STRUCTURAL AND MINERALOGICAL CONTROL OF ORE
LINCHBURG MINE, SOCORRO CO., N. M.

By

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INTRODUCTION

The Linchburg Mine, owned by The New Jersey Zinc Company and operated during the last decade by C. S. Elayer and Co., is located in the Magdalena Mining District of Socorro County, New Mexico.

The Magdalena Mining District has been described in some detail by G. F. Loughlin and A. H. Koschmann in U.S.G.S. Professional Paper 200. This paper describes some of the early development work in and the basic geologic setting of the Linchburg Mine which is located in the south end of the District. However, development work done in the mine since the writing of that paper has opened a considerable amount of underground area, and made possible further study of geologic features of this portion of the District. Perhaps the most significant details noted are those which involve the control of ore deposition in the Linchburg orebody.

Controls of ore in the mine are for the most part classical and include stratigraphic favorability, faulting and, to an undetermined extent, folding. The most interesting aspect of control is the effect which the silicate minerals, developed early in the alteration process, have had on the subsequent localization of specific ore minerals. Detailed geologic mapping of the structure and the silicate alteration has established a relationship between ore and gangue minerals which persists throughout the stoped area.

Geologic Setting

The Magdalena Mining District is located in the northern end of the Magdalena Mountains of west central New Mexico. The mountains, which consist of a series of fault blocks, have a rough north-south trend and are located near the southern edge of the Colorado Plateau. The major faulting in the District is of northerly strike and has resulted in the development of a mountain range with a Precambrian core and top, flanked to the west by longitudinal down-dropped blocks capped by Paleozoic sedimentary rocks, and to the east by blocks of the Precambrian complex which have been largely stripped of their sedimentary cover.

The greatest amount of ore mined in the District has been taken from orebodies in the sedimentary rocks which flank the west side of the range. These orebodies have been developed primarily within the Kelly limestone (Mississippian) at its intersection with longitudinal or transverse faults, or at the limestone contacts adjoining monzonite and granite intrusions.

Orebodies around the intrusives are typical of the pyrometasomatic type as is evidenced by their location with respect to the intrusions and by the characteristic silicate minerals which constitute the principal gangue. The silicate minerals which have been developed are two predominant types of garnet (andradite and grossularite), two prevailing pyroxenes (diopside and hedenbergite), and various amphiboles, clays, and chlorite minerals. Magnetite is abundant near the intrusions where it forms massive bodies, but less abundant in the ores where it is generally finely disseminated.. Hematite is widespread and of less restricted distribution with respect to intrusions than is magnetite. The ore minerals mined in the District have been sphalerite and galena with their oxidized products and lesser amounts of chalcopyrite. Pyrite is present in most of the ores near the intrusive masses but is not important as a constituent of the orebodies which lie at some distance from the intrusions.

The Linchburg Mine is located at the southern end of the District along one of the major longitudinal faults. Surface exposures in the area of the mine and in the greater portion of the south end of the District are restricted to upper Paleozoic rocks and post Paleozoic volcanic rocks. Very little geologic knowledge regarding the location of the ore shoots has been obtained from surface geology although some of the oreshoots lie but a short distance below the surface.

The orebody is typical in most respects of the other orebodies in the District except for the lack of any known igneous intrusion. On the basis of intense silicate alteration which is present in association with the Linchburg ores, Loughlin and Koschmann (1942) have postulated that an igneous body underlies the southern end of the District.

GENERAL FEATURES OF THE ORE SHOOTS

The major ore shoots in the Linchburg Mine which make up the main orebody occur in the Kelly limestone and are discontinuous, elongate features of nearly equidimensional cross-sectional size. The orebody itself has a nearly north-south strike and is continuous over a known distance of some 1600 feet. The ore shoots which comprise the orebody are high grade masses of ore associated with faults or fractures and strike generally north or northwest. They are separated from each other by intervening areas of mineralized ground of lesser value. The effects of stratigraphy are pronounced in their influence upon the shape of the various ore shoots. Bedding replacement has taken place along faults or fractures and, as a result, tabular bodies of ore which conform to the sedimentary structures persist for considerable distances away from the major feeders.

