GEOLOGY OF THE ZINC–LEAD DEPOSIT AT PECOS, NEW MEXICO—PART I.

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CONTENTS.

INTRODUCTION.

THE Pecos ore deposit represents a complex mixture of zinc, lead and copper sulphides containing a minor amount of gold and silver. It forms lenticular masses within a broad shear zone. The country rock consists of ancient metamorphic schists, diabase, granite and related types of igneous rocks. A complex mixture of ore minerals of this type of occurrence is seldom found in quantity. The mine at Pecos, however, with a capacity

750 tons per day, is the second largest producing mine in New Mexico, in terms of calculated gross value of recoverable metals.

The shear zone in which the ore occurs is worthy of comment. It can be definitely traced along its strike for a distance of several miles in the vicinity of the mine, and may extend for a much greater distance both northeast and southwest. The shearing follows a zone of weakness in the older diabase of the district. It varies in width from a few feet to about 600 feet. It has been traced in the mine to a vertical depth of 1,500 feet, and probably extends much deeper. A major shear zone is bounded by parallel zones of lesser magnitude, with some cross shearing. The ore, which occurs as lenses within these zones, is prospected by following the strike of the rock structure and crosscutting wherever underground conditions appear favorable. From certain features observed in the underground workings it is believed that the shear zone has been developed along still older fractures in the diabase.

The general geologic setting is as follows: Pennsylvanian sediments overlie the pre-Cambrian rocks of the mine, and are separated from them by a great unconformity. A striking feature is the broad, uniformly even pre-Cambrian surface, which has a gentle dip of almost exactly 7 degrees to the southwest. Such an even surface, which has retained its uniformity of plane since pre-Cambrian time, suggests the absence of pronounced deformation. Notwithstanding the intense shearing developed before the pre-Pennsylvanian erosion, deformation since that time has been comparatively insignificant. Furthermore, the introduction of the ore, which is absent in the overlying sediments, appears to have occurred in pre-Cambrian time.

One of the interesting features of the ore deposit is the distribution of rounded, isolated blocks of more or less barren diabase, some of which have been silicified. They occur throughout the shear zone and the ores are found around these blocks as well as in portions of the shear zone between them, although it seldom occurs within the blocks themselves. They are believed to have originated in the fracturing of the diabase before shearing took place and were isolated by the injection of granitic material around them. Later intense shearing and crushing gav them the rounded appearance they now have, and served t isolate them still further from the surrounding rock. The bloc vary in size from that of a hand specimen to more than 100 fe in longest dimension. The outer edges of these blocks a sometimes replaced by ore minerals, and their borders are alter to some extent in nearly every instance.

The petrologic relations of the country rocks are worthy o special mention. The rock history, as interpreted by microscop study, points to igneous attack of variable intensity, with th infusion of end-stage magmatic juices into a diabase that ha initially a considerable range in texture, and to a lesser degr in composition as well. This was followed by dynamic di- turbance resulting in movement of sufficient intensity to form broad shear zone, with subsequent replacement and mineralizati of the schistose rocks affected by ore-bearing solutions. De formation within the shear zone took place both before an during deposition of the ore.

Location and Accessibility.—The Pecos Mine of the Americ Metal Company, Limited, is located in northwestern San Migu County, New Mexico. It is reached by a highway which skir the southern end of the Sangre de Cristo Mountains and follo the Pecos River Canyon for 12 miles north of Pecos, Ne Mexico. The property is approximately 17 miles due east o Santa Fe and 27 miles west of Las Vegas, New Mexic Glorieta, on the Santa Fe Railroad, is the nearest station. Th ore is carried from the mine to the mill, near Pecos, by a twel mile aerial tramway. The mill is on a branch line connec with the Santa Fe Railroad.

History and Development.—What is now known as the Pec Mine of the American Metal Company, Limited, was first di covered in 1881. In March, 1882, the Pecos River Min Company was organized. It was not until 1905, however, wh the property was known as the Hamilton, or the Cowles Mi that any extensive development work was attempted. At th time development consisted mainly of a tunnel, driven into th ore body about on a level with Willow Creek, and a shaft, su to a depth of approximately 200 feet. Between the years 1905 and 1910 this work was extended to a depth of 400 feet and levels were cut for the extraction of ore. At that time the property was worked primarily as a copper mine. The ore near

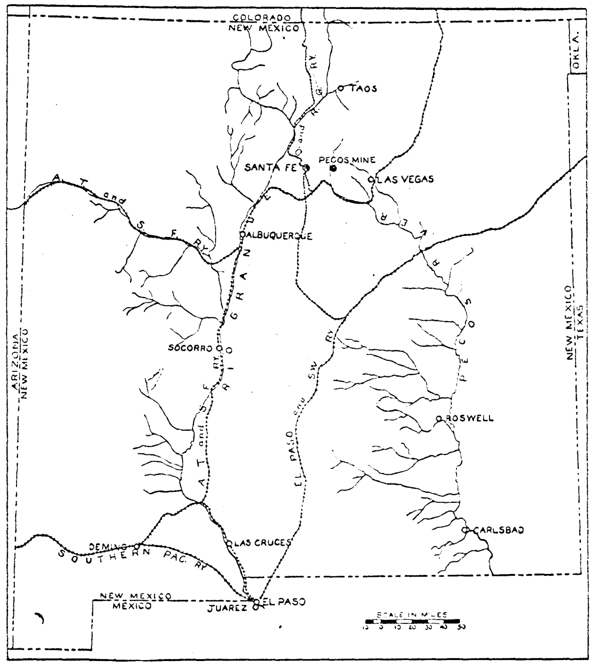

FIG. 1. Sketch map showing location of Pecos Mine.

the surface consisted mainly of irregular masses of pyrite, chalcopyrite and a small amount of sphalerite, with practically no galena. A small amount of ore was shipped, but there are no records available concerning the exact tonnage.

In 1916 the property was taken over by the Goodrich-Lockhart Company, which extended the scope of operations. An intensive program of development was inaugurated and sufficient ore was found to insure production for several years. As development was extended to greater depth, however, the ore became primarily a complex pyritic zinc-lead ore with only a small quantity of copper. Careful metallurgical research, carried on both in this country and in Europe, resulted in finding a successful method for treating the ore by differential flotation.

In 1926 the American Metal Company, Limited, the present owners, purchased the property. The greatest development and production was begun and has been carried on by this company. Modern equipment has been installed, a new mill erected and a twelve-mile aerial tramway has been constructed. The program of mining and development since then has been carried on in a vigorous and efficient manner.

Access to the ore bodies is gained through two vertical shafts. The Evangeline, located approximately in the center of the mine, was sunk in the more massive diabase between the two principal ore bodies to a depth of 1,060 feet. The Katydid shaft, located to the northeast of the Evangeline shaft, is reached through a tunnel from the surface and extends to the 600 level.

At the present time eight levels, at 100-foot intervals are used for stoping operations. The 900 and 1000 levels have been driven from the Evangeline shaft along the strike of the main shear zone to intercept ore previously encountered on these levels by diamond drilling. Crosscuts are driven at intervals along the main drifts in order to fully develop the shear zone. An extensive program of diamond drilling is carried on continuously in order to prospect ground farther away from the immediate shear zone. Workings extend along the strike of the shear zone for approximately 2,000 feet, and sufficient ore reserves have been blocked out to insure production for a number of years.

No records are available on the production of the mine before its operation by the American Metal Company. For the three years that this company has been operating, however, a total of 584,158 tons of ore have been produced having an average content of 16.06% zinc; 3.73% lead; 1.02% copper; 3.39 ounces of silver and 0.109 ounce of gold per ton. This includes all production up to January, 1930.

Previous Geologic Work and Scope of Present Study.—The earliest record of the geology of the Pecos Mine (then the Hamilton Mine) is by Lindgren and Graton.[1] In this study no attempt

[1] Lindgren, W. and Graton, L. C.: "A Reconnaissance of the Mineral Deposits of New Mexico." U. S. Geol. Surv., Bull. 285, pp. 74–86, 1906.

was made to give a detailed description of the geology of the mine. It served as a basis, however, for a more extended study of the mineral deposits of New Mexico in 1910 by Lindgren, Graton and Gordon,[2] in which the general features of the Pecos district are discussed. An interesting account by Hubbell [3] gives an excellent description of the mine and presents the views of Prescott [4] regarding the origin of the ore deposit and the significance of some of the structural features.

The present paper is intended to present primarily the results of co-ordinated field and microscopic study dealing with the character of the ore, its origin and structural relations. It lays greater emphasis on the details of mineralization, structural characteristics and relationship of the ore deposit to the surrounding country rock.

The field work of the present study occupied the summer of 1930, and was followed by a petrologic study of a selected suite of representative specimens. Although the greater part of this work was confined to the mine itself, the investigation included a reconnaissance of an area of about 25 square miles in the immediate vicinity of the mine.

Acknowledgments.—The officials and staff of the American Metal Company of New Mexico have shown extreme courtesy in assisting the progress of the work. Opportunity was offered to make a detailed study of the mine, and the use of mine maps and equipment was freely given. The utmost hospitality was shown while at the property. Mr. Van Dyne Howbert, Mr. J. T. Matson, Mr. Charles E. Stott, Mr. C. Hoag and Mr. C. E. Anderson of the American Metal Company of New Mexico gave freely of their time and advice and offered many valuable suggestions as the work progressed.

