Geologic Controls of Lead and Zinc Deposits in Goodsprings (Yellow Pine) District, Nevada

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Study of ore deposits and descriptions of the mines

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GEOLOGIC CONTROLS OF LEAD AND ZINC DEPOSITS IN THE GOODSPRINGS (YELLOW PINE) DISTRICT, NEVADA

By Claude C. Albritton, Jr., Arthur Richards, Arnold L. Brokaw, and John A. Reinemund

ABSTRACT

Lead-zinc ore of the Goodsprings district typically occurs as flattened pipes and tabular bodies replacing dolomitized limestone in zones of fracturing and brecciation. Although a thick section of sedimentary rock, measuring from 11,000 to 12,000 feet, existed before mineralization, the known ore bodies occupy a narrow stratigraphic interval. About 98 percent of the combined lead and zinc output has come from one formation, the Monte Cristo (Mississippian) limestone, which averages only 700 feet in thickness. Furthermore, the ore apparently is concentrated within certain parts of this formation. Of the five members into which it has been subdivided (the Dawn, Anchor, Bullion, Arrowhead, and Yellowpine, named in ascending order) the Anchor and Yellowpine have been most productive. The uppermost or Yellowpine limestone member, although only 140 feet in maximum thickness, has accounted for about 85 percent of the combined lead and zinc. The Anchor limestone member has accounted for an additional 10 percent. An unconformity separates the Monte Cristo limestone from the overlying Bird Spring (Pennsylvania) formation. As the surface of unconformity is irregular, the thickness of the Monte Cristo varies from place to place, and one or more of its members are missing in certain parts of the district.

The areal distribution of ore bodies is related to a complex pattern of faulting. As described by D. F. Hewett,[1] the terrain is divided by thrust faults into imbricate blocks from 1.5 to 3 miles thick. These faults trend generally with the strike of the beds, but in most places their dip exceeds the dip of the bedding. Blocks bounded by the principal thrusts are intricately broken by smaller thrust faults as well as by high-angle faults, many of which apparently represent rifts and tears. Conspicuous reefs of breccia border many of the faults, but the effects of brecciation and fracturing vary according to the character of the beds involved in the faulting. Massive sequences of limestone yielded to deformation largely by fracturing, whereas thinly bedded sequences yielded more by gliding and flowage. Thus the Monte Cristo limestone, a comparatively massive unit between thinly bedded units, is complexly fractured at many places where the overlying Bird Spring formation remains relatively intact.

It was chiefly due to this fracturing that the Monte Cristo limestone became the host for most of the ore bodies. Detailed studies of 17 of the mines suggest that the conduits along which the mineralizing solutions rose were where faults

[1] Hewett, D. F., 1931, Geology and ore deposits of the Goodsprings quadrangle, Nevada: U. S. Geol. Survey Prof. Paper 162, p. 42–54.

and joints of different trends converge and link without offset, or where differential movement had created openings along arcuate faults. Locally the breccia along the feeding fissures was mineralized; more commonly the ore formed in permeable ground that was marginal to the fissures. The high permeability of the Monte Cristo limestone favored lateral spreading of fluids and replacement of the limestone or dolomitized rock by sulfides. In some places the paths of maximum permeability were partings between beds, or sandy fillings in old caves; more commonly they were zones of fractured ground along flexures or faults. Relatively impermeable bodies of mudstone and altered porphyry, as well as films of clayey gouge along thrust planes, locally contributed to the formation of ore by retarding upward progress of fluids.

Beneath some of these impermeable caps the ore remains unaltered and consists principally of galena and sphalerite. In most places, however, the ore is oxidized to undetermined depths below present mine workings. Sphalerite has been altered to hydrozincite and calamine. Locally the galena has also been altered—to cerussite or less commonly to anglesite—but mostly it remains as scattered pods and lentils in the oxidized ore. This common association of the primary lead sulfide with the secondary zinc carbonate and silicate indicates that the oxidation of primary ore was accomplished without significant change in position or shape of the ore bodies.

At the end of 1944 the district had produced about 93,000 tons of zinc and 37,000 tons of lead. The peak of production was reached during World War I, when the camp was the principal source of zinc in Nevada. In 1943–44, when ore was again selling at premium prices, only one of every four lead-zinc properties in the district could produce, and the total output from the productive mines was less than 10,000 tons of combined metals. The known ore bodies thus appear to be nearly exhausted.

Some persons have hoped to revive the district by finding faulted continuations of bodies already mined. Although many bodies of ore end downward in zones of high-angle faults, extensions will not ordinarily exist because most of the faults are older than the ore. A more reasonable program of prospecting would search for superposed ore bodies either above or below those already mined. Superposed ore bodies existed in the Yellowpine and Bullion members of the Monte Cristo limestone at the two largest mines in the district. Yet no mine has explored both the favorable zones in the Yellowpine and the Anchor members.

GEOLOGY OF THE GOODSPRINGS DISTRICT

By Claude C. Albritton, Jr.

INTRODUCTION

The Goodsprings or Yellow Pine district is in the Spring Mountains of southern Nevada. Figure 1 shows the general location and figure 2 shows the topography and distribution of mines. At the end of 1944 the district had produced about 93,000 tons of zinc and 37,000 tons of lead. Prospecting began as early as 1857, but the peak of production came during World War I, when the camp was the principal source of zinc in the State. There was little mining during the interval 1921–23. After a wave of renewed activity beginning in 1924 and continuing for 4 years, the district was virtually dormant until the outbreak of World War II. In 1943–44 ore was purchased at premium prices by the Metals Reserve Co. and stored at Jean station on the Union Pacific Railroad. According to records of the company the stockpile contains about 6,900 tons of zinc and 785 tons of lead. Only 15 of the 60 lead-zinc properties in the district contributed, and at

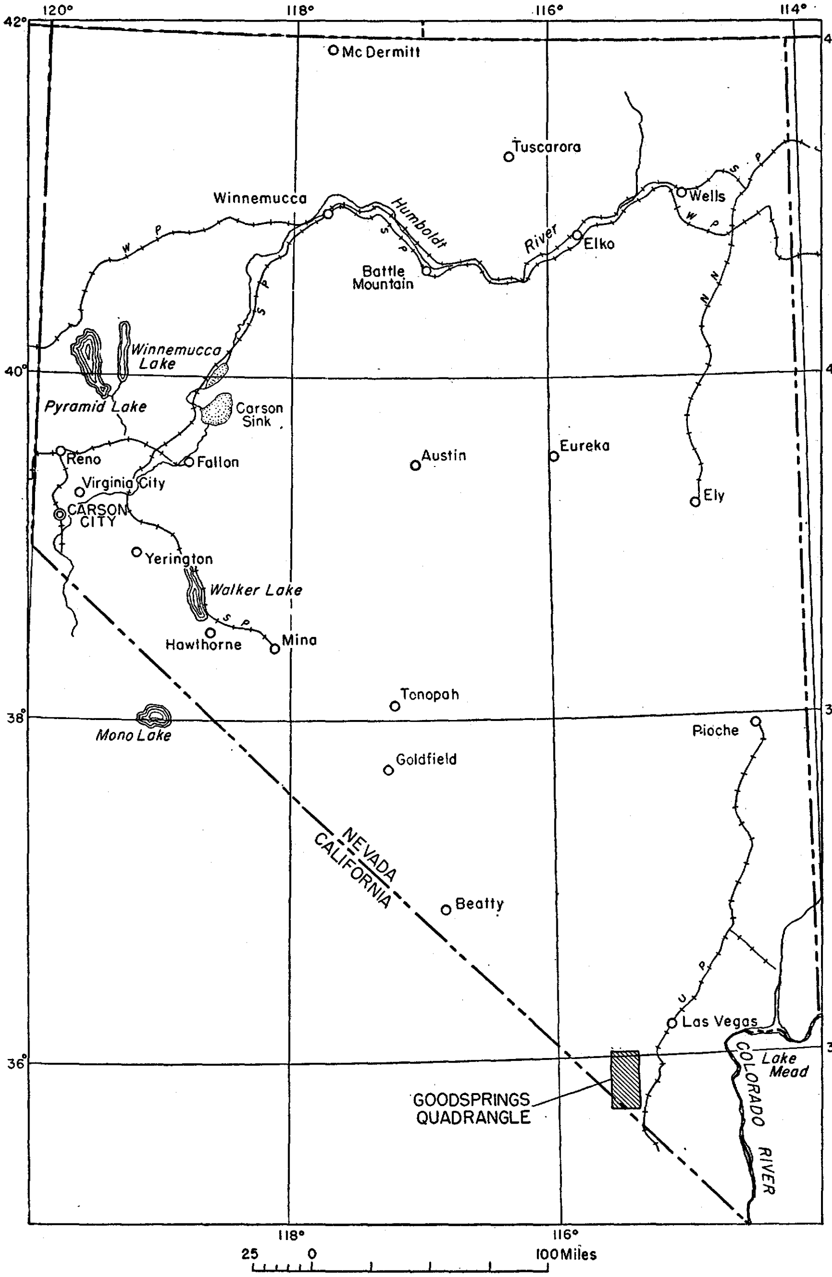

FIGURE 1.—Index map showing location of Goodsprings quadrangle, Nevada–California.

least one-fourth of the combined metal content is accounted for by reworking of materials mined or processed before 1928.

The fact that mining activity has largely coincided with emergency periods when the prices of metals were higher than average has largely been due to geographic location and character of the ore.

