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GEOLOGICAL SUMMARY OF THE MAGDALENA MINING DISTRICT, SOCORRO COUNTY, NEW MEXICO [1]

By
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INTRODUCTION

The Magdalena district is located on the west slopes of the northern Magdalena Mountains and lies some 28 miles west of Socorro, New Mexico. Although mining activity there is now largely dormant, the district was, for a period of years, the largest producer of lead and zinc ores in New Mexico. Mining operations now are principally those of small lease-holders.

Of general north-south trend, the northern Magdalena Mountains consist of an uplifted core of Precambrian igneous and sedimentary rocks which is flanked to the west by downfaulted blocks of Paleozoic sedimentary rocks. East of the exposed Precambrian core, younger volcanic rocks and the Precambrian sedimentary unit are the prevailing rock types that comprise a rather large area of mountainous terrain.

Principal structures in the district are faults that parallel the trend of the range and exhibit dip displacements as great as 1,500 feet. Transverse or east-west faults are present but do not exhibit the continuity or magnitude of displacement that characterize the longitudinal breaks.

Although not dated more precisely than post-Permian there are extensive exposures in the district of "Laramide" igneous rocks, both intrusive and extrusive. Three major stocks are known, one composed of monzonite that is closely related, spatially, to the ore deposits and the other two composed of granite. Other igneous rocks in the form of dikes, sills or flows range in composition from lamprophyre to rhyolite. Most production of minerals in the district comes from pyrometasomatic and mesothermal deposits, although there are some hypothermal and leptothermal deposits.

The district has been studied in considerable detail by the U. S. Geological Survey and the results have been published in two papers. Earliest of these was the work by Lindgren, Graton, and Gordon (1910) and the other, a more recent study carried out by Loughlin and Koschmann (1942). Considerable detail in this paper, particularly maps and geologic data on the older mines in the district, has been taken from these two publications.

GENERAL INFORMATION

Location and Access

The general area can be reached by U. S. Highway 60 which passes through the town of Magdalena, New Mexico, 28 miles west of Socorro, New Mexico. A good road, paved in part, leads from Magdalena to the old townsite of Kelly, some 4 miles south of Magdalena. From Kelly, secondary and jeep roads lead to most of the larger mines in the district.

History

Discovery of ore in the Magdalena district probably occurred around 1866, but it was not until about 1878 that the first sizable orebodies were discovered in the Kelly and Graphic Mines (Loughlin and Koschmann, 1942, p. 76). Production records for the district covering the period from 1878 to 1898 indicate that gold, silver, and lead were the primary products of mining during the early history of the area. By 1882 a branch of the Atchison, Topeka and Santa Fe Railroad had been laid from Socorro to Magdalena. Much of the early production from the district was shipped by rail to Socorro where a smelter had been constructed in 1881. Reserves of high grade lead carbonate ore were diminished around 1902 but at this same time, rich orebodies of zinc carbonates were found which added another generation of mining to the life of the district.

Intermittent mining has continued for the past 30 years and, although extraction of the oxidized ores has continued, production has been largely from primary orebodies.

Production

During the period of 1904 to 1928 the district was very active and produced 46 percent of the total zinc mined in New Mexico and 34 percent of the lead, (Anderson, 1957, p. 137), producing from both primary and secondary orebodies. World War II brought about renewed mining efforts, particularly in the Waldo mine which was operated by the American Smelting and Refining Company from 1942 to 1949. Since 1950, most of the district production has come from the Linchburg mine, owned by the New Jersey Zinc Company and leased by C. S. Elayer and Company of Silver City.

Anderson (1957, p. 138) estimates that the total production of the district to 1954 had amounted to $44,389,792 in revenue from ore shipped.

GEOLOGY

The Magdalena Mountains, in which the district is situated, are a north-south range of block-fault mountains located on the southeast edge of the Colorado Plateau. The northern part of the range is characterized by a high central ridge composed principally of Precambrian rocks that have been stripped of their sedimentary cover by erosion. To the east of this central ridge and at lower altitudes, Precambrian sedimentary and igneous rocks and some younger volcanic rocks underlie an extensive area of rugged mountainous terrain. Altitudes range from 6,000 feet to 9,650 feet.