The study on which the present work is based has been carried on under the direction of Dr. Charles P. Berkey, Professor of

[2] Lindgren, W., Graton, L. C. and Gordon, C. H.: "The Ore Deposits of New Mexico." U. S. Geol. Surv. Prof. Paper 68, 1910.

[3] Hubbell, A. H.: "Pecos Mine: A New Zinc-Lead Project." Eng. and Min. Jour., vol. 122, no. 26, pp. 1004–1009, 1926.

[4] Prescott, Basil: Private report.

Geology, Columbia University, to whom sincere appreciation is extended for his friendly advice and criticism, and the benefit of his wide experience in problems of this type. While the field work was being carried on a visit to the property by Dr. Paul F. Kerr aided materially in the interpretation of the field evidence. Thanks are also due for helpful guidance in the preparation of the manuscript. The author is indebted to Professors Roy J. Colony and William M. Agar for their valuable aid in the petrographic study and interpretation.

GEOLOGY OF THE PECOS DISTRICT.

Relief and Drainage.—About 20 miles south of Taos, New Mexico, the Rocky Mountains split to form two main ranges. The ranges extend southward in the form of a broad V and plunge below later sediments near the cities of Santa Fe and Las Vegas, names also applied locally to the two mountain ranges. The Pecos district, which lies between these two ranges, thus falls between two prongs of the broad uplift of the Colorado Plateau. The two prongs form the southern extension of the Sangre de Cristo Range described by Melton[5] as a part of the Ancestral Rocky Mountains of Colorado and New Mexico.

Topographically, all of the region north of Glorieta forms a series of high ridges and mesas through which the Pecos River and its tributaries have cut deep, and in places, box-like canyons. West of the Pecos River, in the vicinity of the mine, the mountains rise abruptly from an elevation of 7,800 feet at the river level to 10,000 and 11,000 feet in the higher portions of the Santa Fe Range. They reach their greatest height in the vicinity of Baldy Peak, which has an elevation of 12,623 feet. On the eastern side, toward the Las Vegas Range, the rise is less abrupt, although to equally high elevations. This may be accounted for by the geologic structure of the region, with its gentle dip to the west. In places drainage channels have migrated down the dip of the sediments and the old pre-Cambrian surface, leaving broad

[5] Melton, F. A.: "The Ancestral Rocky Mountains of Colorado and New Mexico." *Jour. Geol.*, vol. 33, no. 1, pp. 84–89, 1925.

flat areas along the east side of the river which now form excellent grazing and farm land.

The Pecos River, the principal stream of the district, heads about 15 miles north of the mine and flows south and southwest through New Mexico and Texas until it finally empties into the Rio Grande near the Mexican Border.

Geologic Formations and Their Distribution.—The geologic formations of the Pecos district can be referred to two large divisions, the old pre-Cambrian crystalline rocks and the Pennsylvanian sediments. The pre-Cambrian rocks consist of diabase, granite, schists and related types of rocks which make up the backbone of the Rocky Mountains throughout their southern extent. They form the basement floor on which later sediments were laid down, and can themselves be divided into units representing different periods of igneous activity and dynamic disturbance.

An unconformity between the overlying sediments and the pre-Cambrian rocks represents a great interval of time during which the older rocks were worn down to a peneplaned surface. On this smooth surface sediments of Pennsylvanian age were deposited. They are made up of alternating beds of limestone, sandstone and arkose that have an estimated thickness of about 1500 feet.

The pre-Cambrian rocks of the district are well exposed in all the canyons east of the Pecos River and for several miles along the Pecos River north of the mine. A small exposure also occurs about two miles south of the mine at the mouth of Holy Ghost Creek. The dip of the old pre-Cambrian surface, with the overlying Pennsylvanian sediments, is from 7–12 degrees to the southwest. The contact between the pre-Cambrian and the Pennsylvanian intersects the Pecos Canyon slightly below the water level south of the mine. Thus, for some distance along the Pecos River, and in all the canyons immediately to the west of the river, within the area mapped, it is concealed from view by the overlying sediments. The best exposures are found along Willow Creek and Mora Creek.

Upstream from the mouth of Willow Creek the pre-Cambrian rocks may be traced almost to the head of the stream. An outcrop of siliceous rock, more resistant to erosion than the surrounding schist, stands out prominently at the surface directly above the mine workings. The schist appears to grade into a diabasic rock farther up the canyon. About a mile and a half east of the mine the diabase is intruded by a medium-textured granite which stands out as a prominent bluff above the river.

The exposures in the canyon of Mora Creek consist of diabase which has been intruded by numerous aplitic and pegmatitic dikes, believed to represent the end-stage crystallization products of the granite magma. Similar exposures are found along the Pecos River north of the mine. Here, also, occur numerous dikes, which range in size from a few inches to more than 30 feet in width.

Davis Canyon shows similar exposures to those seen along Willow Creek. A variety of rocks, ranging from altered diabasic and granitic types and their syntectic products, to a series of metamorphic schists, can be seen. The more acid rocks and their syntectic products are believed to represent phases of the same granitic intrusion. The schists are believed to be the product of the same dynamo-metamorphism which was responsible for the development of the shear zone.

Small local shear zones occur along both Willow Creek and Davis Creek. These generally conform in strike to the main shear zone of the mine. The remainder of the area mapped con-

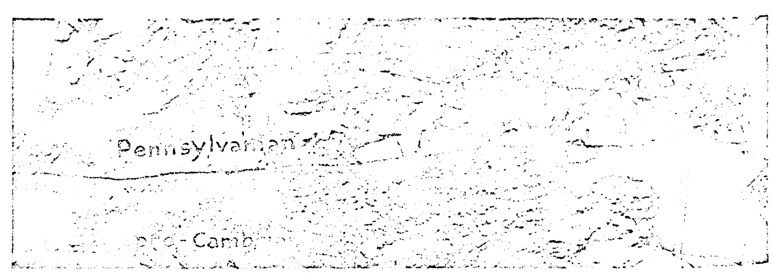

FIG. 2. Photograph showing the unconformable contact between the pre-Cambrian crystalline schists and the overlying Pennsylvanian sediments. Note the gently undulating dip of the old pre-Cambrian surface.

sts of the Pennsylvanian sediments which lie unconformably n the pre-Cambrian. An excellent exposure of the unconformity ay be seen at the mine (Fig. 2). An areal map shows the istribution of the pre-Cambrian rocks and the Pennsylvanian ediments (Fig. 3).

As the mineralization at the mine is confined to the pre-Cam-

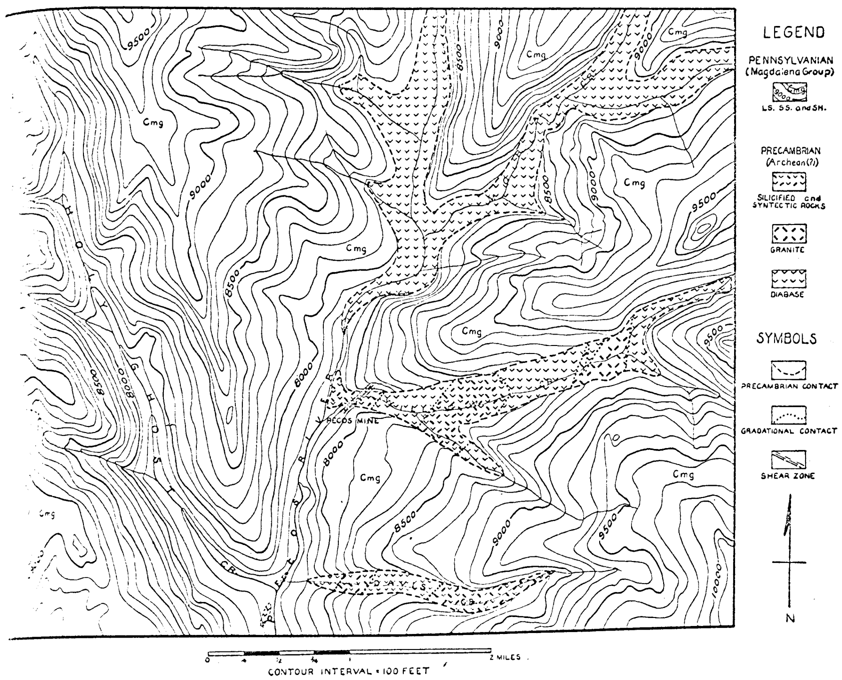

FIG 3. Areal map showing distribution of pre-Cambrian rocks and ennsylvanian sediments in vicinity of mine.

rian rocks, only these are considered in the following petrologic udies. The sedimentary rocks have been described by a number writers and sections along the Pecos River have been recorded Darton [6] and Gardner.[7]

6 Darton, N. H.: "Red Beds and Associated Formations in New Mexico." U. S. ol. Surv., Bull. 794, pp. 255–256, 1928.

7 Gardner, J. H.: "Isolated Coal Fields in Santa Fe and San Miguel Counties, w Mexico." U. S. Geol. Surv., Bull. 381, pp. 449–451, 1910.

PETROLOGIC STUDIES.

The pre-Cambrian rocks closely related to the mineralization at the Pecos Mine consist of diabase, the oldest rock of which any evidence was to be found in this district; and granite, younger than the diabase and intruded into it. Syntectic rocks were developed as a consequence of the intrusion by the granite. This occurred as a result of the infusion of diabasic material within the granite mass. A variety of schistose rocks were developed as a result of the dynamic disturbance accompanying the intrusion. These range from simple biotite schists to quartz-sericite, chlorite and actinolite schists.