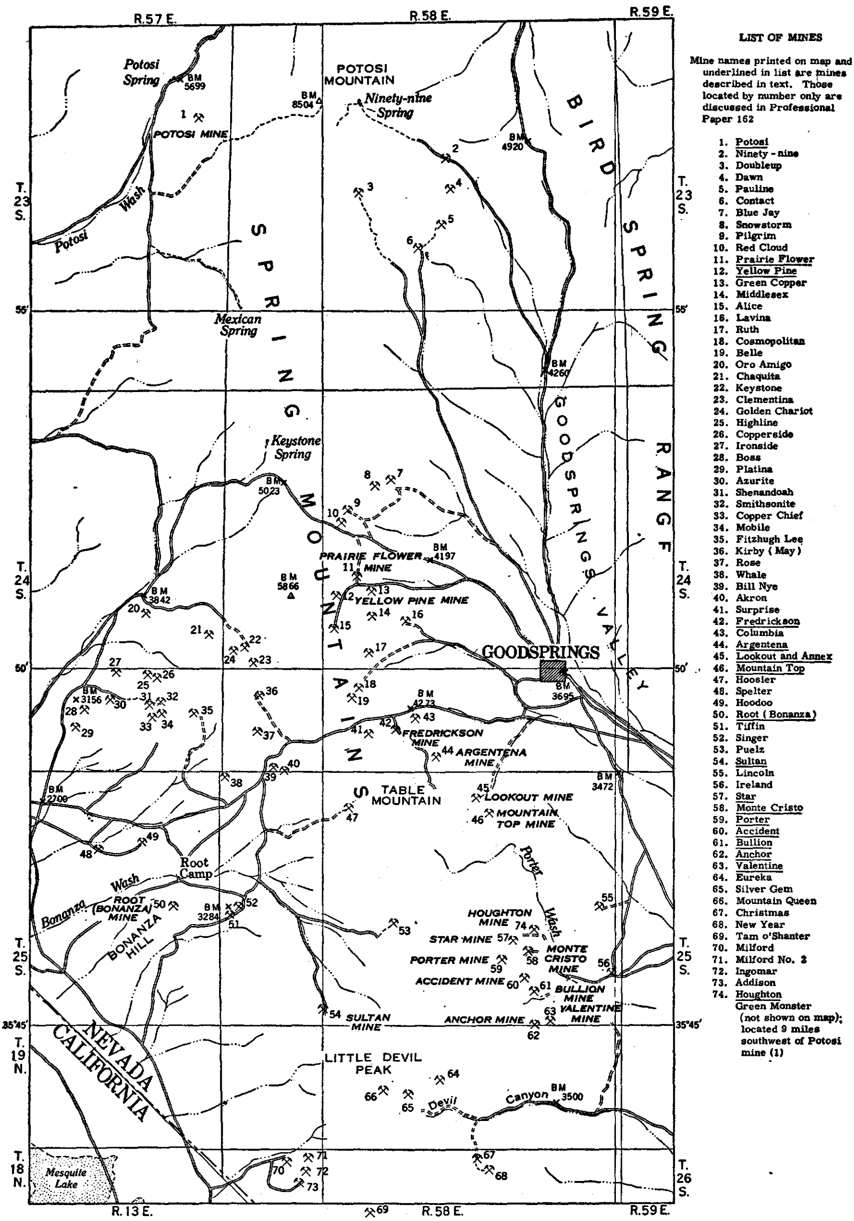

Figure 2.—Map showing location of the mines of the Goodsprings quadrangle, Nevada-California.

As the district is remote from the principal ore markets, shipping costs are relatively high. The zinc ore is mostly oxidized and is difficult to concentrate. In 1943, when plans had been laid for a Waelz-type plant at Jean, the specifications called for ore containing combined lead and zinc not less than 20 percent and with a lead-zinc ratio of not more than 1 to 5. Few mines could produce ore of this quality.

As the tonnage of new ore produced in 1943–44 was small compared with that mined in the past during similar periods of favorable economic conditions, as only one out of every four mines has been productive in recent months, and as reserves of 20 percent ore are limited, it would appear that the district is nearly exhausted. Allowance must be made for improved metallurgical processes that might encourage the mining of low-grade ore that is now discarded or ignored. Improved methods of concentrating the oxidized ore would also brighten the outlook. But the critical question is this: Are new ore bodies and new mines likely to be found?

On this question the operators as well as visiting engineers and geologists have expressed varied opinions. Some, observing the clean walls of stopes in which hardly a trace of ore remains, and marking the barren ground in lower workings of many mines, have concluded that the district is already exhausted. Others, noting that exploration has been mostly at the grassroots and nowhere extends more than 600 feet below the surface, are persuaded that there is hope for new ore and perhaps for new mines at depth. In some of the mines there are blocks of untested ground within the productive zones. Two such blocks at the Yellow Pine mine were tested by the U. S. Bureau of Mines in 1944, following recommendations by the Geological Survey, but the results were disappointing.

The economic aims of this report are to determine, first of all, whether it is necessary to conclude that the district is bottomed, and, if not, then what general procedures may be followed in the search for new deposits.

Field work began June 17, 1943 and ended September 30, 1945. Other commitments prevented any one of the four authors from remaining with the project from beginning to end, but the work was guided and coordinated through Geological Survey offices at Washington, D. C., and Salt Lake City, Utah.

During the first half of 1945 David A. Phoenix was a member of the field party, and it was largely due to his energy and enthusiasm that studies of the mines were completed on schedule. His name appears with the list of authors in several parts of this report.

D. F. Hewett of the U. S. Geological Survey contributed not only his voluminous notes on the Goodsprings quadrangle but also his unpublished data on the Ivanpah quadrangle, of which the Goodsprings area is a relatively small part. The party was allowed use

of a field office by the Coronado Copper and Zinc Co. Work was greatly facilitated by the generous cooperation of all the operators in the district, who gave free access to their mines as well as to their maps and records. E. E. Kinney, Superintendent at the Yellow Pine mine, was a partner in underground studies there and on the adjoining Prairie Flower property, and Fred Piehl gave generously of his time in helping with studies at the Argentena mine. The campaign of drilling at the Yellow Pine mine is pleasantly remembered for the many courtesies extended by R. W. Geehan, engineer in charge of the Bureau of Mines project.

Seventeen mines, including the five largest and a sampling of the smaller ones, were studied in detail and are described in this report. These properties have accounted for about 90 percent of the combined lead and zinc production.

Hewett has described at length the general geology as well as the principal characteristics of ore deposits in the Goodsprings district.[2] It is hoped that the reader has access to this comprehensive report and that the geologic and tectonic maps which accompany it are before him as he reads the introductory parts of this paper. Many phases of the geology, including the lithology of beds above and below the zone of lead-zinc occurrences, the broad problems of rock alteration related to dolomitization and silicification, the relationships between lead-zinc and other metalliferous deposits, and the mineralogy of the ore bodies, which are treated at length by Hewett, are only touched upon here. The following account of geologic history is largely condensed from his report.

REVIEW OF GEOLOGIC HISTORY

Pre-Pennsylvanian sedimentation.—As interpreted from rocks exposed in the district, the geologic record begins with deposition of limy muds near the beginning of the Paleozoic era. Although there were doubtless many pauses and interruptions in sedimentation, the floor of the sea was probably not widely exposed to subaerial erosion at any time between the Cambrian and the Pennsylvanian. During this interval, from 3,500 to 4,600 feet of stratified rock, predominantly limestone and dolomitic limestone, was laid down. This accumulation is seen now in the Goodsprings dolomite (Cambrian to Devonian), the Sultan limestone (Devonian) and the Monte Cristo limestone (Mississippian).

Late Mississippian or early Pennsylvanian interval of erosion.—With emergence of the area in the late Mississippian or early Pennsylvanian, the upper beds of the Monte Cristo were eroded to a surface of low relief. Valleys a hundred feet or more deep were locally cut in the limestone, and solution by circulating ground water opened

[2] Hewett, D. F., op. cit.

small caves and watercourses to depths a few tens of feet below the land surface.

Late Paleozoic and early Mesozoic sedimentation.—In time the area again subsided and what had been land became the floor of a shallow sea. Deposits of dark mud filled some of the hollows as well as caves extending downward from the bottoms and sides of depressions. Over most of the area, however, a blanket of sand and gravel from a few feet to 50 feet thick was deposited, sifting down into caves connecting with the higher ground and largely filling them. Subsequent deposits were mostly limy muds alternating with laminae of mud containing less lime. The record of this stage in the sedimentary history is preserved in some 2,500 feet of the Bird Spring (Pennsylvanian) formation, which is composed predominantly of thin limestone beds parted by seams of shale.

The area continued to receive sediments throughout the remainder of the Paleozoic and early part of the Mesozoic, and by the Jurassic, an additional 5,200 to 5,700 feet of rocks had been added. These were predominantly sandstone, shale, and conglomerate with subordinate amounts of limestone. In order from oldest to youngest the upper Paleozoic formations include the Supai formation and Kaibab limestone, and the Mesozoic formations include the Moenkopi formation, Shinarump conglomerate, Chinle formation, and Aztec sandstone.

Late Mesozoic or early Tertiary orogeny.—At some time between the Late Jurassic and the middle Tertiary, the rocks in the district were folded and faulted. The terrain was broken into imbricate blocks from 1½ to 3 miles thick by thrust faults that strike prevailingly north and dip westward at moderate angles. Displacements along these faults amount to between a mile and several miles. Within the thrust blocks the strata were bent into folds whose axes are generally parallel to the strikes of the thrusts. The folds are relatively broad and open in massive sequences but are more closely spaced in the thinly bedded sequences. Along the master thrusts, the bedding is locally overturned.

As thrusting progressed, high-angle tears and rifts developed within the imbricate blocks. Most of these faults trend northwest, but a considerable number trend northeast. Many of them bottom along the soles of thrusts, and thus were contemporaneous with the thrusts. Others displace the thrusts by relatively small amounts, and are younger, although all probably were formed during a single stage of deformation.

Within the imbricate blocks are minor thrusts, tears, and rifts showing the same relation on smaller scales as exhibited by the master faults of the district.

Magma was injected up and into the intricately broken sedimentary rocks to form dikes along high-angle faults and sills along low-angle faults or bedding. The most widespread type of igneous rock thus formed was a granite porphyry that crops out in scattered patches. There are in addition a few inconspicuous lamprophyre dikes. Although the igneous bodies were largely controlled by faults that must have been in existence before intrusion, there is clear evidence from several localities that the faulting continued until after the magma had consolidated. Dikes and sills are commonly sheared by minor thrusts and high-angle strike-slip faults similar in trend and pattern to faults in adjacent sedimentary rocks.

There followed a stage of hydrothermal activity. Mineralizing solutions, perhaps originating at the same sources as the magma, moved upward along the high-angle faults and spread laterally along bedding surfaces and through broken ground related to the faulting and folding. The most widespread effect of this activity was the conversion of large bodies of limestone to dolomite. Where the bedding surfaces are closely spaced and separated by seams of clay, the dolomitization is generally limited to broken zones related to bedding slip and faulting. Where the rock is more massive, or where obscure bedding surfaces are without partings of clay, the dolomite forms broader zones.

Hydrothermal solutions also produced notable effects in the alteration of igneous rock. The granite porphyry is locally changed almost completely to sericite and to clay of the montmorillonite group.

During or closely following this phase of hydrothermal activity, the solutions brought lead, zinc, and other metallic elements into the largely dolomitized zones of permeable ground. Galena and sphalerite locally filled interstices but in most places they appear to have replaced dolomite and to a lesser extent limestone. Although lead and zinc bodies have a wide stratigraphic range, extending from near the middle of the Bird Spring formation nearly to the base of the exposed Paleozoic section, the Monte Cristo limestone has yielded about 98 percent of the production.

Erosion during the late Mesozoic and early Tertiary.—The area had stood above sea level since the early Mesozoic, and deposition of terrestrial sediments was in progress at least until the middle of the era. Erosion has been in progress throughout most of subsequent geologic time. By mid-Tertiary time, the Mesozoic and late Paleozoic sediments had been stripped from most of the area, and the oldest rocks of the district as well as the intrusive igneous rocks that had solidified at depth showed at the surface in many places.

Mid-Tertiary volcanism.—In the middle of the Tertiary, possibly during the Miocene, there was volcanic activity that included deposition of tuff and outpouring of lava to form layers of latite, andesite, rhyolite, and basalt. The mountain valleys were filled partly or entirely with these materials. After the volcanics had been deposited they were locally broken by normal faults, although it is impossible to say just when the faulting began or when it ended. Observed displacements are of the order of a few feet or a few tens of feet, and the faulting apparently has been mostly along the lines of high-angle rifts and tears formed during the earlier stage of deformation.