Although each ore shoot will vary slightly in mineral composition and assay, the orebody can be considered to contain sphalerite with subordinate galena, some chalcopyrite and, very rarely, pyrite. Gangue minerals are most commonly the various silicate, oxide, and carbonate minerals.

Stratigraphic Control

The first recorded deposition upon the Precambrian basement is Mississippian and is represented by some 125 feet of crinoidal limestone. This sequence of rocks, the Kelly formation, represents the most favorable ore carrier. It has been separated into four units for the purpose of description and definition of stratigraphic control. The base of the formation consists of a horizon of sandy, arkosic or quartzitic limestone, averaging 6 feet in thickness. Above it are 50 feet of crinoidal limestones which are only locally important as ore-bearing beds. The "Silver Pipe" horizon caps the lower crystalline beds and is a persistent stratigraphic marker throughout the District. A dense, lithographic bed some 8 feet in thickness, the "Silver Pipe" is seldom ever replaced by ore minerals. Lying above the Silver Pipe and making up the remaining portion of the Kelly section is a sequence of coarsely crystalline limestones in which the greatest amount of sulfide minerals found to date have been deposited.

The most favorable portion of this upper crystalline section is a span of limestone beds about 35 feet thick which bottoms approximately 10 feet above the Silver Pipe beds. Minor amounts of ore have been mined from beds below the Silver Pipe, particularly near fractures, but the extent and persistence of ore in these portions of the section has been unimportant.

Structural Control

Faulting

Faults in the Linchburg Mine can be separated into two broad classes. The first class includes those faults which have had apparently little or no effect upon direct control of ore within the orebody itself, but may have had considerable influence as major conduits along which the ore fluids passed. The other group of fractures or faults are those which have apparently served as feeding and controlling structures within the orebody itself. The classes appear to be genetically related.

To the first class of faults, belong the major longitudinal faults in the District, one of which is the Linchburg Fault, associated with the Linchburg orebody. This fault constitutes a major break which has dropped the sedimentary horizons some 500 feet vertically, to their present position in the Linchburg Mine.

To the second class of faults, belong two sets of easterly dipping faults and fractures. These breaks dip toward the Linchburg Fault and strike north and northwest. The principal controlling faults are the northwesterly-striking breaks which cut across the orebody at a slight angle, and have apparently controlled the location of most of the high grade ore shoots. The high grade ore adjacent to the Linchburg Fault has been localized by the north trending fault set.

Folding

The sedimentary beds are gently folded perpendicular to the strike of the main ore zone. The most conspicous feature is the presence of a large, gentle anticline, which over the length of the mineralized zone raises the marker horizons 80 feet. Each limb has minor attendant folds and the plunge of all is gently westward.

The relationship of folds to ore deposition is obscure. The location of the highest grade ore within the ore shoots, however, has been along the crests of the minor folds where they have been intersected by the north and northwesterly-striking faults. Further, the only location in the mine in which any extensive ore has been found beneath the Silver Pipe horizon is in an area at the north end of the orebody where a sharp syncline has been developed along the limb of the principal fold. Although the beds below the Silver Pipe have been passively explored, there are no other such occurrences of ore except locally in horizons immediately adjoining the Linchburg Fault zone. It seems possible to speculate from this that development of zones of low compression in the downwarped portions of the fold may have taken place in the horizons below the Silver Pipe with similar development of low compression areas as in the beds above it in the anticlinal areas. Aside from speculation as to cause, however, the apparent relationship of folds to the ore shoots requires some consideration in the concept of ore control.

Mineralogy

The minerals which have been developed in the Linchburg orebody are typical of those found in most pyrometasomatic deposits and include suites of silicate minerals, sulfide minerals and oxide minerals. Erosion has not been extensive enough to develop any more than minor amounts of secondary minerals, which are found at depth, mainly along faults.