Diabase.—The largest single formational unit of pre-Cambrian rock within the area examined is a diabase which outcrops all along the canyon of the Pecos River north of the mine, along Mora Creek, and in a number of places along Willow Creek and Davis Creek. In some places, particularly along Willow Creek and Davis Creek, the diabase grades into mixed granitic types which are believed to represent syntectic products, produced by the intrusion and intimate mixing of granitic magma and its end-stage products with the original diabase. These syntectic products will be described separately.

A number of varietal facies of the diabase occur. Within the area studied, no rocks were found which had not been affected, to some extent at least, by the invading granite mass or its end-stage products. The original rock itself was variable in texture, and to a lesser degree in its mineral composition. Some facies resemble a fine-grained dolerite which originally carried an abundance of pyroxene that has now been completely uralitized, while other facies are coarse-textured and carry orthotectic hornblende as the principal ferro-magnesian mineral.

Megascopically, the diabase is a medium-textured, massive dark rock that weathers dark gray or nearly black. In thin section the rock shows good diabasic structure. Hornblende is one of the principal ferro-magnesian components, in some extreme cases constituting 60–70 per cent. of the rock. It is deep bluish-green, occurring usually in imperfect crystals as much as 2 mm. in length.

The crystals are rarely idiomorphic. The principal feldspar comes within the oligoclase-andesine range. Some of the feldspars show slight zoning, the cores being slightly more calcic than the outer margins. The feldspar crystals are usually ragged in outline and appear to have been affected by the introduction and attack of aqueo-igneous solutions from the granite magma. This attack is manifested in the irregular outlines of feldspar phenocrysts, in which the outer borders are replaced by a more sodic feldspar, and by the development of sericite from the older

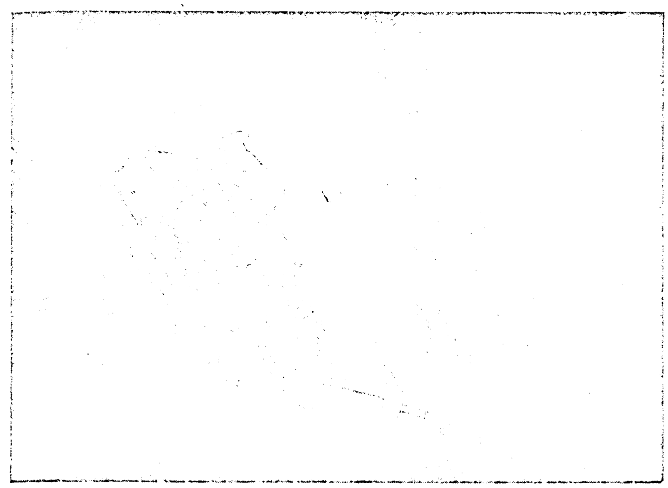

Fig. 4. An outcrop of the diabase showing the manner in which it has been injected by granitic material. The black areas are diabase; the white areas are granitic material in which some of the diabase has become assimilated.

feldspar. A deep brown biotite, a metamorphic product of the hornblende, occurs in small flakes intimately associated with the hornblende. Accessory minerals, apatite, titanite, magnetite, and zircon, are distributed irregularly throughout the rock and probably belong to the normal orthotectic minerals of the diabase.

The moth-eaten appearance of most of the principal minerals of the rock; the production of a large variety of secondary products such as sericite, epidote, zoisite, uralite, saussurite, chlorite, biotite and leucoxene; the interstitial character of most of the quartz and the attack and replacement along the margins of the feldspars, all together strongly support the idea of profound alteration as the result of flooding and attack by the aqueo-igneous emanations of some invading or underlying magma.

Varietal facies of the diabase are numerous along Willow Creek and Davis Creek. They occur abundantly in the mine and have all been affected to some degree by magmatic emanations. In the mine and the near vicinity, alteration has been more intense, resulting in a larger variety of rocks. Some have been completely silicified; others have been so greatly altered that their original nature can only be inferred from the character of their alteration products. Uralite, judged to have been derived from original pyroxene, is one of the most prominent of the secondary products. Still others show such extreme chloritization that only remnants or faint outlines of the original minerals remain. Nearly all of them show addition of quartz and feldspar together with the development of zoisite, epidote, sericite and saussurite. Although initially the diabase had a considerable range in texture, and although it has been altered with variable intensity, the different facies form a reasonably constant petrographic unit distinguishable under the microscope.

The diabase is judged to be the oldest recognizable rock unit in the district. It may have constituted a thick sill intruded into still older pre-Cambrian sediments which are now either entirely destroyed or hidden from view by overlying Pennsylvanian sediments. During pre-Cambrian time, the diabase was caught up in and intruded by a granite. The effect of the granite intrusion is undoubtedly responsible for the profound changes that have taken place in the diabase. It is thought that the diabase may now represent a roof pendant within the granite that has been exposed to permeation and flooding by aqueo-igneous solutions and gases from the granite mass. During the end-stage crystallization period of the granite intrusion, the mineralizers responsible for the metallization within the shear zone were produced.

The Granite.—A steep bluff with a large talus accumulation of rectangular blocks of rock, located about a mile and a half east of the mine, offers an excellent exposure of the granite. It also outcrops at the head of Davis Creek and in a number of places to the south and west of the immediate area.

The normal granite is massive and uniform in its medium-grained crystalline texture. A flesh-colored orthoclase gives the rock a decided pinkish tinge.

Microscopic examination shows the granite to be holocrystalline and typically medium granitoid in texture, made up mainly of allotriomorphic crystals ranging up to 4 mm. in size. The small quantity of ferro-magnesian minerals in the granite is a striking feature. Biotite is present in only minute amounts. From its interstitial position and its distribution along the margins of quartz and feldspars, it does not appear to have been derived from the normal crystallization of the magma, but is probably a product of assimilation of the older diabase. The biotite is usually associated with quartz and albite.

The granite consists largely of soda-microcline, quartz, orthoclase, perthite and albite. Titanite, magnetite, and muscovite are minor accessory minerals. The orthoclase commonly occurs as idiomorphic phenocrysts 2 to 4 mm. in length, somewhat modified by the attack of end-stage crystallization residuum which brought about the development of sericite and very fine aggregates of kaolinitic material. Carlsbad twinning is prominent. Some of the crystals are traversed by microscopic quartz-filled cracks. Microcline is one of the most prominent constituents of the granite. It is especially interesting because it shows a tendency toward poikilitic development. It was probably one of the last of the orthotectic minerals to crystallize, for in many instances it completely incloses earlier-formed crystals of orthoclase and quartz. Irregular masses of microcline are also distributed interstitially, and in some places it is intimately mixed with fine aggregates of quartz and albite. In some instances albite has penetrated the microcline and orthoclase, producing a perthitic appearance. As the microcline was one of the later minerals to crystallize, and as it may itself have been one of the end-stage components, it has escaped deuteric attack, whereas the orthoclase was considerably affected.

The quartz of the granite exists not only in large unit areas, but it also is distributed interstitially, intimately associated with albite and microcline. It may contain characteristic fluid cavities common to rocks of this type. Albite, with quartz and probably microcline also, is one of the final consolidation residua of the granite magma and is in part responsible for the slight deuteric attack on the normal orthotectic minerals of the rock. The attack on the granite is not so intense as that which affected the diabase. This may have been because the granite was in more stable equilibrium with its own end-stage products, whereas the diabase was compelled to undergo greater reorganization upon the invasion of the granitic material. Alteration products of the granite consist of sericite, muscovite, kaolinite, leucoxene and a small amount of epidote and saussurite. The granite is quite fresh in appearance and has not been greatly affected by superficial weathering agencies.

Relation of the Granite to the Diabase.—The granite is intrusive into the diabase. Good evidence of this is to be found in the outcrops along Willow Creek and at the head of Davis Creek. Small dikes and stringers of the granite cut the diabase, many of which can be traced directly back to the granite mass. A comparison of the mineral components of the granite with those of the granite dikes which are intruded into the diabase shows a marked similarity in composition. The suites of minerals in both the main body of the granite and in the invading granitic dikes are rich in soda-microcline, quartz and albite.