Late Tertiary and Quaternary erosion.—From late Tertiary time until the present the area has been characterized by erosion in the uplands and deposition of wash in the valleys and intermontane basins. The volcanic rocks have been largely stripped away from the Spring Mountains, and in the course of denudation the present rugged topography of the uplands has been carved by streams.

Since the time of their formation the lead and zinc bodies have been oxidized, and the sulfides largely converted to carbonates or silicates.

FAULTS

Faults are numerous in the Goodsprings district and are integrated to form curious patterns, as is shown by the maps of this report. Thrusts, tears, and rifts are the major lineaments. Of the thrusts the Keystone [3] is the most conspicuous and perhaps the most persistent, as it has been mapped not only along the length of the Goodsprings quadrangle, but is known to continue for several miles north and south. The two largest mines in the district lie in the block below this thrust, and the other mines described in this report lie in the overlying block. The other persistent thrusts above and below the Keystone divide the terrain into imbricate slices from 1½ to 3 miles thick.

The master rifts and tears belong to two principal systems. The more conspicuous of these includes faults that trend northwest, and the other includes faults that trend northeast. There is evidence that some of the faults of both systems are limited to one or another of the imbricate thrust blocks. Thus the Fredrickson is a rift of the northwest system in the hanging-wall block of the Keystone thrust, and the Ironside is a northeasterly tear in the same block. Other high-angle faults cross and displace the thrusts, but commonly the displacement on one side of a thrust greatly exceeds that on the other. For example, the stratigraphic throw along the Cottonwood fault, a member of the northwest system, is more than 1 mile in the footwall block of the Keystone thrust, whereas the displacement of the Keystone thrust is only about 40 feet. It is fair to conclude in such cases that the high-angle faults originated as tears within thrust blocks, and that the rupture of the thrust faults was a later and relatively insignificant development. Excluding such minor adjustments that may have occurred later than the Miocene and hence long after the main orogeny in the district, it is apparent that the broad tectonic pattern is one in

[3] Hewett, D. F., op. cit., pls. 1, 11.

which imbricate thrust blocks are subdivided into additional blocks by large rifts and tears spaced at intervals of a few miles. Although it is not claimed that the principal thrusts, rifts, and tears in the district originated simultaneously, all evidence points to the conclusion that they developed during a single orogeny, and are in this sense contemporaneous.

Conspicuous breccia reefs and zones of strongly sheared ground mark the traces of the principal high- and low-angle faults. Within the brecciated ground there are commonly many shears which on fresh exposure show as distinct surfaces, smooth except for striations. Orientation of striae indicates predominant strike-slip movement on most of the high-angle shears in zones of rifting and tearing, and dip-slip movement on most of the low-angle shears in zones of thrusting.

In the following paragraphs are treated special aspects of faulting that bear on the problems of ore deposition.

LINKAGE OF HIGH-ANGLE FAULTS

Perhaps the rarest structural feature in the Goodsprings district is the offset of one high-angle fault by another—this in spite of the fact that high-angle faults are commonly so closely spaced that it is impossible to map all of them on a scale of an inch to 50 feet. Faults or fault zones of different strikes generally link or join without offset (pl. 1). Where the faults are closely spaced and have the same general trend, the pattern resembles the complexly anastomosing channels in an aggrading stream. Good examples are at the Argentena and Sultan mines (pls. 16 and 20). Where there are fault zones with average strikes differing by 45° to 90°, the pattern is commonly that of an open network designated in this report as a reticulate pattern. Good examples can be seen in the southern part of the 700 level at the Yellow Pine mine (pl. 7) and in parts of the Potosi mine (southeastern workings of 1,042 level, pl. 11).

What is true for individual mine areas is also true for the district as a whole. Hewett's tectonic map shows that if the thrust faults with dip-slip movement are excluded, the remaining pattern is a combination of anastomosing and reticulate elements.

INTERRELATIONSHIP OF RIFTS, TEARS, AND THRUSTS

Within the larger blocks bounded by the master faults—including thrusts, rifts, and tears—are innumerable smaller blocks bounded by subsidiary faults of all three classes. Thus the Potosi mine area is within the block between the large Contact and Keystone thrust faults, along each of which the dip-slip component of movement amounts to several miles. The terrain is further subdivided into imbricate blocks by thrusts spaced at intervals of several hundred feet, along which the slip ranges from a few tens to several hundreds of feet. The footwall block in the most conspicuous of these thrusts is still further divided into imbricate blocks by smaller thrusts spaced at intervals of a few feet to a few tens of feet. In the center of the mine area these smallest thrust plates are further subdivided by rifts and tears. In plan such a pattern of faulting is generally reticulate, and right-angle junctions between high and low-angle faults are common.

In the same areas where the ground is largely subdivided by linked high- and low-angle faults, there are also rifts and tears that are not confined to a single thrust block but which cut across the thrusts and displace them. Thus in the Yellow Pine-Prairie Flower area there are separate sets in the hanging-wall and footwall blocks of the Potosi thrust (followed by a sill of granite porphyry), yet in the footwall block there are subsidiary thrusts dipping with the Potosi and displaced by certain tears and rifts in the hanging-wall block. The subsidiary thrusts are older than the high-angle faults in question, but the latter probably developed along with the Potosi thrust. To emphasize the differences in age which are hereby implied would tend to conceal the more significant fact that all these faults originated during a single stage of folding and faulting.

CURVED FAULT SURFACES

Fault surfaces are rarely planes, but the curvature along many faults in the Spring Mountains is unusual. Differences in angle of fault dip commonly are as much as 40° in distances of only a few tens of feet along the fault. This variation is seen along high-angle and low-angle faults alike and is a common source of difficulty in correlating from one mine level to the next. No less impressive is the curvature of strike lines along some faults. Plate 8 shows that the trace of the principal thrust in the Potosi mine is sinuous, the strike locally changing by as much as 70° within short distances. The more persistent thrusts in the Anchor mine are broadly arcuate in plan and undulatory in cross section (pls. 12, 14), and the *R* thrust in the Yellow Pine mine shows irregularities of the same sort (pls. 4, 5, 6). On a broader scale the trace of the large Keystone thrust is remarkably sinuous, almost semicircular over the central and northern parts of the Goodsprings quadrangle.

Many of the high-angle faults in the district also have broadly arcuate traces. This is true for most of the persistent examples in the Anchor area (pl. 12). Pronounced fault arcs characterize the Yellow Pine-Prairie Flower area. The strongest rift zone in the Yellow Pine mine (K, K_1 and K_2 faults on pl. 6) changes average strike by 60° to 80° along a curve with radius of 400 to 700 feet, and there are several similar faults nearby with similar degrees of curvature (K_3, Alice fault, and fault at Copper Glance mine, pl. 4).

STRUCTURAL UNCONFORMITIES

The contact between the Bird Spring and Monte Cristo formations is of first importance from a structural as well as a stratigraphic point of view. It marks the dividing line between relatively massive beds of limestone and dolomite below and relatively thin-bedded strata above. During folding and thrusting, stresses operating in the Bird Spring were commonly relieved by warping attended by gliding along the closely spaced bedding, a process facilitated by the common presence of shaly partings. By contrast, the Yellowpine member of the Monte Cristo limestone, which underlies the Bird Spring at most places, is massive throughout thick zones, and shaly partings such as might facilitate shearing are rare. As a consequence, the Yellowpine has yielded to stress largely by fracturing and faulting. Thus, generally, the Yellowpine is conspicuously more broken than the Bird Spring, and the contact between the two is a structural as well as a stratigraphic unconformity. Master faults cross this line and break the beds above and below it, but there are many more subsidiary tears, rifts, and thrusts in the upper Yellowpine than in the lower Bird Spring. This phenomenon is described further in the sections on the Fredrickson, Root, and Argentena mines.

A similar but less imposing structural unconformity is related to the Arrowhead member, a thin unit of shaly limestone sandwiched between the thicker and more massive Yellowpine and Bullion members of the Monte Cristo limestone. In many places it is clear that much of the differential movement attending folding in this part of the section has been localized by bedding shears in the Arrowhead. In the Green Monster area the upper and lower contacts of this unit are followed by shears along which several minor tears terminate and from which several minor thrusts branch.

CHARACTER AND FORM OF ORE BODIES

The primary ore minerals were mainly galena and sphalerite. At most places the sphalerite has been converted by oxidation to hydrozincite and calamine. Galena generally remains as scattered pods and lentils in the oxidized ore, but locally it has been changed to cerussite or less commonly to anglesite. Chalcopyrite that was originally present in a few deposits has been largely altered to carbonate and silicate minerals.

There are a few ore bodies that contain zinc but no lead, and a few others that contain lead but no zinc. Average ore contains both lead and zinc in proportions between 1:2 and 1:4. Crude ore has averaged from 15 to 40 percent combined metals, with a few ounces of silver to the ton of ore.

Even where the sphalerite has disappeared by oxidation, the common association of galena with the zinc carbonate and silicate indicates that the oxidation of primary ore bodies was largely in place. Only locally has there been migration of secondary zinc compounds to distances of a few tens of feet away from the primary bodies of ore.

In places it is clear that the sulfides filled voids and cavities from a few inches to several feet across. As a rule, however, the primary ore apparently has replaced the country rock along and adjacent to zones of fracturing and shearing. Dolomite was the common host, but limestone was replaced along the margins of several of the larger ore bodies.

Where the bedding is flat, the ore body is generally tabular and parallel with the bedding. Where the bedding is inclined at moderate or steep angles, the ore body is generally in flattish pipes from a few tens of feet to a thousand feet long and with cross-sectional areas ranging from 100 to 3,500 square feet. Many of the pipes are flattened in the plane of the bedding, others cut across bedding at low angles, and a few bodies follow fissures that cut across bedding at high angles. The axes of the pipes are linear, curved, or sinuous and there is no regularity in their orientation with respect to the directions of dip and strike of associated bedding surfaces.

GEOLOGIC CONTROLS OF ORE DEPOSITS

POSITION OF MINES IN THE TECTONIC FRAMEWORK

Recent mapping on aerial photographs of the southeastern part of the Goodsprings district has shown that the Anchor, Valentine, Bullion, Accident, Monte Cristo, Porter, Houghton, Star, Mountain Top, Lookout, Argentena, and Fredrickson mines are all within a northwesterly belt of pronounced shearing which may be designated as the Fredrickson rift zone, after the principal fault already named by Hewett from exposures on the east of Table Mountain (pl. 1). This is almost exclusively a lead-zinc belt, although at the extreme northern end, where the faults pass into bedding shears along Columbia Pass, there is a copper property, the Columbia mine.

Similarly, the high-angle fault zone that passes through the Sultan mine area and trends parallel with the Fredrickson zone also marks a belt in which only lead-zinc mines or prospects are known. The Puelz mine, a lead-zinc property, is the only mine of consequence between the Sultan and Fredrickson belts of rifting, and it too is along a northwesterly rift, the Puelz fault.