West of the central core of the mountains and paralleling the range, faults of considerable length have dropped elongate blocks as much as 1,500 feet. It is in these down-dropped fault blocks, capped by Paleozoic sediments and younger volcanic rocks, that the large orebodies of the district are found.

Stratigraphy

The oldest sediments in the district are those comprising the Precambrian argillite. This rock unit is exposed only locally in the district but is areally extensive on the eastern side of the range. It consists of quartz grains, sericite, and chlorite and in some places has been intensely folded. Its thickness is unknown but Loughlin and Koschmann (1942, p. 7) indicate that there may be as much as 2,000 feet exposed in any one area.

The Precambrian rocks were beveled nearly smooth during pre-Mississippian time and nearly pure, coarsely crystalline, fossiliferous limestone of the Kelly formation was deposited upon this smooth surface.

The Kelly formation, which is the only unit of the Mississippian system present in the district, attains a thick-

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[2] New Jersey Zinc Company, Tucson, Ariz.

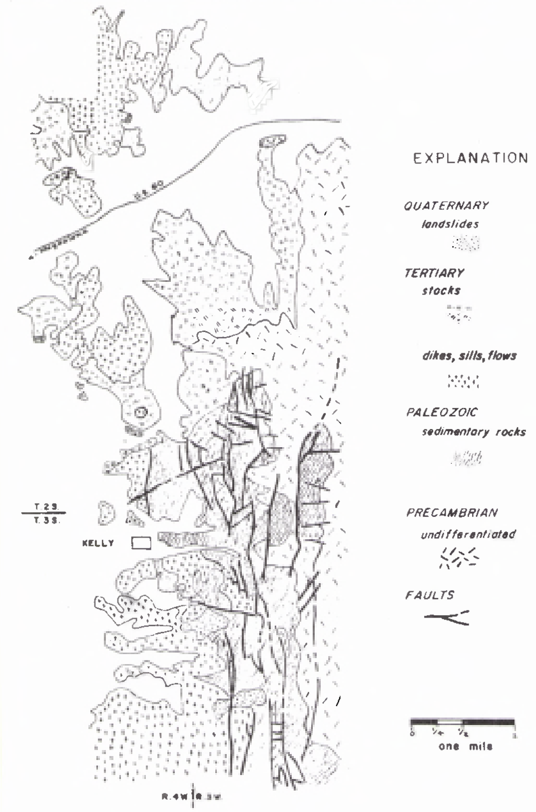

Figure 1.--GENERALIZED GEOLOGIC MAP of the MAGDALENA DISTRICT

(Modified after Loughlin and Koschmann, 1942)

ness of about 125 feet. The Kelly formation contains the most productive orebodies that have been found. In the Magdalena district, the Kelly formation has been subdivided into (a) a basal sandy, locally quartzitic bed 1 to 6 feet thick, (b) a lower crystalline member about 50 feet thick containing lenses of a dense microgranular limestone, (c) a microgranular dolomitic and shaly unit 4 to 12 feet thick known as the "Silver Pipe" and, (d) an upper crystalline unit 50 to 60 feet thick.

Overlying the Kelly limestone, with apparent conformity or only slight disconformity, is a sequence of Pennsylvanian clastic and calcareous rocks having an aggregate thickness in the Magdalena district of about 1,200 feet. This rock sequence, the Magdalena group, has been separated in this area into two formational units. The lower unit is the Sandia formation, composed of quartzite and shales approximately 600 feet thick. Interbedded with this clastic sequence are beds of impure limestone and limy shale. The clastic rocks change rather abruptly to a sequence of marine limestones and interbedded shales 600 feet thick; this largely calcareous section of rock is known as the Madera formation. The Magdalena group has been of importance only locally in the depositional process of ore.

Lying in slight angular unconformity on top of the Magdalena group are the fine clastic rocks and red sandstones called the Abo formation of Permian age. No complete section of this sequence has been measured in the Magdalena district but it is known, from discontinuous exposures, to be at least 175 feet thick.

The only consolidated rocks known to be younger than the Permian in the district are the poorly cemented gray sandstones of the Datil (?) formation of Tertiary(?) age. These beds are exposed in the northern part of the district where Loughlin and Koschmann (1942, p. 22) found that the sandstone sometimes occurs as inclusions in one of the younger granites of the district. No age designation more precise than post-Permian and pre-granite intrusion can be given to this sedimentary unit.