Syntectic Products.—In the vicinity of the granite intrusion, particularly along Willow Creek and Davis Creek, a variety of syntectic products have been developed. They are products of the intimate mixing and assimilation of the diabase with the invading granite magma and its late-stage crystallization products. The minerals of the older diabase have been attacked and reorganized so that in some cases only remnants are left, or recrystallization has taken place so that minerals of the older diabase have been greatly altered. Most of the syntectic products differ in appearance from the normal granite or diabase, and from their light color they have been referred to at the mine only as a more "acid

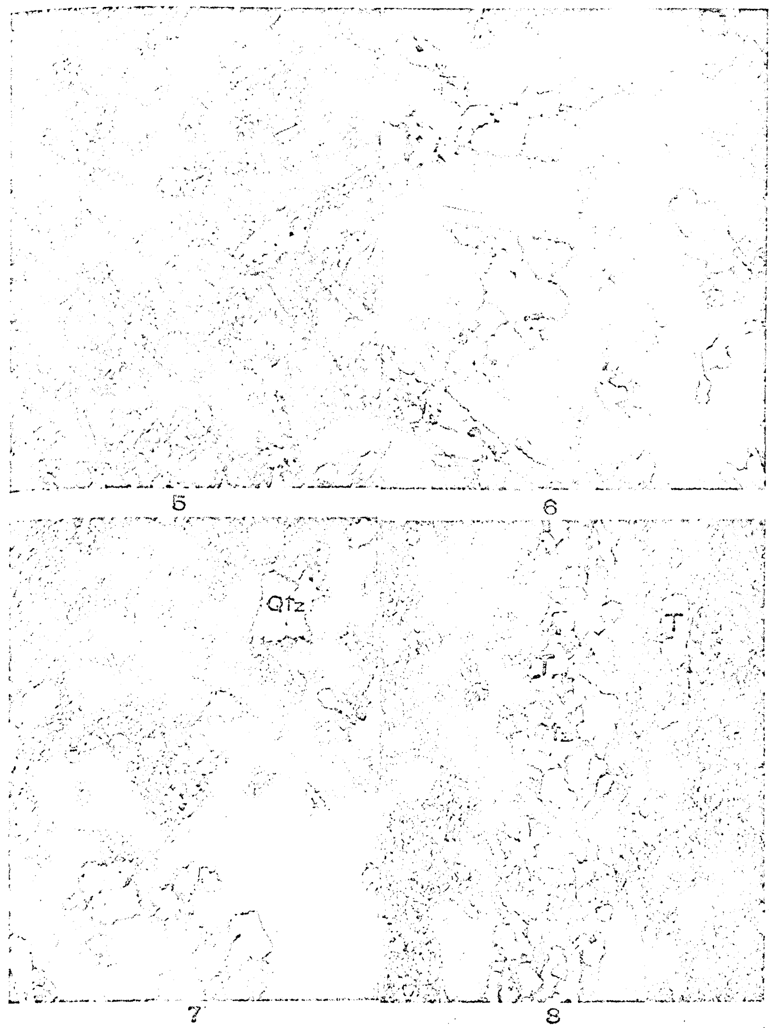

FIG. 5. Thin section of the diabase showing the structure and the manner in which the minerals have been modified by the end-stage constituents of the granite. × 20.

FIG. 6. Thin section of the granite, showing the structure and mineral composition. A rounded crystal of orthoclase has been partially altered to sericite with the addition of more sodic feldspar around its outer margin. × 15.

FIG. 7. Thin section of one of the syntectic rocks, showing the masses of uralite (*Ur*) formed from original ferro-magnesian minerals of the diabase, and the interstitial character of the quartz (*Qtz*). × 15.

FIG. 8. Thin section of quartz-sericite schist, penetrated by quartz (*Qtz*) veinlet and tourmaline (*T*). × 15.

rock." They vary in texture and structure. The coarser varieties, such as some of the specimens taken from the upper end of Davis Canyon, more nearly resemble the granite in a hand specimen. The rocks from this vicinity also show an abundance of quartz and soda feldspar, as though the invading material had been particularly rich in these components. Remnants of minerals believed to have been a part of the original diabase are present. They may usually be distinguished by their greater alteration and by the manner in which they have been completely surrounded with, and partially assimilated by the invading granite mass. The original ferro-magnesian minerals of the diabase have been highly altered by this process. A deep brown biotite has been developed from hornblende and now occupies mainly an interstitial position between minerals of the granite, and is intimately associated with uralite. Muscovite and sericite have been formed as alteration products of the feldspars.

A specimen (S–38) from Davis Canyon shows a coarsely crystalline mixture, somewhat resembling material from the pegmatite dikes of the region. Caught up within it, however, are patches of the material from the diabase that have been almost completely assimilated or digested by the granite magma. Irregular outlines of feldspar crystals occur, their center portions composed of highly altered and partially assimilated feldspar of the diabase, whereas the outer portions consist of alkali feldspar of the granite that has attacked and replaced part of the older mineral.

Myrmekite-like intergrowths, similar to those described by Sederholm,[8] occur abundantly. These are usually intergrowths of quartz and orthoclase and are not the true intergrowths of myrmekite of Sederholm, which are of quartz and plagioclase feldspar. Patches of acicular, bluish-green amphibole (uralite) are common in the syntectic rocks. These have also been partially assimilated by the granite magma, and their edges usually show fine aggregates of quartz and feldspar, and they are often intimately intergrown with quartz. Although the patches of

[8] Sederholm, J. J.: "On Synantetic Minerals and Related Phenomena." Bull. Geol. de Finlande, No. 48, 1916.

partially assimilated uralite and highly altered feldspar are believed to represent minerals of the older diabase, the percentage of these minerals in the syntectic rocks is not great and most of the rocks are made up of the normal minerals of the granite.

Quite a different variety of syntectic rock occurs in places along Willow Creek. It is finer in texture and is made up mainly of granular quartz and feldspar. Occasionally larger phenocrysts of feldspar occur; their borders present a ragged and moth-eaten appearance, and they are traversed by microscopic fractures which are filled with small flakes of brown biotite. The feldspar phenocrysts are usually surrounded by fine aggregates of quartz, feldspar and biotite, and they exhibit the effect of partial assimilation and recrystallization. Muscovite is a common alteration product of the feldspars. Irregular patches of the finely crystalline mixed aggregates also occur as individual units. These are also believed to represent minerals of the diabase that have suffered attack, partial assimilation and recrystallization by the intrusion of the granite. Myrmekite-like intergrowths are also common in this variety. The quartz of the granitic material occurs as larger euhedral crystals, often enclosing masses of the recrystallized or highly altered aggregates of mixed minerals of the diabase.

Still another variety is made up almost entirely of recrystallized quartz and feldspar. If it were not for the occasional larger phenocrysts of feldspar and the presence of small flakes of biotite or chlorite in irregular aggregates, the rock would closely resemble a quartzite that had been metamorphosed sufficiently to cause recrystallization. That the rock has been affected by some deformation is evident in the undulatory extinction shown by most of the quartz grains. Some of the quartz was introduced after most of the reorganization had been effected and now occupies small veinlets within the mass.

The diversity in mineral composition, texture and structure of these syntectic rocks is believed to be due to variation in the intensity of attack by the granite; the degree to which the diabase has become assimilated; and to movement affecting the rocks after invasion had taken place. They appear to grade from the normal granite to the diabase. Isolated blocks of the diabase, however, occur in places within the areas of syntectic rocks. They appear to have been caught up bodily within the magma and show the effect of the granite intrusion only around their margins. Good exposures of these are to be seen along Willow Creek and Davis Creek.

The Schists.—Where dynamic movement and deformation in the zone of weakness of the diabase has taken place, with the development of a sheared zone, a variety of schistose rocks have been developed. Most of the underground workings of the mine are confined to this zone and here, except for the relatively unaffected masses of diabase, the rocks are all of a schistose nature. Deformation within the shear zone has not been uniform, and the schists themselves vary in mineral composition as well as in the degree to which they have been affected by dynamo-metamorphism.

Most of the schistose rocks are judged to have been derived from granitic material or the more acid segregations of the granite magma that was intruded into the zone of weakness before deformation took place. The rocks are mainly quartz-sericite schists with only minor amounts of chlorite and biotite. Other varieties are judged to have been derived from a mixture of granitic material with the diabase. These show an abundance of both sericite and chlorite as well as schistose quartz, all arranged in a foliate manner. A simpler variety, produced from the shearing of the diabase, shows a preponderance of biotite with only a small amount of chlorite, quartz and sericite.

Quartz-Sericite Schist.—The quartz-sericite schist is widely distributed throughout the mine, and is encountered in most of the drill holes away from the more strongly mineralized areas. In a hand specimen it shows a fine granular or sugary texture. The schistose structure is not always prominent, but if the rock is examined with a hand lens the orientation of the mica flakes is readily seen.

In thin section the schistose structure of the rock is brought out prominently. Quartz is by far the most abundant mineral and makes up the greater part of the rock. Sericite is next in abundance and only minor amounts of chlorite or biotite are present. There is a variety of textures even in a single slide. Patches of fine-grained, mixed schistose quartz and sericite show good evidence of shearing and granulation. These patches of fine-grained material commonly serve as a matrix for larger unit areas of clear quartz, much coarser in texture than the matrix and sometimes fractured, with inclusions of finer quartz and sericite. Small veinlets of introduced quartz may follow the foliation planes of the rock and were evidently introduced after most of the shearing had taken place.

The rock is a good example of a schist developed through the shearing and granulation of a granite or granite pegmatite. The areas of coarser quartz are believed to be original quartz of the granite; the finer masses of mixed quartz and sericite, with a decided schistose structure, are derived from the shearing and granulation of the feldspars and the finer-grained quartz. In some of the unsheared granites and the more acid syntectic rocks, poikilitic intergrowths are common. It is thought that the finest mixed patches of quartz and sericite occurring in the schists may represent areas of these intergrowths that have been much sheared and granulated. All three textures may be seen in the same field under the microscope.

Quartz-Chlorite Schist.—Another variety of schistose rock that occurs in abundance within the shear zone is a mottled, greenish, fine-grained rock that is essentially a quartz-chlorite schist. It is found in the areas of greatest disturbance and along the walls where movement has taken place. Much of the metallization appears to be associated with this type of rock, and for this reason it may be of importance from the standpoint of ore localization.