As the Fredrickson rift zone marks a belt of predominant lead-zinc mineralization, so does the Ironside tear zone mark a belt of copper mineralization. The Ironside fault trends northeast and hence almost at right angles to the trend of the three rift zones noted above.

There is also a spatial coincidence between zones of thrusting and zones of mineralization. Thus the Potosi mine must be regarded as in the outer zone of Keystone thrusting, for the overturning of beds related to drag along this fault is apparent at the portals of the mine, even though the sole of the thrust probably lay several hundred feet above. Nearly all the gold produced in the district has come from a group of properties along this same thrust several miles south of the Potosi mine. The Yellow Pine and Lavina mines are in the zones of thrusting along the Potosi and Contact thrusts respectively, and the Green Monster is in a similar zone related to a large thrust as yet unnamed.

No further evidence is required to demonstrate that the mines are almost without exception associated with persistent fault lines. What is true for the mines holds also for the three largest outcropping bodies of granite porphyry in the district. The largest of these is intruded along the Potosi thrust and its related tears and rifts. The second largest body is along the Keystone thrust in the area of the two most productive gold properties, and the third is along the south end of the Contact thrust in the area of the Lavina mine.

There is a peculiarity in the fault pattern that may in part explain the concentration of mines in what might be termed the heart of the district. In the southern part of the Goodsprings quadrangle, the structural pattern as defined by the trends of high-angle faults is prevailingly northwest. The same is true for the northern part of the district. In between there is an area in which the fault pattern tends to be reticulate, by the presence of lineaments trending both northeast and northwest. Northeast tears are most common and locally they are predominant, but there are also many northwest-trending rifts. The approximate northern boundary of this area runs from the Lavina mine on the east through the Yellow Pine mine area and westward to the southern junction of the Ironside and Keystone faults. The southeast side runs from the Lavina mine southwest through Singer Wash on the south side of Bonanza Hill. From this area, which is a relatively small part of what is generally called the Goodsprings or Yellow Pine district, has come more than 60 percent of the combined lead and zinc and nearly all the gold. Copper is more widely distributed than at any other place in the camp, and there is some platinum along the Ironside fault. This is also the area of the larger porphyry intrusives. Elsewhere in the district the folds are generally alined toward the north; here they trend prevailingly east-west and are unusually sharp. The causes of the structures are not known, but the net result of deformation is quite clear; the heart of the Goodsprings mining district is the area within which the major faults tend to make a reticulate pattern.

POSITION OF MINES IN THE STRATIGRAPHIC COLUMN

Hewett (1931) has shown [4] that the lead-zinc ore has a narrow stratigraphic range and is with slight exceptions limited to the Monte Cristo limestone (pl. 2). Scattered deposits in the lower part of the Bird Spring and at horizons below the Monte Cristo account for less than 3 percent of the combined lead and zinc production.

Within the Monte Cristo the ore has come mostly from the Yellowpine member. Although the maximum thickness of the Yellowpine is only 140 feet—hardly more than 1 percent of the 11,000 to 12,000 feet of sedimentary rock in existence before mineralization—about 85 percent of the combined lead and zinc has come from it. The Anchor member has accounted for additional 10 percent. There are a few mines in the Bullion member, and at the two largest the upper part of the Bullion, together with the Arrowhead, is locally mineralized around ore bodies that lie chiefly in the Yellowpine member. Of the five members of the Monte Cristo, the Dawn is the only one that has not produced.

In explaining the localization of ore in this narrow stratigraphic zone, Hewett has noted that the Monte Cristo, above the top of the Dawn, is relatively more massive than the beds above or below. During folding and faulting these massive beds have been extensively and intensively fractured, whereas thin-bedded sequences above and below have more commonly folded and slipped along the bedding, taking on new shapes by rock flowage but remaining relatively intact in the process. Thus the Monte Cristo by virtue of its generally broken character was highly permeable and allowed free ingress of mineralizing solutions. One qualification should perhaps be added. There are places where the Yellowpine member has remained relatively intact, and in several such areas it is the local thinly bedded facies rather than the typical massive rock that is favorable for ore. But again permeability, provided by openings along bedding surfaces, apparently has been the controlling factor.

POSITION OF ORE BODIES WITHIN MINE AREAS

From the preceding paragraphs it is evident that the lead-zinc mines are not only confined to a narrow stratigraphic zone but are also mostly confined to those parts of the favorable zone that are cut by conspicuous faults or fault zones. However, there are many more conspicuous high-angle faults in the district that are barren than there are faults associated with ore. It is furthermore true that within many fault zones the master shears along which the greatest displacements have occurred are barren, whereas subsidiary shears along

[4] Hewett, D. F., op. cit., p. 95–96.

which the displacement is small are mineralized. A further peculiarity is that the ore bodies rarely lie along high-angle faults except for short distances. Commonly the long axes of the ore bodies trend at right angles with the strike of associated high-angle faults, and several such ore bodies have their lower terminations either within fault zones or on single high-angle faults that continue downward beyond the foot of the ore shoot.

It is therefore not surprising that much effort has been given to searching for faulted continuations of ore bodies that end downward or laterally against fault walls or within fault zones. Exploration of this sort has been generally fruitless except where it has led to the discovery of new ore bodies in territory that might not otherwise have been tested. Hewett's [5] examination led him to believe that mineralizing solutions responsible for the ore have risen along the high-angle faults and spread into favorable stratigraphic zones following bedding and thrust breccias. Evidence for feeding along high-angle faults was found in local concentrations of galena in the fault breccia and in the fact that rock along some faults is dolomitized whereas the same rock at distances from the faults is unaltered. There was also the empirical evidence from several places and notably in the Yellow Pine mine that thorough exploration has failed to locate faulted extensions.

Even so, some geologists maintain that the conspicuous faults in the mines are younger than the ore, and that many faulted extensions of ore bodies therefore await discovery. As the arguments for and against these competing hypotheses depend on detailed evidence, they are reserved for discussion in the section on the Yellowpine-Prairie Flower area, but the conclusions reached by the writers from their own investigations are summarized below.

The pattern of high-angle and low-angle faulting in the district is premineralization, and subsequent postmineralization movement has been negligible for the mines considered. Conduits along which mineralizing solutions rose were openings along high-angle faults and joints, but generally the feeding channels were localized along relatively short segments of fissures or groups of fissures. The feeding segments were localized where shears of different trends converge and link without offset, or where strike-slip movement on an arcuate fault opened fissures along parts of the arc, possibly along those parts with relatively small radii of curvature. In some places the breccia along the feeding fissures themselves was replaced by sulfides to form ore bodies. More commonly the ore formed marginal to the fissures in ground that was permeable because it was broken, or because it con-

[5] Hewett, D. F., op. cit., p. 101–102.

tained openings along bedding surfaces, or open watercourses and small caves, or sandy filling in old watercourses and caves. The simpler types of ore deposits known to the writers are tentatively classified below according to the factor of permeability in the favorable ground.

A. Permeability of favorable ground largely primary and due to openings between surfaces of bedding. (Example: Lower part of Discovery run at Yellow Pine mine.)

B. Permeability of ground largely secondary and related to:

1. Openings dissolved by ground water circulating during Monte Cristo and Bird Spring interval of erosion. (Example: Ore bodies of Accident mine.)
2. Openings produced mechanically by breaking of rocks due mainly to:
    a. Shearing along bedding and minor thrusts; effects largely localized in relatively massive rock either
        (1) Overlain by relatively thin-bedded rock. (Example: Green Monster mine.)
        (2) Interbedded with relatively thin-bedded rock. (Example: Bullion mine.)
    b. Faulting and jointing in and along flexures. (Examples: Ore body 709 at Yellow Pine mine; ore body *B* at Root mine.)
    c. Rifting and tearing. (Example: Ore bodies of Sultan mine.)

The examples used to illustrate this classification include bodies small or intermediate in size. Productive ground was generally made permeable by a combination of factors. Thus the favorable ground at the Argentena mine was prepared in part by shearing along the structural unconformity at the base of the Bird Spring and in part by rifting and tearing of the Yellowpine member below the unconformity. The deposits might be classified as $2a_1.2c$. By grouping the categories in this way a number of additional small to intermediate bodies could be classified.

However, neither this nor any other simple scheme based solely on the permeability of the favorable ground could be wholly satisfactory when the largest ore bodies are considered. In the two principal mines there was not only juxtaposition of conduits and permeable ground, but there were also highly unfavorable conditions for upward migration of mineralizing solutions above the favorable zones. At the Yellow Pine a thick sill of altered granite porphyry capped the productive zone; at the Potosi there were impermeable barriers or baffles in the form of a blanket of black shale and several persistent thrust walls layered with clay gouge.

In advance of detailed descriptions, the maps and sections on plate 3 will serve to illustrate as well as summarize the several geologic factors believed to have influenced ore deposition.

YELLOW PINE AND PRAIRIE FLOWER MINES

By Claude C. Albritton, Jr., and John A. Reinemund

GENERAL FEATURES

The Yellow Pine and Prairie Flower properties are in Porphyry Gulch about 3.5 miles northwest of Goodsprings, and are connected with the town by a graveled road. Topography of the mine area is shown on plate 4.

Originally developed as separate mines, the underground workings are now connected, and for some years both have been controlled by the Yellow Pine Mining Co. As little work has been done in the Prairie Flower since the mine was mapped and described by Hewett,[6] this report deals mainly with the Yellow Pine, where considerable exploratory work and mining operations have been carried out in recent years.

Hewett's history of mining in this area covers developments beginning with location of the first claims in 1892 and continues through the interval 1911–28 during which time the mine was most productive. With decline in price of metals, the Yellow Pine Mining Co. ceased operations in 1931 and the mine lay idle for 2 years. The U. S. Smelting, Refining, and Mining Exploration Co. took lease and option from the Yellow Pine Co. in 1934, resuming operations that have continued intermittently until the present, though under different managements. In 1936 the lease passed to C. K. Barns, and in February 1939, the property was taken under lease and option by Harold Jarman. From May until December, 1942, Basil Prescott held the property under lease from Jarman. From September, 1942, to January, 1943, 64 core-drill holes having a total length of 5,161 feet were drilled by the U. S. Bureau of Mines. In December, 1942, the lease and option passed to the Coronado Copper and Zinc Co., which continued operations until the spring of 1949. In 1944, the Bureau of Mines carried out a second exploration project, drilling 35 core-drill holes with a total length of 5,113 feet.[7]

In spite of recent extensive exploration based on repeated examinations by geologists and engineers, the production at the Yellow Pine has not maintained the level reached during early years of mining, and no large ore bodies have been discovered since 1922.

SEDIMENTARY ROCKS

Characteristics of rock units mapped in the area are summarized in the following columnar section:

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[6] Hewett, D. F., op. cit., p. 127–129.

[7] Data on history of developments from E. E. Kinney. Results of core-drilling, *in* Geehan, R. W., and Benson, W. T., 1949, Investigations of the Yellow Pine zinc-lead mine, Clark County, Nevada: U. S. Bur. Mines Rept. Inv. 4613.