During Quaternary time extensive landsliding took place probably as a result of oversteepening of the slopes on the western side of the range (Loughlin and Koschmann, 1942, p. 22). Some of this landslide debris crops out in the southern part of the district as caps on spurs and, in one area, as extensive cover on the slope of the range.

Igneous Rocks

Two long periods of igneous activity are recognized in the district — one of pre-Mississippian and probable Precambrian age and the other, covering an unknown time span after the Permian (see fig. 1 for distribution).

The earlier period of intrusive activity is characterized by widespread intrusion into the Precambrian argillite by gabbro, felsite, granite and diabase, from oldest to youngest respectively as indicated by mutual relationships. All have been truncated by the pre-Mississippian erosion surface. Of the four rock types, the granite appears to be the most abundant and widespread and apparently is more stock-like in structural character than rocks of the other types which, more commonly, are dikes and sills.

The Precambrian granite is composed of pink feldspar and quartz, the latter sometimes approaching nearly 50 percent of the total composition of the rock. Primary mafic minerals are almost completely absent although the granite exhibits secondary chloritized biotite (Loughlin and Koschmann, 1942, p. 12, 13).

The later, post-Permian period of igneous activity resulted in emplacement of a wide variety of phaneritic to aphanitic and porphyritic rocks. Emplaced during this time were three major stocks and numerous sills and dikes (fig. 1). The intrusive activity was preceded, at least in part, by extrusion of a broad compositional variety of aphanitic and porphyritic rocks.

Earliest recognizable activity during the post-Permian period was the outpouring, on the post-Permian surface, of effusive rocks varying in composition from andesite breccia and tuff to latite tuff. These rock types lie unconformably on the Madera, Sandia and Abo formations. Following emplacement of these effusive rocks was the intrusion of rhyolite porphyry sills and the extrusion of a banded rhyolite. Aggregate thickness of these sills and volcanic rocks ranges from 4,000 feet in the northern part of the district to about 1,500 feet in the southern part. A sequence of andesites and red rhyolites, exposed in the southwestern part of the district, probably was deposited over the entire district but subsequently was removed, in great part, by erosion.

Three major stocks and a minor one (fig. 1) were emplaced in the district during the later period of igneous activity. All except one of these is demonstrably younger than the intrusion of the porphyritic rhyolite sills emplaced during this period. Stratigraphic relations of the fourth stock with respect to the effusive rocks are not clear but compositional similarity of that stock to other stocks has prompted Loughlin and Koschmann (1942, p. 36) to consider it to be of the same age as the other stocks. Loughlin and Koschmann (1942, p. 36) have dated all stocks in the district as Tertiary(?) in age.

Two of the four stocks are composed of granite. These granite stocks are exposed at Granite Mountain in the north end of the district and at Anchor Canyon in the principal area of ore deposition. Both stocks are identical in composition and consist of quartz (20 percent), othoclase (60 percent), plagioclase (An_{20}, 15 percent). Biotite makes up about 5 per cent of the rock. Hornblende is sometimes present and accessory minerals included are sphene, apatite and zircon. The granites are medium-grained, porphyritic and are distinctly different from the Precambrian types, primarily in that their quartz content is less.

One of the remaining two stocks, exposed near the center of the district, is a typical monzonite. It usually is non-porphyritic, fine-grained, and consists of about equal parts of orthoclase and plagioclase which make up 70 percent of the mineral composition, up to 5 percent quartz, 15 percent pyroxene, 10 percent biotite, and sometimes several percent magnetite. This intrusive, called the Nitt stock, is close to another intrusive, near Stendel Ridge, which appears to be a composite stock grading from monzonite to granite in composition. All stocks comprise a zone of northerly alignment and Loughlin and Koschmann (1942, p. 69) have proposed a common origin for them.

Following emplacement of the stocks, scattered intrusion of lamprophyre dikes and white rhyolite dikes and sills occurred.