In thin section the rock is strongly schistose. It is composed mainly of quartz, chlorite and sericite, all oriented in the same direction. The quartz grains may be slightly elongated and have an average size of about 1 mm. The sericite is intimately associated with the quartz, but rare patches occur that consist almost entirely of sericite. These patches probably represent feldspar crystals that have been completely altered. A peculiar feature of the rock is the distribution of large, prominent patches of chlorite that may show a parallel intergrowth of muscovite and biotite. The origin of the chloritic patches in the rock is obscure. They are believed to have been derived from the ferro-magnesian minerals of the diabase, and it is judged that the rock itself was originally a mixed one; a product of assimilation and intimate mixing of some of the diabase with the invading granitic material. With the advent of shearing, a mottled, patchy, schistose rock was developed that appears to have been particularly susceptible to mineralization.

Biotite Schist.—Where shearing has taken place around the outer margins of isolated blocks of diabase, a black, biotite schist has been developed. This type of schist consists mainly of biotite with only minor amounts of quartz and sericite. The biotite may be slightly altered to chlorite. The biotite is a metamorphic product derived from the ferro-magnesian minerals of the diabase during the dynamic movement that was responsible for the shear zone.

All the schistose rocks vary in the degree to which they have been affected by dynamo-metamorphism. Where definite planes along which movement has taken place can be seen, "talcy" schistose gouge is present. If the movement has been post-mineralization, ore has often been caught up with the gouge and has been dragged along the plane of movement.

(*To be concluded in next number.*)

GEOLOGY OF THE ZINC-LEAD DEPOSITS AT PECOS, NEW MEXICO—PART II.

PHILIP KRIEGER.

CONTENTS.

STRUCTURAL FEATURES.

General.—The structural features of the Pecos Mine present a number of problems that appear to be of economic importance for carrying on a successful program of development and operation. Not only was localization of the ore largely controlled by the structural conditions existing at the time of ore deposition, but the size, grade and continuity of the ore bodies appear also to follow rather definite structural trends. The method of mining is almost entirely dependent upon the structural conditions within the shear zone. For these reasons, detailed mapping of the mine workings and a careful study of the existing structures are necessary.

It is by no means certain that all of these problems have been completely solved in the present work. Solutions have been arrived at, however, that seem to account satisfactorily for many of the features observed, and subsequent development, viewed in the light of these interpretations, appears to bear out most of the ideas concerning the structure. Additional development work will, no doubt, throw further light on some of these problems.

The Shear Zone.—The shear zone in which the ore occurs strikes approximately north 45° east, and at the surface, it dips from 70° to 80° to the west. The maximum width of the sheared area is about 600 feet.

Numerous smaller areas in which shearing has taken place are exposed throughout the region. These conform, in general, to the direction of the main shear zone, but none have yet been found that showed evidence of mineralization similar to the larger one in which the mine is located. In the main zone of shearing local variations in the strike of the foliation may exist.

Within the area explored, the greatest intensity of shearing appears to have taken place along a major axis, with the development of parallel zones of lesser magnitude, but all being a part of a rather broad, general zone of deformation. The largest area of mineralization, in which is located the Evangeline ore body, occurs along a major axis of shear. The Katydid ore body is located parallel to the Evangeline, and about 200 feet to the west, occupying a shear zone similar to the Evangeline but of smaller size. What may represent a third zone [8a] containing ore mineralization was discovered during the summer of 1930 by diamond drilling from the lower levels of the mine. This is located approximately 300 feet east of the Evangeline ore body, and so far as could be determined from the evidence of two widely spaced drill holes, it likewise occupies a position approximately parallel to the major axis.

Movement evidently continued along the major axis during a greater part of the mineralization period. The ore within this area is distributed more irregularly, and replacement has not been so thorough as in the Katydid ore body. Post-mineralization movement is also more evident; the rocks are more broken and sheared, and patches of waste rock in the ore are more frequently encountered, making mining operations necessarily more selective.

In the Katydid zone replacement of the schistose rocks has been more complete and without the amount of movement during mineralization that characterizes the Evangeline ore body. The

[8a] Since proved to be the Evangeline shear zone [Editor].

ground does not tend to cave so readily; less timber is used and a cleaner ore is extracted.

Cross shearing in an east-west direction showing a small amount of mineralization has been encountered on some of the levels. In the northeastern part of the adit level the major shear turns to follow a direction almost due east. The same cross system of shear has been encountered in some of the crosscuts on this level, as well as on some of the lower levels. It has been followed toward the east for about 700 feet, but with the exception of small stringers of ore, no important mineralization has been found in it. It is thought that this shear eventually turns to follow the general northeast direction of the main shear zone, but there has not yet been sufficient development work done in this part of the mine to determine this.

Within the mine the dip of the foliation varies from 45 degrees to vertical. The most consistent dips, however, are from 75° to 80°. Above the 600 level the dips are all toward the west, but at about the 600 level they become nearly vertical, and below this point they change to 75°–80° E., then flatten to 40° E. just below the 900 level. This change in the direction of the dip has an important bearing on the ore mineralization and will be discussed more fully. Both the Evangeline and the Katydid ore bodies have a decided plunge toward the southwest. This can be best seen in the longitudinal section of the Evangeline ore body showing the areas that have been mined out (Fig. 10).

Relation of Massive Diabase Blocks to Structure.—Throughout the explored length of the shear zone there occur numerous massive, unsheared blocks or "horses" of diabase. They are commonly oval in shape and show evidence of intense shearing only around their outer margins. The rare mineralization in them is mostly confined to their outer margins or sheared portions.

These "horses" are believed to represent blocks of the diabase that have parted from the main mass along the joint planes, either during a pre-granite deformation or during the earlier stages of the deformation responsible for the present shear zone. Much of the granitic material penetrated around and between these blocks, isolating them from the main body of the dia-

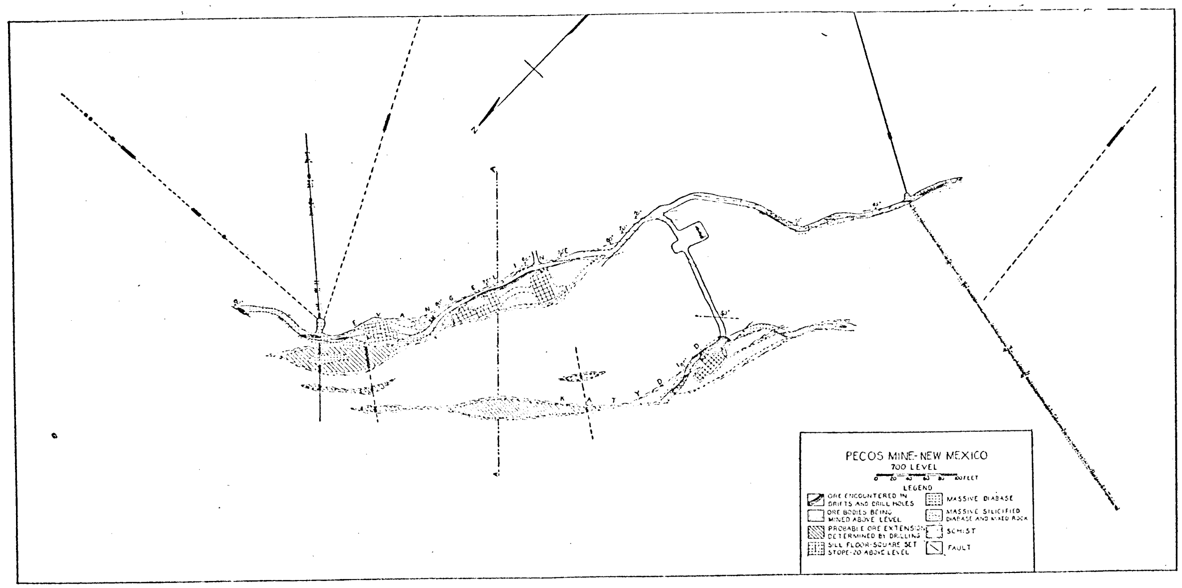

FIG. 9. Plan view of one of the mine levels, showing the relation of the two principal ore bodies.

base; some of it may have penetrated these areas with assimilating any great amount of the diabase. Other p tions did accomplish some assimilation and reorganization material. When movement took place, the granitic areas betw the diabase blocks proved to be more susceptible to shearing th the more resistant diabase, so in these areas a mixed variety schistose rocks were formed. The complexity of the shear areas served at first to disguise successfully the true character the rocks, but with the recognition of these features, their nat and occurrence may be easily explained. The diabase blocks h a tendency to divert the direction of shear, causing local vari tions within the zone of deformation.

These features can be seen throughout the length of the she zone on almost any of the levels and are particularly promin in some of the stopes where the schistose rocks have been r placed by ore minerals. In such places, massive sulphide shows the schistose structure of the rock which was replac Within the ore, large blocks or "horses" of massive diabase a found that exhibit no schistosity except around their outer ma gins, and have not been affected by ore mineralization. An e amination of the antecedent structures preserved in the ore sho the schistosity going around the block and then continuing in general northeast-southwest direction when beyond the influe of the more massive rock.