The following relationships appear to be persistent with respect to paragenesis. Silicate minerals developed early in the alteration process and were overlapped to some extent and followed by extensive deposition of hematite and, locally, magnetite. Sulfide minerals were deposited last and replaced silicate minerals.

During the time of deposition of sulfides, some recrystallization of silicates may have taken place. Detailed work on the chemical nature of the minerals is presently in progress, hence only the megascopic and microscopic relationships and inferences can be given at this time except as otherwise noted.

Sulfides

Four sulfide minerals comprise in excess of 99% of the hypogene ore minerals present. In order of decreasing abundance, these are sphalerite, galena, chalcopyrite and pyrite.

Sphalerite ranges in color from a dark, presumably high iron variety to an amber to almost honey yellow type that is assumed to represent a variety of lower iron content. All gradations of color are present but the darkest and lightest varieties are to be found at the eastern and western extremes respectively of the ore shoots. The dark variety is most commonly found next to the fault zones and the features which are presumed to represent the channelways of the ore-bearing fluid. The light colored types are found somewhat removed from such features. Most commonly, sphalerite replaces the garnets present in the gangue assemblage and more rarely, the pyroxene minerals.

Galena is present, usually in association with the sphalerite, but invariably associated with pyroxene minerals. From the standpoint of spatial relationship to feeding structure, the galena is generally to be found some distance away. The exception to this relationship may be found in the few scattered shows in the orebody where galena is in abundance along feeding structures that have been characterized by adjacent alteration of the host rock to epidote. However, where the epidotization ends, galena becomes less abundant.

Chalcopyrite is found in practically all of the ores in close association with sphalerite. Locally, it occurs abundantly enough to be considered ore. Its spatial relationship to feeding structure is inconsistent and it appears to be more closely related to sphalerite deposition than it does to any proximity of structure.

Pyrite, although noted as one of the four sulfides is lacking in most of the Linchburg ores. Where found, it usually lies along the edges of the ore shoots and is most commonly seen in the areas of silicification and marbelization.

Silicates

Garnet is the most abundant silicate mineral present and is represented by two varieties. Andradite is the earliest formed and is found close to the major faults. Grossularite, apparently formed later in the process of silication, is less common but is found primarily at the fringe of the main garnet zones. The garnets form a conspicuous zone of mineralization adjoining structure, but also persist away from the feeding structures beyond the zone composed mainly of the garnet, and are present in silicate zones in which other minerals are the predominant alteration feature.

Pyroxenes are present primarily in an area outside of the garnet zone where they are the most abundant of the silicate minerals present. Two pyroxene types have been positively identified, diopside and hedenbergite, and a third is problematical. Little pyroxene is present in the main garnetized zone adjoining the structures, but beyond the garnet areas it is abundant.

Epidote is very localized in its occurrence but where found, occurs almost to the exclusion of other silicate minerals. It forms no persistent zone but rather, as noted previously, it is related to structures at only widely separated localities.

Local areas of amphibole are present, associated usually with the pyroxene from which they appear to be derived. Distribution is erratic and no zonal relationships appear to be persistent. The identity of the amphibole has not yet been positively established but it may be cummingtonite.

Silica is present throughout the orebody, usually found adjoining feeding structures and locally at the outer fringes of the silicated areas. Pyrite is sometimes present as a replacement in the silica zone but generally occurs as isolated crystalline masses of small size.

Oxides

The oxides of iron are the only oxides present in appreciable quantities. Massive magnetite occurs in only two closely related areas near the center of the known limits of the orebody. However, it may be found in small amounts in most of the more intensely sulfidized zones in the orebody.

Hematite is abundant and widespread throughout the orebody. It is least abundant in the areas of intense garnetization but is widespread in the areas of pyroxenes and in the marbelized zones which fringe the orebodies. In such zones it is finely disseminated and occurs uniformly distributed.

Zones

Careful attention to the details of mineralogy in the mapping of the orebody has revealed a persistent nature to the habits of occurrence of the various silicate and sulfide minerals with respect to certain faults or feeding structures. The zones have been assigned numbers to indicate associations of ore minerals with silicates and, in most respects, it is believed that such zoning represents an "intensity" of silicate and sulfide alteration.