Age	Formation	Member	Character	Thickness (feet)
Recent.	Alluvium (Qal).		Clay, unconsolidated sandy; sand, and gravel of local origin. Fills channels in older rocks.	0–50
	Unconformity.			
Pleistocene.	Later gravel (Qlg).		Gravel, indurated coarse, containing boulders of limestone, dolomite, sandstone, quartzite, and granite porphyry as much as 2½ feet across. Fills channels in older rocks.	0–100
	Unconformity.			
Pennsylvanian.	Bird Spring formation (Cbs).		Limestone, gray, and dolomite, generally bedded in units from a few inches to a few feet thick, but with local massive layers as much as 60 feet thick. Basal beds generally buff sandstone or quartzite, locally grading into black shale. Nodular chert common in calcareous beds.	[1] 750+
	Unconformity.			
Mississippian.	Monte Cristo limestone.	Yellowpine limestone (Cy).	Limestone, gray and dolomite, prevailingly massive, but containing local thinly bedded sequences from 2 to 20 feet thick within which beds are from a few inches to 2 feet thick.	[2] 70–140
		Arrowhead limestone (Ca).	Limestone, dense, or dolomite in layers averaging 2 inches thick parted by seams of clay.	10
		Bullion dolomite (Cb).	Dolomite, gray, inconspicuously bedded in most places; locally thinly bedded in layers a few inches thick. Upper 20 feet thinly bedded in most places. Lentils of dark gray chert scattered throughout, but most abundant in upper 20 feet.	300
		Anchor limestone: Upper beds of Anchor (Cau).	Limestone, light-gray and dolomite in layers from a few inches to several feet thick. Lentils of light-gray or tan chert abundant.	125
		Anchor limestone: Lower beds of Anchor (Cal).	Limestone, gray to black, and dolomite with scattered lentils of dark-gray chert. Bedded in layers from 1 to 10 feet thick.	270
		Dawn limestone (Cd).	Limestone, gray, and dolomite bedded in layers averaging a foot thick.	40
Devonian.	Sultan limestone.	Crystal Pass limestone (Dsc).	Limestone, laminated light-gray.	150+
		Main part of Sultan limestone.	Limestone, dark-gray, and dolomite, locally laminated.	(?) [3]

[1] Total thickness 2,500 feet; lower 750 feet exposed in area mapped.
[2] Variable due to unconformity above.
[3] Base not exposed.

STRUCTURE

PORPHYRY GULCH ANTICLINE

The mines are in the northwest limb of the southwesterly plunging Porphyry Gulch anticline. The areal map (pl. 4) covers only a small part of this fold; most of the area shown is on the northwestern limb. The southeastern limb shows only in the northeast, most clearly along Lavina Ridge. (See also section *I–I*, pl. 5.) At the southern end of the area on Flat Top and near Alice Tunnel incline, the rocks strike northwest and dip southwest with the plunge of the broad anticlinal nose.

In the Yellow Pine and Prairie Flower mines the beds of the Monte Cristo strike prevailingly between north-northeast and northeast, and dip northwest at angles from 30° to 60°. Disregarding local variations in attitude of bedding around faults and minor flexures, there is a progressive steepening of the dip from southwest to northeast, accompanied by a change in strike from north-northeast to northeast in that same direction. Thus at the southwest end of the Yellow Pine mine the beds strike from N. 15° E. to N. 25° E., and the dip averages 35°. At the northeast end of the Prairie Flower workings the strike is from N. 55° E. to N. 65° E., and the dip is from 55° to 60° (pl. 6).

FAULTS

The northwestern limb of the Porphyry Gulch anticline is broken by many faults that make a complex pattern. The master faults, as well as most of the subsidiary shears, are classified as thrusts, tears, or rifts.

Thrusts.—Principal examples are the Copper Glance, Bedelia, *R*, and Potosi thrusts. These strike generally north and dip west.

Along the line of section *I–I′* (pl. 5), the Copper Glance thrust is a bedding fault in the western limb of the anticline. In the arch of the fold, however, it cuts across bedding so that older rocks of the lower part of the Anchor (Cal) have been moved onto overturned younger rocks of the upper part of the Anchor (Cau). A few hundred feet to the north, the Bullion dolomite member is beneath the thrust.

Section *I–I′* also shows the Bedelia thrust as a bedding fault in the lower part of the Bullion, although by projection it cuts across bedding to the north where presumably the younger beds of the Bullion have been thrust over older beds of the Anchor.

The *R* thrust is in the Arrowhead member along the greater length of its outcrop, although underground it breaks into the overlying Yellowpine member (secs. *CC′*, *EE′*, *HH′*). North of Como dike it cuts across the bedding on the outcrop so that the younger beds of the Yellowpine member rest on older beds of the Bullion member.

The sill of granite porphyry west of the Yellow Pine and Prairie Flower mines lies along a thrust, which from all evidence was essentially a bedding fault near the base of the Bird Spring formation. This is regarded as the southern continuation of the Potosi thrust, mapped farther to the north by Hewett.[8]

Stratigraphic displacement along the Copper Glance and Bedelia thrusts decreases from north to south. Both faults terminate southward against tears, and neither extends into the southern half of the mapped area (pl. 4). The *R* thrust loses its identity in the southern part of the Yellow Pine mine where it passes into bedding shears. There is no evidence to suggest that the Potosi thrust extends south of the map area; presumably this fault also passes into bedding shears south of Capitano Gulch. East of the area mapped, the Contact thrust, a master fault in the Goodsprings district, has its southern termination about a mile to the east of the Alice Tunnel incline. About 1 mile west of the incline, the Wilson thrust, another persistent fault, terminates. The Yellow Pine-Prairie Flower area is thus within a transverse zone along which a number of thrust faults terminate at the south either by ending against high-angle faults or by passing into bedding shears.

Tears.—The tears are high-angle faults striking between north and west. Principal examples showing on the surface are the Capitano, Scorpion, Vertical Shaft, Prairie Flower, and Como faults.

The Capitano and Scorpion faults are tears in the hanging wall of the Potosi thrust. Maximum horizontal separation of the Bird Spring formation ranges from 250 to 300 feet along the strike of each fault. Neither fault continues downward through the porphyry sill and into the mine workings.

The Vertical Shaft and Prairie Flower dikes follow tears at the south and north ends respectively of the Bedelia thrust. Between these tears, the thrust block moved relatively toward the southeast from 100 to 300 feet. Both tears are in the footwall of the Potosi thrust, and their displacements can be measured in the mine workings below the porphyry sill.

The Como dike follows a tear that has produced an offset in the bedding ranging from a few feet to a hundred feet. Similar tears in the footwall of the Potosi thrust, which are conspicuous underground but which do not apparently persist to the surface, include the *L*, *M*, *O*, and possibly the *P* faults (pl. 6).

With the exception of the Prairie Flower and *P* faults, all the larger and most of the subsidiary tears have displaced the northeast side to the southeast. Many of the faults of this group are vertical; the others dip at high angles either toward the northeast or southwest, although the northeast-dipping faults appear to be the more numerous.

[8] Hewett, D. F., op. cit., pl. 1.

Rifts.—Principal faults of this group include the Alice (followed by the Alice dike); the K_3, the K_2, and K_1, that merge at depth to form a single fault; and the X–Y zone. Toward the south the Alice, K_3, K_2, and K_1 faults strike between north and northeast; northward the strikes arc toward the west and lie in the northwest quadrant. In places the fault surfaces are vertical; elsewhere they dip eastward at angles of 60° or more. Displacements are normal, but where slickensides are preserved they are inclined prevailingly less than 45° with the horizontal, indicating that the strike-slip component of movement may have been greater than the dip-slip component.

The Alice fault continues south of the map area and has been crossed at several places by workings connecting with the Alice Tunnel incline. In such places the slickensides are within 20° of the horizontal. Partly on this evidence Hewett concluded that the Alice fault is one of a group of faults along which the eastern blocks have moved northward with respect to the western blocks.[9] By contrast most of the rifts west of the Alice show displacement in the opposite direction.

The K_1, and K_2 faults are crossed on the 200, 300, 700, and 900 levels in the central part of the Yellow Pine mine. Between the 700 and 900 levels they join to form the K fault. The change in strike of this zone between the 200 and 900 levels is from 60° to 80°, and is distributed along an arc concave toward the west, with radius of curvature ranging from 400 to 700 feet. The existence of this pronounced arc could hardly have been inferred from the surface geology, although similar but less conspicuous curvatures are seen along the Alice and K_3 faults.

In the southern part of the Yellow Pine mine the workings between the 300 and 900 levels cross a conspicuous rift zone bordered on the west by the Y fault and on the east by the X zone (of which the Strike fault is considered a member). The X–Y belt of faults has a maximum exposed width of 170 feet on the south 600 level. In most individual shears the strike ranges from N. 10° W. to N. 30° E., generally intersecting the strike of bedding at angles less than 25° and locally striking with the bedding. The trace of the Y fault is broadly concave toward the west, but the opposite edge of the belt is concave toward the east. Slickensides are commonly within a few degrees of horizontal. Despite the generally broken character of the ground and the fact that many of the faults form impressive surfaces in the mine workings, the greatest observed horizontal separation of bedding along any fault in the group was only 16 feet (Y fault, 900 level). However, considering the over-all parallelism between fault strike and bedding strike, and the nearly horizontal movement along the

[9] Hewett, D. F., op. cit., p. 138–139.

faults, the aggregate displacement of the entire zone may be considerable.

Between the K_1 and X–Y zones are a number of conspicuous high-angle faults that are persistent in the mine but which are not recognized on the surface. These are designated on plate 6 by the letters *A*, *B*, *E*, *G*, *H*, and *S*. They dip east to northeast at angles generally greater than 55°. Striations are inclined generally less than 30° with the horizontal. Horizontal separation does not exceed 60 feet along any fault in the group. These faults are evidently related in origin with the rifts, which they resemble in direction of dip and in direction of offset. The *A* and *B* faults join the Strike fault without offset; presumably the same relationship holds for the *E* fault and the Strike fault. The *G*, *H*, and *S* faults are arcuate in plan and are concentric with the arc of the K_1 fault; along the 200-foot level they merge to form a meridional zone of rifting about 60 feet across.

FLEXURES

Minor flexures are superimposed on the western limb of the Porphyry Gulch anticline. These are inconspicuous structures that can be defined only where the positions of stratigraphic markers are known from drill cores as well as from exposures on the surface and underground. Between the *E* and Vertical Shaft faults the data are adequate for contouring the Yellowpine and Arrowhead contact, and the positions of flexures influencing this contact can be determined with reasonable accuracy. The significance of these minor flexures is discussed in the section on ore deposits (pp. 32–34).

GRANITE PORPHYRY

The Paleozoic rocks of the area are intruded by granite porphyry. Where unaltered, this rock is remarkable for the abundance and perfection of orthoclase phenocrysts commonly from a quarter to half an inch long in a groundmass largely of microcrystalline feldspar. Quartz commonly forms rounded particles, locally comparable in size with the feldspar phenocrysts.