The influence of these diabase "horses" on the direction shear is not confined to the horizontal direction only, but affe also the dip in a similar manner. Local changes in the dip a common, and in the case of the Evangeline ore body, the gen direction of the dip of the shear zone and the ore has been versed at about the 600 level. It is believed that the immedi area in which the change occurs may represent an area of diabase that was not greatly broken before shearing took pl that the granitic material had penetrated only a narrow open between two larger masses of diabase that acted as buttres during the movement. Only a narrow area of schistose rock w developed here; one which was considerably tighter than mos

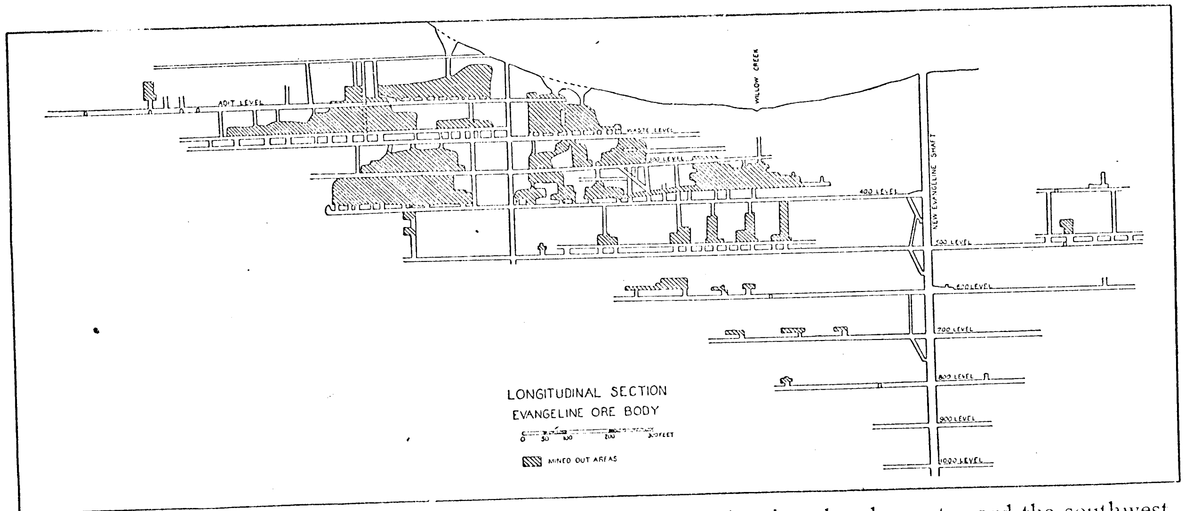

FIG. 10. Longitudinal section of the Evangeline ore body, showing the plunge toward the southwest.

the shear zone. For this reason mineralizing solutions did n penetrate so readily, or over so wide an area, and ore here occu only in narrow stringers which are not of sufficient width to worth mining. This condition is encountered on most of the 6 level except to the northeast of the main shaft, where the plun of the ore body brings the tight area slightly above the level.

The recognition of the origin of these massive areas and th relation to the structure and mineralization is believed to be of im portance in directing prospecting within the shear zone. In t stopes, the massive diabase blocks may completely cut off the for the width of the area being mined, but ore is apt to be fou on their opposite side if the shearing has been directed complet around them. This feature was brought out in one of the sto on the 600 level. The ore on the eastern side of the stope w cut off abruptly by an area of massive diabase, but in cutti through this, which proved to be about 30 feet wide, 25 feet ore was encountered on the opposite side.

Structural Differences Between the Evangeline and the Ka did Ore Bodies.—Some outstanding differences between Evangeline and the Katydid ore bodies are of significance cause of their relation to the structure within the general zone deformation. It was earlier stated that greater shearing is lieved to have taken place along a major axis, the zone in wh the Evangeline ore body occurs. This is manifested in more broken character of the rock, and greater intensity of sh as well as post-mineralization movement. The economic portance lies in the fact that in the Evangeline zone, minera tion has taken place with a more patchy distribution, presuma because of the greater number of openings through which m eralizing solutions were able to penetrate. The Evangeline z is also much broader than the Katydid, which, with the mo ment that undoubtedly accompanied mineralization, permitted access of solutions to a large number of smaller areas in wh replacement took place. The diabase in this area is also thou to have been more finely broken or fractured, permitting entr a greater quantity of granitic material and more extensive si fication of the diabase.

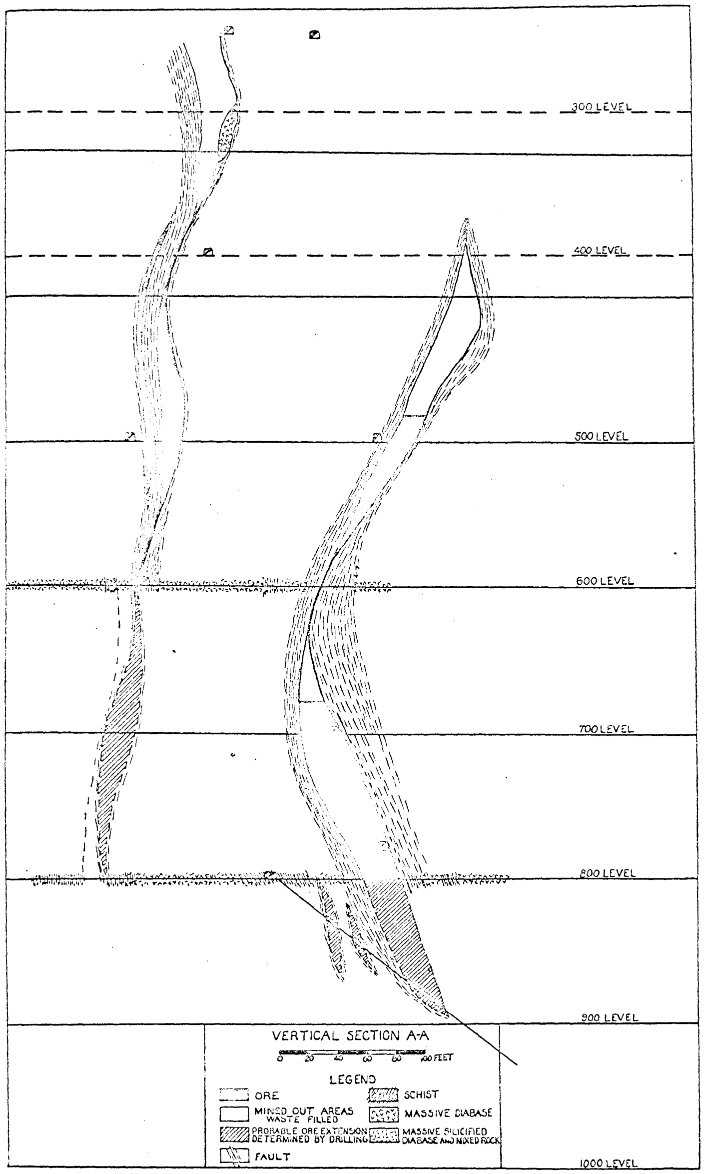

FIG. 11. Vertical section, showing the changes in dip of the two ore bodies.

That some post-mineralization movement took place within this zone is evidenced by the quantity of gouge found along the walls that commonly contains fragments of ore. A well-defined surface of post-mineral movement can be traced over several levels on the east side of the Evangeline ore body. Such movement as took place was probably distributed over a number of surfaces

FIG. 12. Xenoliths of the diabase broken along joint planes and caught up in the granite magma.

extending across the width of the Evangeline shear zone. The effect of such a movement would account for much of the waste rock with which the ore in this area is so intimately mixed.

Another feature of significance in the Evangeline ore body is that here one sees the most striking evidence of the selective replacement of schistose rocks rather than the wall rock by ore minerals. It is as though the solutions had freer access to more porous rock and were not confined long enough in one place to accomplish replacement of the wall rock.

These features are less prominent in the Katydid ore body. Replacement here has operated more extensively, and although the greater part of the mineralization occurs in the schistose rocks, the wall rock has been replaced also. The area is in general much smaller than the Evangeline, but there is not the dilution of ore due to the more irregular distribution that characterizes the Evangeline ore body. The mineralizing solutions that penetrated this zone were apparently confined to a smaller area, without the opportunity of distributing themselves through a large number of openings, or passing through with only slight replacement. In consequence, replacement was more thorough and even the wall rock was affected in some instances. This has materially aided mining operations in the Katydid ore body, as well as yielding a higher grade of ore per ton mined.

The Katydid ore body, in contrast to the Evangeline, has not been greatly affected by post-mineral movement. Its walls are commonly sharp and well defined. Both ore bodies carry considerable quantities of water. The porous and fractured nature of the Evangeline allows it to gradually seep away, and when water is encountered in this area by drill holes the pressure is not great. The Katydid area, on the other hand, appears to act as a reservoir for surface waters, and when encountered in drill holes the pressure is often sufficient to materially hinder the drilling operations.

What may prove to be a third zone of mineralization, occupying a position similar to the Katydid but on the opposite side of the Evangeline or major shear zone, was encountered in two drill holes from the 700 level. In plotting the position of this ore it was found to lie approximately 300 feet east of the Evangeline and 150 to 200 feet below the present workings of the Evangeline, that of the 800 level. From the evidence available at the time the field study was made this appeared to be another distinct zone of shearing and mineralization. Since then, however, development work has been extended to this depth in the vicinity of the main Evangeline shaft and exceedingly flat dips in the shear have been encountered. These appear to extend from the Evangeline zone to the new ore. In this vicinity the new zone of shear has been proved to unite with the Evangeline, similar to the manner in which the Katydid zone approaches and appears to join the Evangeline in the northeast end of the mine. Although development on the lower levels at the present time has not progressed sufficiently to draw final conclusions regarding the structure on the lower levels, additional development should reveal some interesting features in this respect.

THE ORE DEPOSITS.