Zone 1

This is the zone of intense silicification which adjoins major faults. It is seldom of commercial importance although, locally it may be replaced by very slight amounts of sphalerite and galena. It seldom exceeds a known 10 feet in width but is found through most of the stratigraphic thickness of the Kelly formation along most of the length of the Linchburg Fault zone. This is the only example in the group of zones in which there is some doubt as to the expression of intensity. The origin of the silica is not clear; the problem of whether it represents material which has migrated through the major fault zones under high physical conditions, or is a late low temperature feature has not been resolved.

Zone 2

This zone is characterized by a mixture of the two garnet types present in the silicate assemblage. In this zone garnet occurs with the complete exclusion of any other minerals excepting minor quartz and very rare calcite. The zone is not always present along the Linchburg and associated faults, but appears to be more widely distributed than does Zone 1. Its width is variable, ranging from a few feet up to 20 feet or more - most commonly it is about 15 feet wide. Commercial mineralization in this zone consists of the dark sphalerite most of which occurs on the outer fringe of the zone and not adjoining the faults.

Zone 3

The gangue mineral assemblage in this zone consists primarily of light garnet, pyroxene (diopside) and hematite. Minor amounts of calcite and quartz are present. The relative quantities of the various minerals present vary across the zone with a higher ratio of pyroxene to garnet at the Zone 2 contact than is to be found at the inner border of the zone. At this outer edge of the zone, however, the presence of garnet in the pyroxene assemblage is sufficient to classify the rock type as belonging to Zone 3. Sulfide mineralization in this zone is primarily galena-sphalerite with sphalerite predominating at the Zone 2 border and galena becoming increasingly abundant as the outer margin of Zone 3 is approached.

Zone 4

Alteration minerals are primarily diopside and hematite which have been replaced by galena and, rarely, sphalerite. Most of the disseminated chalcopyrite mentioned earlier occurs with the sphalerite which is found in the outer areas of Zone 3, the preceding zone, and the inner areas of Zone 4. Zones 3 and 4 have the widest horizontal extent and have accounted for the largest tonnages of lead-zinc ore mined although not the highest grade.

Zone 5

This zone is characterized by a hematized limestone with only minor isolated amounts of the pyroxene minerals. It occupies a narrow strip at the outer edge of Zone 4 and gives way rather imperceptibly to Zone 6 (marble) and the unaltered limestones containing fine disseminations of the sulfide minerals.

Significance of the Zones

The most immediate importance of the mapping of the silicate zones has been the establishment of criteria whereby the various structures which controlled ore deposition can be recognized. The presence of a high intensity zone of silicate alteration in the barren walls of a stope has generally indicated a northwesterly striking break that has been productive for considerable distances beyond the main western limit of ore.

The zones established are of academic interest from the standpoint of the study of the influences surrounding ore deposition. Further work is now in progress on this aspect of the problem, but the field observations have indicated a definite replacement favorability of certain sulfide minerals for particular silicate minerals. This favorability may possibly be shown in part to represent a thermal gradient controlled by the location of certain faults. However, of most importance, the mineralization in Zones 3 and 4 appears to be the result of chemical favorability rather than the existence of thermal gradients set up at the time of the ore-forming process.

Finally, the recognition of the various zones has indicated a definite relationship between the ore deposits and controlling or feeding structure. The ore deposit can be considered to be pyrometasomatic in all aspects except for the lack of an igneous body. The so-called "contact effects" of alteration are not confined to the immediate area of an intrusion but have spread out along faulted ground wherever the openings were available for transfer of material. A careful search for structural effects seems warranted in further study of these deposit types.

ACKNOWLEDGEMENT

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REFERENCES

Loughlin, G. F. and Koschmann, A. H. (1942) Geology and Ore Deposits of the Magdalena Mining District, New Mexico, *U. S. Geol. Survey Prof. Paper* 200.