A sill-like body (Yellow Pine sill) ranging in thickness from 400 to 800 feet has been intruded into the basal Bird Spring and upper beds of the Monte Cristo along the eastern foothills of Shenandoah Mountain. At the south end of the area the porphyry outcrop extends eastward around part of the anticlinical nose and joins the Alice dike. The dike in turn connects across the crest of Rover Hill with irregular sill-like bodies cropping out along Middlesex Wash and to the south. Other dikes connecting with the Yellow Pine sill follow faults in the hanging wall of the sill (Pocahontas dike) and in the footwall (Como, Vertical Shaft, and Prairie Flower dikes). Walls are sharply defined and are characterized by angular irregularities related to joints and subsidiary fractures. The Como and Vertical Shaft dikes end southeastward at faults. Beneath the alluvium of Porphyry Gulch the Prairie Flower dike presumably tapers to an end as a wedge along the Bedelia thrust.

The base of the Yellow Pine sill is exposed underground in a number of places. Northeast of the Vertical Shaft fault the sill clearly cuts across bedding, in some places bottoming within the Bird Spring, elsewhere within the Yellowpine. Along the lines of sections *J–J′* and *K–K′* (pl. 5) the base of the sill locally coincides with thrusts. South of the Vertical Shaft fault the base is seen only at scattered localities. In the zone of the *L* fault the porphyry has locally crosscut into the underlying Yellowpine; elsewhere the base of the sill apparently is generally concordant with bedding in the Bird Spring from 10 to 100 feet above the base of that formation.

Porphyry bodies in the area were largely controlled by preintrusion structures or else by structures formed during intrusion. The Yellow Pine sill, especially north of Capitano Gulch, has followed offsets along tears in the hanging wall of the Potosi thrust which do not persist into the footwall, and has followed offsets along tears in the footwall which do not persist into the hanging wall. In the south part of the area the sill follows with at least approximate concordance the arch of the anticlinal nose. Dikes connecting with the sill follow rifts and tears.

The porphyry is poorly exposed over most of its outcrop, and exposures in the mine are few and far apart. Wherever exposures are good, the porphyry is cut by high- and low-angle shears, and locally it is sheared to the same degree as adjacent sedimentary rocks. Along the Prairie Flower mine 400 level the northeast side of the Prairie Flower dike is frozen against the dolomite wallrock, but the contact along the opposite wall is sheared. The porphyry throughout the dike is cut by many high- and low-angle faults forming a pattern similar to that mapped in the adjacent sedimentary rocks. Many of the faults have horizontal slickensides. The Como dike is also cut by shears that have the prevailing westerly trend characteristic of faults in the adjacent sedimentary rocks. The basal part of the Yellow Pine sill on the 300 and 900 levels is likewise cut by high-angle shears paralleling those in adjacent country rock. On the surface in the northern part of the area a few shears can be traced for short distances in the porphyry. Most of these are high-angle fractures trending northwest with the prevailing trend of tears in this area, and a few connect with minor tears in the hanging wall of the sill. A low-angle shear, exposed in a prospect north of and across the wash from the old Prairie Flower shaft, dips west and parallels the strike of bedding in nearby limestone.

SEQUENCE OF STRUCTURAL EVENTS

The evidence suggests the following sequence of events: Initiation of anticlinal folding in the area was attended by development of bedding shears, especially in thinly layered units of the upper Bullion, of the Arrowhead, and locally of the Yellowpine. Undulations developed along the northwest limb of the folds, and within and around these flexures bedding shears broke across the stratification and became minor thrusts. With continued compression the northwestern limb was broken by thrusts and tears in the northeast where the fold had become closed, and by rifts in the southwest where the fold remained open. The rifts and tears dislocated the earlier bedding shears and minor thrusts, but neither group of high-angle faults dislocated the other. Most of the blocks between the rifts and tears were subjected to stresses acting as horizontal couples, and some of the warping to be seen within these blocks may have been produced by the differential movement resulting.

After the principal tears and rifts had developed but before movement along them had ceased, magma was intruded along thrusts or surfaces of stratification in somep laces and along high-angle rifts or tears in others. After the magma had crystallied, continuing movement along the thrusts, rifts, and tears produced shears of all three types in the granite porphyry.

The result of these events is a complex arrangement of folds, master faults, and igneous bodies joined in an integrated pattern. Such a pattern is more logically interpreted as having developed during a single though perhaps long sustained period of deformation rather than during two or more stages of deformation.

ALTERATION OF ROCKS

The rocks in the mine area have been extensively altered by hydrothermal solutions. The limestones are locally altered to dolomite or are silicified. In some places sandstone of the Bird Spring formation has been converted to quartzite by the addition of siliceous cement. Orthoclase crystals in the porphyry are generally altered to sericite,[10] and in zones of shearing the rock is altered largely to an iron-stained clay, probably mortmorillonite. Although all these processes of alteration apparently preceded or accompanied sulfide mineralization, only dolomitization and silicification are of economic importance in the ore-producing zones.

DOLOMITIZATION

Throughout the block of ground explored beneath the surface perhaps 80 percent of the Yellowpine member is dolomite. In contrast to the unaltered limestone, which is typically compact, fine grained,

[10] Hewett, D. F., op. cit., p. 38.

and dark gray, the dolomite is commonly vuggy, medium to coarse textured, and light gray to almost white. Average size of grains in the dolomite is estimated as about 1.5 millimeters,[11] which is one-third larger than the average grain of the unaltered rock. However, some dolomite retains the fine grain and darker color of the original limestone, so that tests with acid are necessary for field determinations.

Where the dolomite is vuggy, the openings range in diameter from a fraction of an inch to 2 inches. Locally the vugs are so closely spaced that the rock has a spongy appearance. Openings commonly contain crystals of calcite, dolomite, or quartz, or fillings of chalcedony. Where vugs have been completely filled with one or more of these minerals the rock generally has a mottled appearance.

Dolomitization locally appears to be related to faults. The most thoroughly altered zone known in the mine borders the Vertical Shaft fault for distances of 100 or more feet on either side. Rocks in the belt of sheared ground along the arc of the K_1 and K_2 faults are, wherever observable, dolomitized throughout and are locally coarsely crystalline and almost white.

Cores obtained by drilling in the block between the *K* and the *E* faults indicate that there is a general decrease in amount of dolomite from northeast to southwest, but that even in the less thoroughly altered areas the Yellowpine section is three-fourths dolomite. Residual limestone forms irregular tabular zones inclined westward with the regional dip but cutting across bedding at generally small angles. Thicknesses of known limestone residuals range from a fraction of a foot to 20 feet.

The *Y* fault generally marks the boundary between more dolomitized ground to the northeast and less dolomitized ground to the southwest, although effects of alteration were observed at the southwestern limits of mining. More detailed information is required to determine the geometrical relationships between the *X*-*Y* fault zone and bodies of dolomite in the Yellowpine.

SILICIFICATION

Silicified zones are generally parallel to the bedding and range from a fraction of a foot to 25 feet in thickness. They occur locally in the Yellowpine member. Within these zones the rock is in part replaced so as to preserve the outward appearance of limestone, and in part layered with irregular lentils and pods of gray, brownish, or black chert generally 1 foot or less thick. Between the K_1 and the *E* faults the upper 30 feet of the Yellowpine is widely silicified, and similar zones doubtless exist elsewhere in the mine.

[11] Hewett, D. F., op. cit., p. 60.

Veins of brown chert from a fraction of 1 inch to 3 feet across follow most shears along the master tears and rifts, and also are found along many of the subsidiary high-angle faults and minor thrusts. In most places the veinlets are films that give a varnished appearance to the fault walls and accentuate the slickensides and minor irregularities.

ORE DEPOSITS

CHARACTER AND GRADE

The typical ore is a mixture of galena and oxidized lead and zinc minerals. Materials remaining in the stopes indicate that most ore was a porous aggregate of calamine crystals and hydrozincite pods and stringers, containing accessory masses of cerussite surrounding nuclei of galena, all stained to some extent with iron oxide. Malachite is commonly present as minute flecks and films; where it is locally abundant, iron oxide is generally abundant also.

Between the richer concentrations of ore are barren ribs of dolomite that may be as much as 10 feet thick but in the more productive areas probably average less than 1 foot in thickness and account for less than one-fifth of the material extracted.

Presumably the primary ore bodies were made up principally of sphalerite and galena, and minor amounts of other sulfides. Subsequent to deposition the ore has been oxidized to an unknown depth below the deepest workings in the mine. Sphalerite changed to hydrozincite ($2ZnCO_3.3Zn(OH)_2$), calamine (H_2ZnSiO_5), and smithsonite ($ZnCO_3$). Within the ore bodies galena remains the only observed representative of the primary minerals, but in many places it too is altered, either partly or completely, to cerussite ($PbCO_3$) and anglesite ($PbSO_4$).

Overall production figures indicate that the lead-zinc ratio ranges from 1:2 to 1:2.5. However, the ratio varies widely within the larger ore bodies and there are small bodies of ore that are predominantly either lead or zinc. Some selective mining has thus been possible. Average grade of the crude ore marketed is from 20 percent to 35 percent combined lead and zinc.

PRINCIPAL ORE BODIES

The forms of the principal ore bodies are briefly described in the following paragraphs. Reference to several of the minor ore bodies is made in the section on geologic controls of ore deposits.

Discovery ore body.—This body has been mined for a distance of about 1,200 feet beginning within a few feet of the surface near the collar of the Discovery shaft and ending along the 700 level. Difference in altitude at opposite ends of the ore run is about 320 feet.

Cross-section areas of the main stope at right angles to the axis are as much 1,400 square feet and as little as 300 square feet.

Southwest of the *E* fault the ore body was broadly tabular and lay generally parallel to bedding in the Yellowpine member. Pillars of barren or slightly mineralized ground divide the ore into irregular flat pipes that are elongated roughly with the strike of the surrounding bedding above the 600 level and with the dip of the bedding below that level. The South 300 stopes mark the known southeast limit of ore up the dip along the 300 level.

Northeast of the *E* fault and between the 500 and 200 levels the stopes are backfilled. Stope maps in the company records indicate that ore in this segment was mostly in the form of a flat pipe whose strike was essentially parallel with the bedding and which was elongated in the direction of dip. Above the 200 level the ore extends for about 400 feet as an irregular pipelike body striking and dipping with the bedding and with the axis inclined southwest at about 5°.

Below the north end of the ore body a layer of barren dolomite separates the Discovery ore from a smaller body, the Sin Nombre. This ore was a few feet thick and lay with the bedding, forming a flat pipe that plunged to the northwest and tapered to an end about 20 feet above the 300 level.

Ore body 700.—As the 700 stopes are inaccessible, except in small and probably unrepresentative areas, they are known mostly from company records, which include undated contour maps and cross sections. According to local residents these records are incomplete. Outlines of the stope shown on plate 6 are the estimated limits of mining before caving occurred, but the sections across the stope (*E–E′* and *F–F′*, pl. 5) are based on the stope contour maps.