Structural Geology

The character and extent of Precambrian and pre-Laramide structures has not been worked out completely in the district because of lack of exposures and because of the complexity of structural features that are Laramide and younger in age. It is known, however, that there was some intense folding of the Precambrian argillite prior to intrusion of the argillite by the Precambrian igneous rock types. Also there probably was some faulting that preceded deposition of the Mississippian sedimentary rocks. Further, there is evidence indicating some tilting and beveling prior to emplacement of the Tertiary(?) effusive rocks. Principal structures in the district, however, were developed after deposition of the Abo formation of Permian age. Structures in the district principally are faults and, to a lesser extent, minor folds.

Most major faulting in the district is post-Paleozoic in age. These faults trend north-south parallel to the long axis of the mountain range. The faults have lowered the Paleozoic rocks in such a manner that these rocks flank the west side of the range and lie at lower altitudes than the Precambrian rocks which form the crest of the northern Magdalena Mountains. Loughlin and Koschmann (1942, p. 69) suggested that much of the faulting took place along the west-dipping limb of a north-trending monocline. The fracture pattern developed on the flank of the monocline has resulted in a mosaic of down-dropped blocks along steeply east-dipping and vertical faults. The general dip of the sedimentary rocks that cap the fault blocks is westward with only local eastward dips.

Major north-south faults, several thousand feet in length, are locally interrupted by transverse faults (fig. 2). Dip-slip displacement on the major faults is as great as

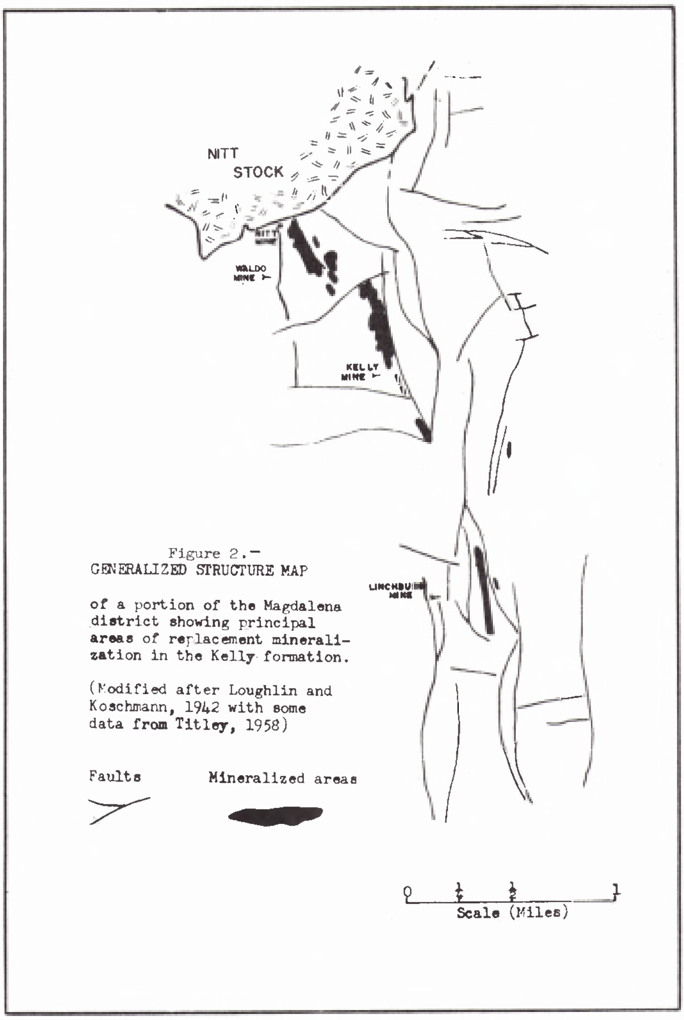

Figure 2.—
GENERALIZED STRUCTURE MAP
of a portion of the Magdalena district showing principal areas of replacement mineralization in the Kelly formation.
(Modified after Loughlin and Koschmann, 1942 with some data from Titley, 1958)

1,500 feet, whereas the transverse faults, located principally in the northern part of the district, are more fracture-like with considerably less dip-slip displacements. Strike-slip on some of the major faults has, in many places, resulted in tension fractures which have localized the structure that is conducive to ore deposition (fig. 2).