General.—Mineral deposits of sufficient size and grade to warrant mining are not abundant in the pre-Cambrian rocks of New Mexico; a few were mined in the early days. Most of these are now either entirely abandoned or are worked only intermittently as the price of metals rises or falls. The majority of these have been described by Lindgren, Graton and Gordon.[9] The Pecos district, according to available information, is the only one in which sufficient ore has been found to warrant mining on a large scale, and the only deposit of consequence belonging to a metallogenic epoch of pre-Cambrian age within the state.

Some mineralization has been found in the pre-Cambrian rocks just outside of the immediate vicinity of the Pecos Mine. The Johnny Jones property, a small prospect located about 6 miles southwest of the Pecos Mine, contains a small amount of sphalerite and chalcopyrite. The character of the mineralization and the rocks with which it is associated suggest an origin similar to that of the Pecos Mine; the property may belong to the same epoch of deformation and mineralization. A small amount of development work has been done on this property but there has been no appreciable production of ore.

Character of the Ore.—The ore of the Pecos Mine consists of sulphides of zinc, lead, and copper intimately mixed with pyrite and always associated with the schistose rocks which make up the greater part of the shear zone. A small but appreciable amount of gold and silver is also present. Pyrite is one of the most abundant of the minerals; so much so that it must first be

[9] *Op. cit.*

eliminated before a concentrate of the more valuable minerals is made. An average analysis of the ore has already been given.

The ore, like the rocks of the mine, is extremely variable. Some specimens contain practically all the major constituents, sphalerite, galena, chalcopyrite and pyrite closely associated with each other. In the majority, however, sphalerite and pyrite, the two most abundant constituents, are dominant. These were the earliest of the metallic minerals to form, the pyrite, in all cases, being the first. This was followed by the deposition of the sphalerite. Wherever these two minerals are observed together the sphalerite always replaces the pyrite, so there is no doubt as to the relations existing between them.

The pyrite commonly occurs in the form of cubes that vary in size from very minute dimensions up to one-half inch or more. It is the most persistent of the metallic minerals and forms large aggregates of crystals in the schistose rocks. The crystallizing power of this mineral is well illustrated near the outer margins of the more massive diabase "horses," where it also occurs in numerous isolated crystals of remarkably well-developed cubical forms embedded in the massive rock. Fractured crystals of pyrite are numerous and indicate recurrent movement during mineralization with later replacement by sphalerite along the fractures.

Two distinct varieties of sphalerite were found; the normal reddish-brown variety with the translucent optical behavior characteristic of sphalerite, and the black iron-bearing variety appearing in thin section as an opaque mineral and usually referred to as marmatite. Some idea as to the composition of the mineralizing solutions may be obtained from the relations existing between these two varieties. The reddish-brown variety was the earliest of these to form. During this stage of mineralization the solutions were evidently rich in zinc and deposition resulted in a nearly pure variety of sphalerite. During the later stages of deposition, however, the solutions appear to have been poorer in zinc and richer in iron, for the black marmatite surrounds the purer reddish-brown sphalerite. Analyses have shown the marmatite to carry as high as 15 per cent. of iron and to be considerably lower in zinc than the normal reddish-brown variety of sphalerite. Quite likely this relation between the zinc and iron is similar to that of many of the isomorphous compounds; the zinc and iron being interchangeable in the atomic structure of the mineral. This may account for some of the low zinc assays obtained on drill core samples that, to the eye, appear to carry more zinc than the assays indicate.

As both marmatite and the normal sphalerite reflect light by vertical illumination in the same manner, they are distinguished from each other with difficulty in a polished plate. In an ordinary thin section the marmatite and normal sphalerite are readily distinguishable; the marmatite appearing opaque whereas the normal sphalerite is reddish-brown and slightly translucent.

The sphalerite commonly occurs as massive bodies replacing the schistose rocks and the pyrite, and may be associated with galena and chalcopyrite. It may contain remnant crystals of pyrite, still showing a more or less cubical form, or the pyrite may be embayed and replaced by it. Sphalerite also contains numerous remnants of unreplaced chlorite, actinolite and sericite within it.

Both chalcopyrite and galena are later than the pyrite and sphalerite and replace the earlier formed minerals. The relation between the chalcopyrite and the galena, however, is less distinct; only one instance was observed where the galena occurs later than the chalcopyrite. The remainder of the specimens examined showed mutual boundaries between these minerals, and in view of the lack of definite evidence such as veinlets of the one mineral transecting the other, or residuals of one within the other, one is led to the conclusion that they were deposited contemporaneously, but definitely later than the pyrite and sphalerite. Slight overlapping may have occurred, with galena showing a tendency to be the later mineral.

Both chalcopyrite and galena occur in irregular masses disseminated through the sphalerite, pyrite and gangue minerals. A number of excellent examples of chalcopyrite replacing sphalerite along cleavage planes were observed in polished surfaces. One of these structures is shown in Fig. 16.

The chalcopyrite and galena also occur together in a number of stringers or veins, some of which cut the foliation of the schist. They probably represent the final stages of mineralization and penetrated the shear zone after most of the deformation had been accomplished.

Pyrrhotite occurs in subordinate amounts and is commonly associated with the earlier sulphide minerals, pyrite and sphalerite, and more rarely with chalcopyrite. Where it has been observed in contact with other minerals it replaces pyrite and sphalerite, but is replaced by chalcopyrite. Micro-chemical tests failed to show the presence of nickel.

Bornite was observed in only a few places; it is of no economic importance. It is associated with, and appears distinctly later than chalcopyrite.

Silver, in a ratio of about one ounce per ton to each percent of lead, occurs as small inclusions in galena and was seen only by etching on a polished plate. It is believed to be present in the form of argentite. Proustite has been reported but the writer was unable to identify it.

Common gangue minerals are quartz, chlorite, actinolite, sericite and tourmaline. The chlorite, actinolite, sericite and some of the quartz are products of recrystallization and alteration of the original rocks due to dynamic metamorphism and hydrothermal attack. Abundant quartz has also been introduced along with the ore minerals. The tourmaline is considered to have been one of the last minerals introduced, after most of the replacement by ore had been effected, but not before dynamic disturbance had completely subsided. The tourmaline crystals are mostly fractured and broken, but only one instance was noted where the fractures had been filled with sulphides. They probably represent the gaseous mineralizers of the crystallizing magma.

Oxidation and secondary enrichment are unimportant. Except for one stope in the upper levels, where a small quantity of secondary sulphides of copper was found, nothing that would indicate such a process was observed. An examination of the pre-Cambrian surface below the Pennsylvanian sediments showed that

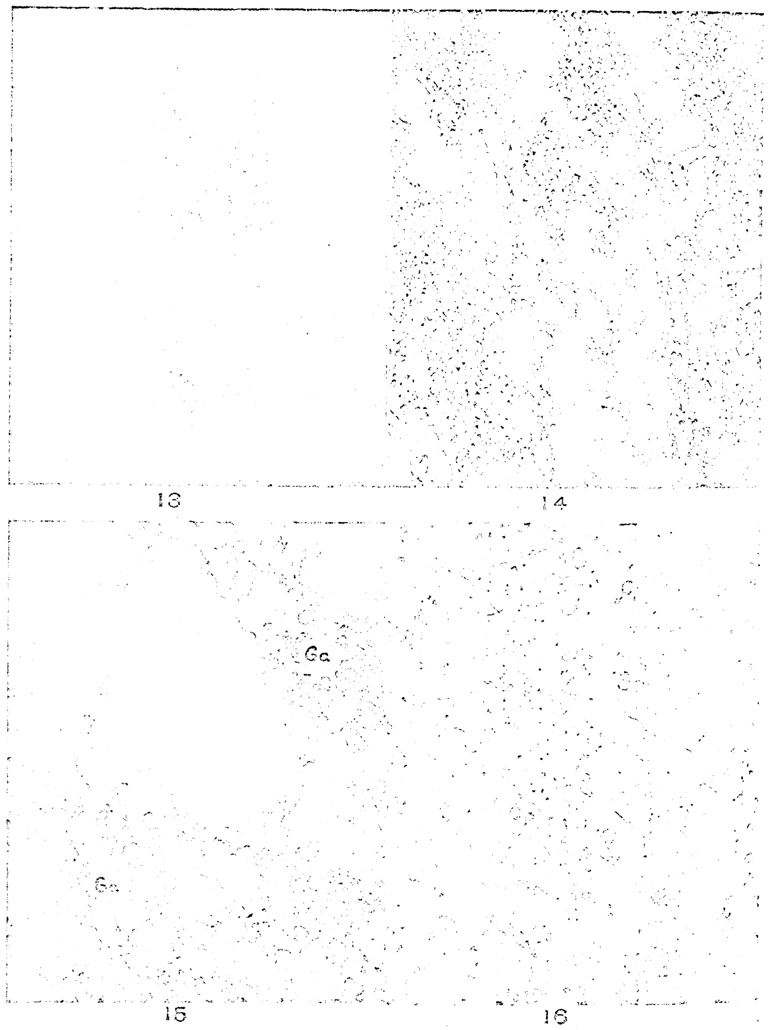

FIG. 13. Thin section of fine-grained schist, showing remnant crystals of feldspar partially crushed and recrystallized. × 15.

FIG. 14. Thin section of ore in schist. The black sulphides show the effect of movement along the plane of schistosity. × 15.

FIG. 15. Polished plate of ore, showing pyrite (*Py*) crystals partially replaced by sphalerite (*Sp*). Galena (*Ga*) replaces both pyrite and sphalerite. × 30.