According to available information, the ore lay as an irregular flat pipe with the strike generally parallel with the strike of the bedding and the dip locally parallel with the dip of the bedding but in most places inclined westward at a lesser angle. The pipe rises from northeast to southwest; the lower limits of the main ore body are about 40 feet above the 900 level and the upper limits roughly are midway between the 700 and 300 levels at an altitude of about 4,480. The main axis is about 500 feet long; it trends between N. 30° E. and N. 40° E. and plunges about 15° toward the northeast. The stope contour maps indicate that the ore zone ranged from 2,300 to 3,300 square feet in cross-section area at most places, but was only 600 square feet in a few places.

From the south-central part of the ore body an arm extending down the dip of the bedding has been mined to the 900 level. The south winze follows farther down a continuation of the mineralized zone, and small quantities of ore have been extracted along the winze and on the south 1,000 level.

Ore bodies 958 and 964.—Ore bodies 958 and 964 are two subparallel flat pipes, each about 330 feet long, that join at the south to form a single ore body. The axes trend between north-northeast and northeast and plunge between 20° and 25° northeast. Contour maps of the stopes indicate that the strike of the ore body was northeast, and that the dip was westward, the same direction as the dip of local bedding but at a lesser angle. In cross section the larger 964 stope measures around 1,000 square feet in area throughout the greater part of its length; stope 958 measures about half this area.

Ore body 970.—Ore body 970 is an elongate tabular body ranging from 3 to 15 feet in thickness that strikes northeast and has been mined for about 150 feet down the plunge toward the west. The upper limit of mining is within a few feet of the 900 level. The stope width increases from about 25 feet at the lower limit of mining to a maximum of 70 feet near the upper limit.

Ore body 200 (including Copper, Bullion, and Little Copper ore bodies).—Stopes at the northeast end of the 200-level indicate a tabular body of roughly circular plan and maximum thickness about 25 feet. This body extended southwestward as two flat pipes, partly superimposed.

The upper pipe or Copper stope ore body was about 275 feet long. The axis trended N. 20° E. and plunged about 5° N. The strike and dip of the ore body were about parallel with the strike and dip of the bedding. The ore was thickest at the north end where the stope measures about 700 square feet in cross section; at the south end the ore wedged and disappeared by thinning.

The lower and smaller pipe, or Bullion ore body, was separated from the upper pipe by 20 feet or less of dolomite and lay about 20 feet above the 200 level. The axis, about 200 feet long, was horizontal, and though sinuous in detail, had an average bearing from N. 20° E. to N. 40° E. The strike and dip of the ore body were essentially parallel with strike and dip of the bedding. The stope measures about 500 square feet in cross section in several places; it becomes smaller toward the south where the ore disappeared by thinning.

Fifty feet up the dip of the bedding from the Copper stope was a smaller but similar ore body, the Little Copper. Ore has been mined for 120 feet along the axis, which is horizontal and bears N. 30° E. The ore zone is about parallel to the bedding, and on the average measures 200 square feet in cross-section area. It becomes narrower from north to south where it grades into sparsely mineralized ground.

EFFECTS OF OXIDATION

Masses of galena generally are scattered throughout the mineralized rocks in and around the principal ore bodies. Only locally can it be established that there has been appreciable migration of oxidized zinc minerals beyond the borders of sulfide mineralization. Oxidation of the primary ore was doubtless attended by redistribution of elements within the mineralized ground, but in the absence of evidence to the contrary it may be reasonably assumed that the shapes of most of the stopes coincide with the primary ore zones.

Two moderately large bodies of oxidized zinc ore have no galena associated with them. One is at the lower side of the Discovery ore body north of the 700 station on the main incline and below the 700 level. Here the Strike fault is followed by a drift. The ore southeast of the fault and above the level contains scattered masses of galena, whereas the ore northwest of the fault and below the level to a depth of about 20 feet is white hydrozincite with no galena. These relationships are interpreted as indicating that the ore northwest of the fault and below the level has formed by deposition of secondary zinc minerals derived from primary ore southeast of the fault and above the level.

The second locality is on the 900 level at the north corner of ore body 700 and southwest of the Como dike. In this locality a number of tabular masses of crystalline white hydrozincite have been mined from near-vertical fissures and from bedding seams in the country rock. The oxidized ore is interpreted as having been derived from the primary ore body 700, the main part of which bottoms about 40 feet above the level. As small bodies of the white hydrozincite have been mined to 60 feet below the 900 level in this area, zinc has migrated at least 100 feet.

GEOLOGIC CONTROLS OF ORE DEPOSITS

DOLOMITIZED GROUND

Pods and stringers of white hydrozincite occur locally in unaltered limestone, but the ore bodies with which galena is associated are all in dolomite. However, in comparison with the volume of dolomite in the Yellowpine member, the volume of mineralized ground is exceedingly small. Even though dolomitization was related to deposition of ore, there were other factors more directly responsible for localization of ore within the dolomite.

GRANITE PORPHYRY

All evidence points to the conclusion that the porphyry in the Yellow Pine-Prairie Flower area was intruded before the replacement of adjacent dolomite by sulfides. Aside from the effects of hydrothermal alteration already noted, the porphyry in the mine area locally contains pyrite and is generally stained with iron probably derived from pyrite by oxidation. It is known that at the nearby Red Cloud mine (fig. 2) quantities of the porphyry have been treated for gold, and that at the Lavina mine, less than 1 mile east of the Yellow Pine property, the porphyry is pyritized and contains sulfide-bearing quartz veins.[12]

No galena was found in the porphyry around the ore bodies of the Yellow Pine mine even at places where the adjacent dolomite contained abundant galena. Apparently the porphyry tended to obstruct the upward or lateral migration of solutions wherever it lay as a sill above or stood as a dike across ground prepared for mineralization.

THINLY STRATIFIED BEDS IN THE YELLOWPINE LIMESTONE MEMBER

The Yellowpine limestone member is predominantly limestone or dolomite and has inconspicuous bedding surfaces spaced at a few feet to a few tens of feet. Locally it is in prominent layers ranging from 3 inches to 1 foot in thickness. However, it is not possible to subdivide the member into massive and thinly bedded submembers, as the two types of rock interfinger laterally and vertically. The thinly bedded facies occurs sporadically in the central and northeastern parts of the mine, but is more common in the area southeast of the *E* fault.

In the accessible parts of the Discovery stope southwest of the *E* fault, the ore lay mainly in the thinly bedded zones, from 20 to 80 feet above the base of the Yellowpine member. Between the 700 and 300 levels along section *A–A′* the approximate base of the thinly stratified layers rises from a position 20 feet above the base of the Yellowpine at the 700 level to 50 feet above the base at the 300 level, and the upper limit rises correspondingly.

Thinly bedded units were also seen in the ore zone of the Discovery stope along part of the 200 level, but it was impossible to determine whether they had controlled in any way the position of the ore.

These thinly stratified units were presumably favorable for ore deposition because they were relatively more permeable than adjacent massive beds. This permeability was probably largely primary and due to openings along bedding surfaces. Locally, however, these surfaces are striated, indicating that there has been shearing along the bedding, and possibly the breaking of the thin beds attending shearing produced additional openings which increased the permeability.

THRUST FAULTS

Southwest of the *E* fault there are few thrusts and most of those could be classified as bedding slips. Northeast of the *E* fault, thrusts are relatively numerous in the upper beds of the Monte Cristo. Most do not persist from one mine level to the next, and only the *R* fault is known throughout the most productive part of the mine, between the E and Vertical Shaft vaults.

[12] Hewett, D. F., op. cit., p. 108.

In a number of places the *R* fault is associated with ore. The fault forms the backs of the Copper and Little Copper stopes and is mineralized at the surface above them. By projection, this same fault either forms or lies near the hanging wall of stope 700 near the southwest end (section *E–E′*), although farther to the northeast it is near the footwall of the 700 ore body (section *F–F′*). It lies along or a few feet below the footwall of stope 958 and forms the hanging wall of stope 964 near its southern end (secs. *G–G′* and *H–H′*).

In the northern part of the mine the Prairie Flower ore body connecting with the old Prairie Flower shaft lay in a thrust zone where the hanging wall of the ore followed the uppermost fault of the zone.

The thrusts are important ore controls, because rocks adjacent to them are brecciated. Where the thrusts are widely spaced in the Yellowpine member they are commonly bordered by rock that shows little or no brecciation. On the other hand, where closely spaced thrusts form zones of shearing, the rock between individual thrusts is broken throughout. Examples of thrust control are the Copper and Bullion stopes, which lie respectively at the upper and lower limits of a shear zone about 40 feet thick. The Prairie Flower ore body is within a similar zone of thrusting. Section *F–F′* indicates that ore body 700 likewise occupies part of a zone of closely spaced thrusts. The unusually large amount of mineralized ground in the block between the Como dike and Vertical Shaft fault may possibly be controlled by the abundance of minor thrusts rather than by the presence of the persistent *R* thrust.

No consistent geometrical relationship exists between the position of thrust surfaces and ore. Only three relatively small ore bodies have thrust surfaces as persistent walls bounding the ore zones on one side. Even in these cases other factors must account for the linear trend of the shoots.

The relationship between position of thrust breccias and ore zones is well established in some places and conjectural in others. In the Copper, Little Copper, Bullion, and Prairie Flower bodies the ore was in zones of broken ground within which low-angle shears are spaced at intervals of a few feet. The same relationship exists in the case of ore body 700, at least in the vicinity of section *F–F′*. However, the presence of tabular bodies of breccia does not in itself account for the localization of ore in elongate pipes within the breccia.

FLEXURES

Ore mined along or within a few feet of the Yellowpine and Arrowhead contact is related to anticlinal noses or to warps at places where bedding steepens. Within the area between the *E* and Vertical Shaft faults there are only four stopes from which ore has been mined along the Yellowpine and Arrowhead contact and from beds immediately adjacent. These stopes are the Copper, Bullion, Little Copper, and 709. The first three occupy in part the arch of a plunging anticlinal nose west of the K_1 fault, although the northeast end of the mineralized zone extends for a short distance into the highly fractured K_1–K_2 fault zone. The northeast end of the Discovery stope together with the Sin Nombre below apparently lie on parts of the same structure.

The "shoestring" stope, 709, is about 350 feet long and follows in part the axis of a warp characterized by gentler dips on the southeast and steeper dips on the northwest. The axis of the warp, as defined by points along which the dip of bedding steepens, trends N. 15° E. to N. 20° E. between sections *E–E′* and *F–F′* and trends N. 20° E. to N. 30° E. between section *F–F′* and the Como dike. The plunge is 15° to 20° N. between the two sections, and about 10° N. between section *F–F′* and the dike. By comparison, the axis of stope 700 trends N. 30° E. to N. 40° E., and the plunge is about 15° N.