Folds present in the district are of questionable age and origin. Nonetheless, some gentle folding or warping, post-Permian in age, has occurred in the southern part of the district (Titley, 1958, p. 44). In the northern part of the district, Gordon (Lindgren and others, 1910, p. 251) noted folds in the mineralized area with axes that strike eastward and plunge westward. Folding in the district was not intense but is represented by gentle warps, which may be related to the period of uplift described by Loughlin and Koschmann (1942, p. 56).

Ore Deposits

The productive area of mineral deposits (partly shown on fig. 2) in the Magdalena district lies along the west side of the mountains and is a narrow belt some 8 miles in length. Types of deposits are varied but for the most part are related closely to the centers of igneous intrusion.

Minerals contained in the deposits are varied and a large number of both primary and oxidized types exists. Primary minerals of the metals consist principally of sphalerite, galena, chalcopyrite, and pyrite. Pyrrhotite and bornite are present but scarce. Typical contact silicates, such as andradite, grossularite, hedenbergite, diopside, wollastonite ,and various minerals of the amphibole and chlorite groups, occur in varying amounts with the primary metallic minerals and are more localized. Magnetite, specularite, and hematite are widespread in the orebodies although they rarely are concrentrated.

A large number of oxidized minerals occur in the Magdalena district. Perhaps the most notable of these minerals is the blue to green variety of botryoidal smithsonite. Other secondary minerals are cerrusite, anglesite, hydrozincite, malachite, azurite, tenorite, hemimorphite and more rarely vanadanite and the various jarosites. Other minerals occur in the district and Loughlin and Koschmann (1942) have discussed most minerals present.

Description. Practically all of the ores mined from the Magdalena district have been formed as replacement orebodies in the Kelly limestone, but some ore occurs in the Precambrian basement rocks. In addition to a marked affinity of the ores for the Kelly limestone, there is a close relation of the larger ore bodies to the major faults in the district(fig's. 2 and 3).

Principal production from the district has been from its central part near Kelly (fig. 1). These particular deposits lie near the larger intrusives and occur in the sedimentary beds adjoining stocks. Generally they are tabular with their greatest dimension trending north-south, parallel to the faults. Their thickness depends on thickness of favorable portions of the Kelly limestone, mainly the "Silver Pipe" (fig. 3). Width of the orebodies is restricted usually by the distance between controlling faults and fractures.

The orebodies are not grouped about the periphery of the intrusives but occur along trends (fig. 2) for several thousands of feet beyond the exposed portions of the massive igneous rocks. Along this trend occur a variety of orebody types when considered from the viewpoint of mineral content and apparent temperature of ore deposition. Although orebody types are gradational into each other, there are distinct mineral associations occurring with sufficient persistence to make some sort of classification possible.

In orebodies near intrusives, and in one located at some distance from known intrusives, there are mineral zones characterized by the presence of magnetite-specularite, magnetite-pyrite or, rarely,, magnetite-pyrrhotite assemblages. Such areas of mineral associations were considered by Loughlin and Koschmann (1942, p. 105) to represent the high temperature centers of mineral formation. These centers are seldom, if ever, of commercial interest. Such centers have been recognized near the central part of the district in the Nitt, Waldo and Kelly mines and another one occurs in the southern part of the district in the Linchburg mine. In addition to the presence of the various magnetite assemblages in the high temperature centers, there are some mineralized zones in which contact-metamorphic silicate minerals such as andradite, grossularite, hedenbergite, and wollastonite have been formed as a result of metasomatic alteration of the Kelly limestone. Orebodies south of and near the Nitt stock are characterized by magnetite and comparatively large orebodies high in pyrite but, in general, lacking any large quantity of silicate minerals. In contrast to this type of high temperature mineral assemblage, are the high temperature mineral assemblages found in the southern end of the district, particularly in the Linchburg mine where magnetite demarks high temperature mineralization centers, deficient in pyrite but characterized by relatively large amounts of contact-metamorphic silicate minerals.