FIG. 16. Polished plate of ore, showing replacement of sphalerite (*Sp*) by chalcopyrite (*Cp*) along cleavage planes. (This type of structure is interpreted by some as being due to unmixing from a solid solution. At the Pecos Mine, however, the evidence is of replacement and has been interpreted as such.) × 75.

oxidation had only penetrated a few feet, or if it did penetrate deeper, it was almost entirely eroded before deposition of the sediments. The fact that secondary enrichment is not an important factor in the mine would support the first view.

Distribution of the Ore.—Where almost complete replacement of the schistose rocks has taken place the ore occurs as massive bodies, lens-like in form, varying from 2 or 3 feet to 40 or 50 feet in width. This type of replacement has occurred throughout most of the two known zones of deformation. The individual ore bodies may taper at their ends to only narrow stringers, or mineralization may disappear entirely, and then widen out again along the strike of the shear zone. Lenses of ore also overlap each other, separated by areas of barren massive diabase showing intense silicification. A number of such lenses may be found along the strike of the shear zone on a single level.

The smaller lens-shaped ore bodies are particularly numerous in the Evangeline shear zone, where the individual masses of ore range up to a few feet in width and are commonly intimately mixed with gangue rock. This mixture of ore minerals with gangue rock is a characteristic feature of the Evangeline and is believed to have been brought about by recurrent movement along the major axis of shear during much of the period of mineralization. A number of these small lenses of ore may occur close to each other, separated by small areas of unmineralized material, but together forming a body of sufficient size and grade to warrant mining.

Ore minerals also occur as fine grains disseminated indiscriminately throughout the schistose rocks without forming a body of definite size or shape. Where such is the case it is usually found that movement has taken place after some of the mineralization was accomplished. Such movement did not take place along a single plane but appears to have been distributed over the width of the shear zone. Gouge is often found in these areas, carrying sulphide minerals that have been dragged along the planes of movement.

Another noticeable feature of the Evangeline ore body is the increase in content of lead, or of copper, on some of the lower levels as compared with the content of these metals in the upper levels or in the Katydid ore body. The stringers or veinlets of quartz carrying galena and chalcopyrite may account for some of this increase but it is also believed to be related to the recurrent movement within the Evangeline shear zone. The chalcopyrite and galena, being the last of the principal ore minerals to form, would be expected to occur more abundantly in those areas where movement and deformation continued over a greater period of time, but ground that was not much broken or sheared subsequent to the deposition of pyrite and sphalerite, would be less likely to carry any great quantity of these later minerals.

In the Katydid ore body, where replacement has been more thorough, the ore is more massive and continuous without the mixture of gangue. This is particularly noticeable in the area above the 500 level southwest of the main shaft, where the ore was mined continuously over an area about 400 feet in length with only slight variations in width except in the upper portions of the body.

The same features observed along the strike of the ore bodies can be seen along the dip. That is, the individual lenses tend to narrow and pinch out and then widen again as depth is obtained. A plan view and a vertical section of the ore bodies brings out this feature.

The variation in size of the mineralized areas and the intimate mixture of ore with gangue, as in the Evangeline, make for a very irregular and patchy distribution of the ore.

Features Controlling Ore Deposition.—Although the mineralizing solutions are judged to have penetrated the shear zone with the more acid, end-stage concentration residuals of a granite magma, the ores themselves appear to show a distinct preference for the chloritic schists. The minerals most likely to form chlorite as an alteration product, such as hornblende, biotite and pyroxene, are almost entirely absent in the normal granite, but are abundant in the diabase and syntectic rocks. The abundance of chlorite in the quartz-chlorite schists, then, is judged to have been derived mainly from the ferro-magnesian minerals of the diabase. That these schists were not derived from the diabase alone is evident from the large amount of quartz in them, which, even allowing for the liberation of silica by the alteration of feldspars, could not be entirely accounted for in this way. The most reasonable conclusion, then, is that these schists represent assimilation of diabasic rock by granitic material, which, on shearing, formed a quartz-chlorite schist that was readily attacked and replaced by ore-bearing solutions circulating through much the same channels as the granitic material which preceded it.

Ore is also found in the quartz-sericite schists, or those which were derived from more nearly normal granitic material. In this type of schist, however, ore is not nearly as abundant or of as high a grade as that found in the chlorite schists. Thus, it cannot be said that one rock has been responsible for ore deposition to the exclusion of others, but only that the chloritic schists have seemed to exert a greater influence on ore deposition than those made up mainly of quartz and sericite. It is quite possible that if assimilation of the diabase by granitic material had been greater in one part of the shear zone than in others, and shearing then produced a mixed quartz-chlorite schist, these would be the more favorable areas for ore deposition.

The character of the rock, then, has had some influence in the localization of the ore, although it may not have been the dominating influence. Undoubtedly, the structural conditions within the shear zone, permitting access to, and penetration by solutions, or confining them within small areas, were the major causes of localization. The weaker, crushed areas determined the direction of circulation, with replacement in this area occurring more readily in the chloritized rocks.

Origin.—The ore deposit at Pecos is considered to be of "primary" or hypogene origin. The minerals and their associations are largely characteristic of high-temperature, high-pressure deposits of late magmatic origin, classified by Lindgren as hypothermal deposits.

Solutions accompanied by gaseous mineralizers probably furnished the mode of transport for the metals. The solutions are believed to have originated as the final consolidation residuals of a granitic magma. Release of pressure, brought about by dynamic movement forming a wide shear or crushed zone, permitted the solutions to escape through the openings and weaknesses thus formed. In this zone they attacked and replaced the existing minerals of the schistose rocks. The presence of tourmaline, distributed throughout the mine, is evidence that gaseous constituents undoubtedly accompanied the mineralization. It is believed, however, that this material developed somewhat later than the principal metallic mineralization but before movement within the shear zone had completely subsided. Tourmaline is found with the sulphides. It is commonly broken and crushed, but only one instance was noted where the fractures in tourmaline were filled with metallic sulphides. This was with galena, one of the last of the metals to form.

The sequence of mineralization indicates that the earlier solutions to penetrate the shear zone were rich in iron and zinc. Later mineralization shows chalcopyrite and galena penetrating and replacing earlier formed minerals, and appearing in those areas where deformation continued over a longer period.

Recurrent movement within the shear zone probably affected both temperature and pressure so that some overlapping of mineralization occurred. In general, however, the temperatures are believed to have been gradually diminishing.

SUMMARY.

Ore deposition at the Pecos Mine is limited to crystalline pre-Cambrian rocks. These rocks form the underlying rock floor of the district and are exposed only along the canyons and river courses. The hills surrounding the Pecos Mine are mainly composed of overlying, slightly inclined, Pennsylvanian sediments.

The sequence of events leading up to the formation of the ore deposit is as follows:

The Diabase.—The earliest recognizable rock unit of the district is a diabase. This may have been intruded into older pre-Cambrian sediments that are now either entirely destroyed or concealed by overlying sediments.

Intrusion by the Granite.—During pre-Cambrian time the diabase was intruded by a granite that penetrated along earlier weaknesses and isolated blocks of diabase that had parted along fractures and joint planes. In some places much of the diabase was assimilated by the granite magma with the formation of syntectic products.

Formation of the Shear Zone.—As a result of the granite intrusion, and before final consolidation of the magma took place, shearing and intense crushing probably occurred along the same lines of weakness into which granitic material had earlier penetrated. This dynamic disturbance was sufficient to form a broad shear zone in which the greatest movement was taken up along at least two, and possibly three, distinct lines to form the Katydid, the Evangeline, and the Evangeline extension encountered during the summer of 1930. The greatest movement took place along the Evangeline and continued in this area for a greater time. The Katydid, and perhaps the new ore zone, probably represent sympathetic movements along a line approximately parallel to the Evangeline.

The isolated blocks of diabase within the shear zone were left as "horses" because movement took place more readily in the injected areas between them. The dynamic disturbance was sufficient to cause intense reorganization of the rocks within the shear zone, forming a variety of schists, some of them made almost entirely from the granitic material, others from the mixed granitic and diabasic material.

Introduction of Ore.—As consolidation of the granite magma proceeded, final concentration residuals resulted, consisting of acid solutions, water vapor and gases that carried sulphides of iron, zinc, copper and lead. Owing to the release of pressure brought about by shearing, these solutions and vapors penetrated the zone of weakness, forcing their way up through the sheared areas, replacing the schistose rocks through which they circulated. Slight movement continued even during deposition of the ore. Probably this occurred as a final readjustment of the almost completely consolidated granite magma, the solutions penetrating the shear zone as long as openings existed.

Replacement appears to have been somewhat selective; chloritic schists being the more favorable, though not sufficiently so as to exclude replacement in other rocks. The largest ore bodies and the richest ores occur intimately associated with the chloritic minerals. In some instances the diabase wall rock is replaced. principally in the Katydid, where it is believed that the solutions were more confined than in the Evangeline. Control of deposition, however, is essentially structural, and the character of the rock acts as a minor secondary control.

The ore minerals consist of pyrite, sphalerite, galena and chalcopyrite with a minor amount of pyrrhotite. All these minerals are of primary, late magmatic origin. Secondary enrichment is negligible. The individual lenses of ore are distributed irregularly throughout the shear zone and vary in size from a few inches in width to 40 or 50 feet. They are all elongated, lens-shaped bodies, aligned in the direction of shear.

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