactory film used. A color shift was detected from red to yellow with increasing exposure time in this film.

All photographs were taken with high speed Ektachrome ASA 125 color slide film (Tungsten 3200K). This film was preferred for the following reasons:

1. Color reproduction is very good.
2. Film and processing are inexpensive.
3. Little color shift takes place with increasing exposure.
4. Blue-filtered light source is not required.
5. It can be developed in your own dark room.

In order to determine whether any infrared radiation was being produced, two 20-exposure rolls of Kodak Ektachrome infrared film were used to photograph cathodoluminescent zonation. Infrared photographs were taken both with and without (Figure 38) filters. Three different filters were used, a dark blue filter (Kodak, No. 48), a dark green filter (Kodak, No. 54) and a yellow filter (Kodak, No. 12). Infrared radiation is recorded as visible red on infrared film. No infrared radiation was recorded on any of the photographs even with exposure times up to eight minutes.

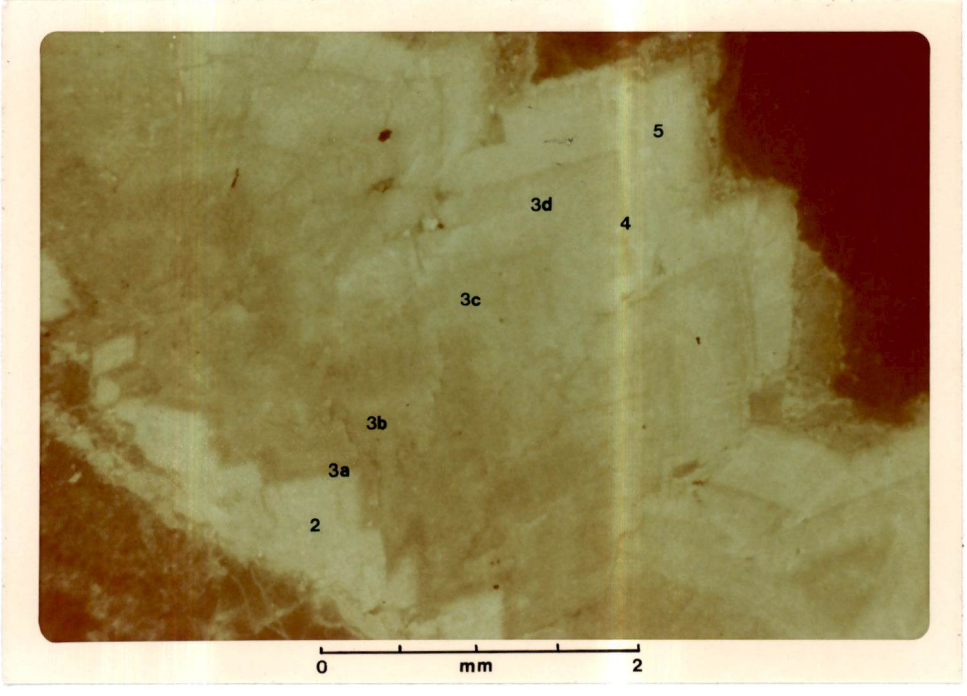


Figure 38. An infrared photomicrograph of cathodoluminescence taken without a colored filter.

This thin section is from the New Market Mine. Zones 2 through 5 are clearly visible. No additional zones were detected with infrared photography. Note the color shift from red to green with infrared film.

VITA

Michael L. Ebers was born in Columbus, Ohio, on October 13, 1946. In 1962 he moved to Norris, Tennessee. He graduated from Norris High School, Norris, Tennessee, in June of 1964. In September 1964 he entered Denison University in Granville, Ohio. He transferred to the University of Tennessee, Knoxville, Tennessee, in September 1965 and received a Bachelor of Science degree in 1969. In March of 1968 he married Wanda Louise Wilson in Starkville, Mississippi. He served with the U.S. Army Corps of Engineers from August 1969 to August 1971. In September 1971 he entered the Graduate School at the University of Tennessee, Knoxville, Tennessee, to begin work on a Master's degree with a major in Geology. During the interim from 1973 to 1976 he has been employed by the New Jersey Zinc Company as a Mine Geologist at their Austinville Mine in Austinville, Virginia. He is an associate member of Sigma Xi and the Society of Economic Geologists and a member of Sigma Gamma Epsilon and the Geological Society of America.