Surrounding or grading laterally away from hypothermal mineralization are the mineral assemblages that comprise the source of most of the district's production. These are mesothermal orebodies and occur primarily in the Kelly limestone and, to a lesser extent, in the overlying Sandia and Madera formations. Mineralogy of these orebodies, like that of the hypothermal types, suggest a two-fold classification of deposits. Of least economic consequence are the small lead-zinc orebodies that occur with large masses of pyrite in the Nitt and Waldo mines. Of most importance, however, are the relatively pyrite-free zinc-lead ores that occur in a gangue of either silicate minerals, quartz or marbleized limestone. In such orebodies, the sphalerite-galena ratio usually is high and the sphalerites invariably are high in iron content. Regardless of host mineral types, all mineral deposits of this type are characterized by hematite, and locally, chlorite. In areas close to the apparent source of the mineralizing fluids, mesothermal processes have influenced the entire section of the Kelly limestone. However, at greater distance from the ore-forming centers, the mineralizing fuilds apparently were more selective and only certain persistent beds of the Kelly limestone contain mineralization.

Leptothermal ore types have been recognized by Loughlin and Koschmann, (1942, p. 110) and are characterized by an envelope of silicified limestone and contain little iron. Pyrite is uncommon and the ratio of sphalerite to galena is considerably lower than that in the mesothermal orebodies. In addition to the sulfide minerals, these leptothermal deposits usually contain barite-fluorite assemblages and sometimes native precious metals. These lower temperature orebodies are found on the fringes of many of the mesothermal ore shoots and are recognizable only because of a gradational change in the mineralogic character of the deposits. Leptothermal deposits have not attained the economic importance that the mesothermal deposits have.

In most orebodies of the district, there is little or no definite demarkation or separation of types of deposits. A single orebody, for example, may have a zone of magnetite adjoining a feeding fracture, this zone surrounded by a mesothermal deposit which grades laterally into leptothermal ores. Distinct lateral rather than vertical zoning can be seen.

Sequence of Hydrothermal Processes. The stages of ore-formation have been described by Loughlin and Koschmann (1942, P. 111-115) and have been summarized briefly by Titley (1958, p. 13-16).

The first stages of mineral deposition apparently occurred during the final consolidation of the monzonite and granite stocks. This stage was accompanied by the development of silicate minerals, particularly tourmaline, wollastonite, diopside, and grossularite. This first stage of mineral deposition took place principally around the intrusive centers where the Kelly limestone has been altered intensely. However, its effects are wide-spread and can be observed in other portions of the stratigraphic section for great distances away from the intrusive centers.

The second stage of mineral deposition took place after consolidation and fracturing of the stocks. Near the intrusive centers, development of hedenbergite, andradite, and recrystallized calcite took place. This type of mineralization is most conspicuous along the main ore zones of the district which follow the major north-south trending fault system. Development of the silicate minerals took place as long as the energy levels in the fluids were high enough to form them. However, as the fluids cooled and continued to move to the outer margins of the district, only deposition of silica occurred forming jasperoid and minor amounts of crystalline quartz. This stage of alteration is widely distributed, particularly throughout the southern part of the district. At a few localities, the monzonite has been silicified. However, the other igneous rocks in the district only rarely exhibit the effects of early silicate alteration.

Following the second alteration phase, deposition of specularite and magnetite took place near the centers of igneous activity, accompanied by the deposition of epidote, some chlorite and abundant quartz. Most of this mineralization is concentrated in the Kelly limestone but major amounts are found in the Precambrian argillite and granite.

The sulfide alteration phase appears to have formed pyrite, sphalerite, galena, and chalcopyrite in that general order. Loughlin and Koschmann (1942, P. 112) believe that the relation of pyrite to specularite indicates a gradual transition rather than an abrupt change between the ore-forming stages and the preceding stages of magnetite-specularite deposition. Pyrite is found in abundance only around mineralization centers in the middle of the district where fluids that carried the pyrite material deposited it in the limestones adjacent to specularite-magnetite zones. Pyrite replaced some interstitial calcite in the silicate rocks and, to a lesser extent, the silicates themselves.

Deposition of sphalerite, which followed the pyrite phase, was the most widespread and extensive of any of the ore-forming stages. The zinc-bearing fluids apparently followed the same channels as the earlier mineral-bearing fluids and replaced those earlier minerals to a slight degree. In general, near the active centers, sphalerite replaced all of the minerals that had not been replaced earlier by pyrite. Coincident with sphalerite deposition, quartz was dissolved, moved away, and redeposited with minor amounts of amber sphalerite, fluorite, and barite. Sphalerite formed near the intrusive centers has a greater iron content than that found in the areas some distance away.

Deposition of galena and chalcopyrite, according to Loughlin and Koschmann (1942, p. 97), exhibits relationships of these minerals that indicate possible contemporaniety but probable deposition of galena following chalcopyrite. However, the idea that the chalcopyrite was deposited during a single phase is not accepted by these authors; it is their opinion that copper minerals may have been introduced during more than one stage.

Alteration of the igneous rocks of the district, during the time of sulfide mineralization in the sedimentary rocks, is markedly different from that which took place in the limestones and other sedimentary rocks. Development of feldspathic dikes and veins in the monzonite, and tourmaline in the fractures of the monzonite and argillite may correspond to the earliest stages of alteration of the limestone. The second silicate stage exhibited in the limestone does not have an obvious counterpart in the igneous rocks. However, the specularite and ore-forming stages in the limestone have equivalent stages in the igneous rocks, and are represented generally by sulphide veins instead of disseminations. Development of sericite along these veins in the monzonite is believed to be closely related to the deposition of pyrite or possibly the entire sulfide sequence.

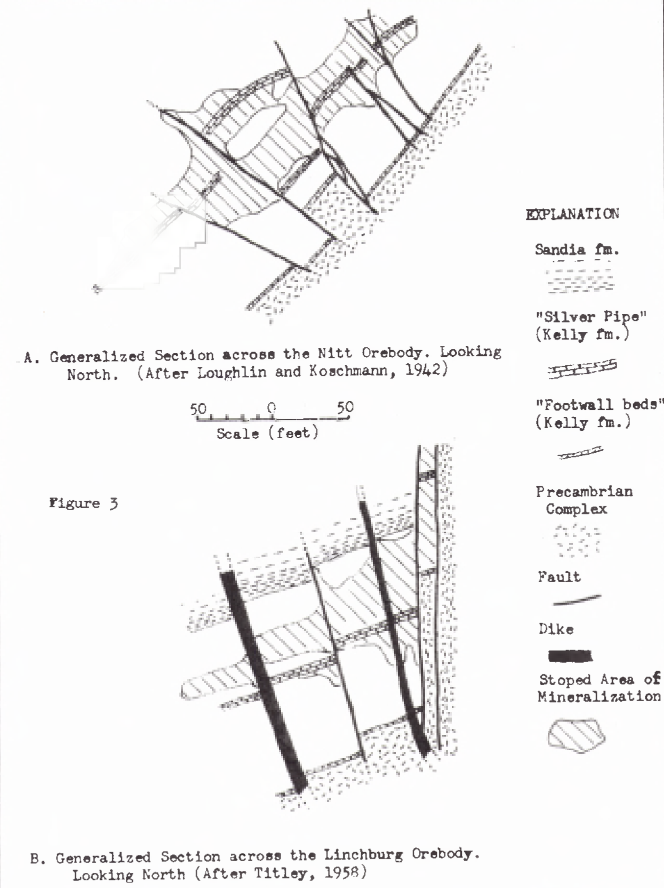

Figure 3

A. Generalized Section across the Nitt Orebody. Looking North. (After Loughlin and Koschmann, 1942)

B. Generalized Section across the Linchburg Orebody. Looking North (After Titley, 1958)

Sericite alteration grades outward from the veins into a chlorite-epidote alteration of somewhat doubtful timing.

In the southern end of the district, beyond any known sizable intrusive body, the same general mineralogical rèlations hold true. However, there is strong suggestion in the orebodies of this property, the Linchburg mine, that although there is definite time relationships of one mineral with respect to another, separate stages of development cannot be recognized. Evidence from a study of those orebodies (Titley, 1958) suggests that while silicification is an early feature of hydrothermal processes, it is also a continuing stage that persists through much of the time of oxide and sulfide deposition. In the Linchburg orebody, all of the hydrothermal stages defined by Loughlin and Koschmann (1942, p. 104-123) are visible on a scale that ranges from hand specimen to the entire orebodies some 75 feet in width. The implication of this study is that a temperature gradient as great as that implied by the terms hydrothermal, mesothermal, and leptothermal did not exist in the Linchburg orebody and that the zoning of minerals must be explained in a different manner, possibly by a reaction gradient.

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