Above the 500 level the Discovery stope follows along the crest of an anticlinal nose (sec. *B–B′*), thence angles northeast above a warp in the bedding which is manifested by steepening of dips toward the northwest. As developed in the Arrowhead and lower beds of the Yellowpine this warp is most pronounced between the 300 and 200 levels and between the *G* and the *S* faults. Whether the structure continues beneath the segment of the Discovery stope between the *S* and the K_1 faults is conjectural. Section *D–D′* is drawn to show that by the simplest interpretation of available data the warp need not persist northeast beyond the *S* fault.

Stopes 970, 958, and 964 apparently lie in part along the arch of an anticlinal nose that shows in the Yellowpine and Arrowhead contact at an altitude of 4,400 feet and less. However, the ore zones are mostly in the middle and upper part of the Yellowpine, so that their relationship to this structure is problematical. A similar questionable relationship exists between ore in the upper Yellowpine cut by drill holes 32–34 and the arch of an anticlinal nose showing in the lower contact of the Yellowpine between the *E* and the *G* faults and below an altitude of 4,460 feet.

To determine the possible influence of flexures in ore deposition, it is desirable to compare ground on the flexures with stratigraphically equivalent ground marginal to the flexures. The distribution of mine workings is most favorable for such comparison in the vicinity of section *F–F′*. This section shows that thrust faults are most abundant along the zone in which the strata bend in conformity with the warp already described. Although the beds of the Yellowpine are thoroughly broken between the north 400 and 700 levels, the same beds are virtually intact where crossed 200 feet down their dip along the 900 level and also 200 to 300 feet up the dip along the surface. With the exception of the *R* fault and one bedding shear in the Bullion member, many thrusts apparently are local and confined to the zone of flexing. It is therefore inferred that the brecciation of beds in the axial zone of the warp is related to the bending which produced the warp itself. In homoclinal structures, adjustment of beds in process of folding would normally be by shearing along surfaces of bedding. If, however, a warp develops across the bedding, bedding shears tend to pass into minor thrusts with accompanying brecciation at the places of bending.

In summary, where ore has been mined along or within a few feet of the Yellowpine and Arrowhead contact, the ore is related to arches of anticlinal noses or to warps at places where bedding steepens. Where ore zones are in the middle or upper part of the Yellowpine the axes of ore zones parallel the axes of structures contoured on the base of the Yellowpine in some places and make acute angles with the axes of warps and noses in others. In the area where ground within a flexure can best be compared with ground outside the flexure, the ground within is conspicuously more broken.

HIGH-ANGLE FAULTS

The Yellow Pine and Prairie Flower workings are divided into six structural blocks by five high-angle faults or fault zones: the *X–Y* zone, the *K* zone (bounded by the K_1 and K_2 faults above the 900 level), the Como dike fault, the Vertical Shaft fault, and the Prairie Flower fault (pl. 6). By far the greatest amount of ore has been mined between the Vertical Shaft fault at the northeast and the *X–Y* zone at the southwest.

The block of ground between the Vertical Shaft fault and the Como dike contained three moderately large ore bodies: the 970, 958, and 964. The extent of ore body 970 is unknown, but the other two ore bodies extended across almost the entire width of the block, with the northern terminations between 30 and 70 feet southwest of the Vertical Shaft fault and the southern end of the combined ore zones extending to or within a few feet of the Como dike.

The block between the Como dike and the *K* fault contained one large ore body, the 700, and a smaller ore body, the 709. Ore body 700 extends across the entire width of the block, ending at the northeast against or within a few tens of feet of the dike, and disappearing at the southwest end within the *K* fault zone. Ore body 709 ends near the *K* zone at the southwest and disappears by thinning in the opposite direction.

The block between the *K* zone and the *X–Y* zone contained one large ore body, the Discovery, together with its satellite ore bodies, the Sin Nombre and South 300; an ore body of intermediate size, the 200; and a small ore body, the Little Copper. The Discovery ore body ends at the southwest along the Strike fault and at the northeast along the edge of the K_1 fault zone. The stopes of ore body 200 end at the northeast within the same fault zone and thin toward the southwest. The Little Copper ore body thins toward the southwest but the northern end has not yet been determined.

All who have studied the mine agree that the high-angle faults and fault zones divide the productive area into blocks and generally bound ore bodies at one or both ends.

There is difference of opinion, however, on the relative ages of the faults and the ore. According to some investigators the faults have dislocated long pipes into segments, each of which now appears to be a separate body of ore. Others maintain that the faults provided the channels along which the mineralizing solutions rose. This issue must be settled before the future of the district is appraised. If the faults are younger than the ore, each pipe ending along one side of a fault must have a corresponding segment on the opposite side. But if the faults are the older, ore bodies might terminate against them.

Hypothesis of postmineralization faulting.—The hypothesis that all the high-angle faults in the mine followed sulfide mineralization has been rather thoroughly tested within the area of the larger ore bodies. Observations made in workings above the 900 level are supplemented by data from about 10,000 feet of drilling.

By this hypothesis ore body 700 might be an extension of ore bodies 958 and 964 combined, the two segments having been separated both by faulting and by emplacement of the Como dike. Although this correlation might help explain why the ore occupies essentially the same stratigraphic position on opposite sides of the dike, it implies that the dike is younger than the ore—an interpretation that is questionable in the light of other evidence.

The hypothesis can be further tested at the next block south where the stopes of ore bodies 700 and 709 lie opposite the Discovery-Sin Nombre and the 200, respectively, across the K fault zone. Obviously ore bodies 700 and 200 cannot be dismembered parts of the same pipe, for the ore is near the top of the Yellowpine in ore body 700 whereas it is along the base of that member and in the underlying beds of the Bullion in ore bodies of the 200. Thus, unless there are additional undiscovered pipes along the K zone in one or the other block, ore body 700 must be correlated with the Discovery-Sin Nombre and the ore body 200 with the 709. In a general way this satisfies the requirement that the corresponding segments should occupy the same stratigraphic zones on opposite sides of the dislocating faults. However, the correlation implies that movement along the K_1 fault was parallel with the dip of the fault surface. This is contrary to the evidence of predominant strike-slip movement provided by slickensides. If we assume, however, that the slickensides are meaningless and that what have been called rifts are gravity faults, the situation is only temporarily improved. The northeast end of the stopes of ore body 200 is on the northeast side of the K_1 fault, whereas the southwest end of the 700 pipe is on the southwest side of this same fault. As the K_1 carries the greater part of the displacement in the K zone, it must now be assumed that what appears to be the continuation of the stopes of ore body 200 on the northeast side of the K_1 fault is in reality the downfaulted part of another ore body which by coincidence has moved opposite the main ore body 200. Also the extreme south end of the ore body 700 must be the upfaulted segment of a different body of ore thrown in a similar way exactly opposite the main 700 run. If now we note that ore body 200 appears to have become strangely shrunken where it was downfaulted to make the 709 pipe, it is apparent that no reasonable correlations of known ore bodies can be made across the K fault zone.

These difficulties have been recognized in part even by the most vigorous supporters of the postmineralization hypothesis. Even before it was established that the K zone cuts across the end of the stope of the 200 ore body, it has been assumed that known ore bodies on opposite sides of the K zone are parts of different manto runs, either 4, 5, or 6 in number depending on whether the Sin Nombre and Little Copper ore bodies are considered as independent of the Discovery and the 200 ore bodies respectively. Thus the block southwest of the K zone should contain the faulted offsets of 700 and 709 ore bodies and the block to the northeast should contain offset segments of the Discovery, the 200, and perhaps of the Little Copper and Sin Nombre as well; in other words, two ore bodies remain to be discovered southwest of the K zone and from two to four bodies remain to be discovered to the northeast.

Before the recent programs of core-drilling, the first of which was formulated in accordance with the postmineralization hypothesis, there may have been some justification for optimism of the sort implied. But in the light of the now extensive exploration in areas bordering the K zone, from the bottom of the south winze to the prospects near the southern exposure of the zone on the surface, the hypothesis of the faulted pipes can no longer be seriously entertained.

Difficulties of a similar kind are encountered when the termination of the Discovery run along the Strike fault is examined in the light of this hypothesis. It was not possible to measure the displacement of the Strike fault. However, if it was of the order of a few feet or a few tens of feet, the ore body would not have been moved beyond the limits of exploration on the 700 level. Or if the strike-slip component of movement was of the order of a few hundred feet, the faulted continuation should have been cored by the YIU series of drill holes from the 800 level or should have been encountered in mine openings along and connecting with the 800 level. Or assuming that the movement along the fault was not northeast on the northwest side, as the striae and fracture pattern would seem to indicate, but was in the reverse direction, the offset segment should have been found in the south 800 level which thoroughly explores the Yellowpine member for 900 feet along the strike to the southwest of the north intercept of the Discovery stope on the 700 level. The fact that thorough and systematic exploration has failed to reveal a faulted extension of the Discovery run across the Strike fault is considered proof that no faulted extension exists.

Hypothesis of premineralization faulting.—This hypothesis is supported by those relationships between high-angle faults and ore that oppose the hypothesis of postmineralization faulting. As the ends of the ore bodies 200 and 700 are not displaced by the K_1 and related faults, it follows that the faults have not moved appreciably since the ore was formed. Also exploration by mining indicates that the Discovery run ends downward against the Strike fault and that the Strike fault was a premineralized feeding-fissure. The apparent displacement of the Discovery ore by the E fault on the 500 level has sometimes been interpreted as due to postmineralization movement, which according to slickensides, was predominantly strike-slip. Yet the ore on the southwest side of the fault is in the upper half of the Yellowpine member, whereas the ore on the opposite side is in the lower half of the same member. This fact, coupled with the additional one that the ore for 30 feet or more both above and below the 500 level was essentially in the form of near-vertical chimneys along the E fault, is explicable only on the assumption that the movement along the fault was predominantly or entirely premineralization.

Examination of the accessible stopes and examination of stope contour maps of the inaccessible stopes provides no unequivocal example where apparent offset of ore matches the displacement along a high-angle fault passing across the stoped zones.

To this point, evidence bearing on the relative ages of faults and ore has been mostly geometrical. In addition there is mineralogical evidence which supports the view that high-angle faults in the mine are older than the mineral deposits. Hewett has noted that if a fault breccia contains crystals of unsheared galena the breccia evidently was present before the introduction of sulfides, and the faulting occurred therefore before mineralization.[13] Using this criterion he concluded that movement along the A fault on the 600 level, B fault on the 700, the L and adjacent faults on the 1,000, and the Como Dike fault occurred before mineralization. If the same criterion is applied to results of the present survey the Strike fault on the 700 level, the E fault on the 500 level, and subsidiary shears in the K zone on the 900 and 200 levels may be added to the list. The validity of the criterion can hardly be

[13] Hewett, D. F., 1931, Geology and ore deposits of the Goodsprings quadrangle, Nevada: U. S. Geol. Survey Prof. Paper 162, p. 134, 136.

denied, but the application is generally difficult and in some cases doubtful. Only along a single branch of the K_1 fault on the 200 level was galena found as a veinlet between the fault walls. Elsewhere the sulfide is generally scattered through broken ground within a few inches or a few feet of the fault surfaces in question. As the ground throughout most of the mine is more or less broken, it is difficult to prove that a body of breccia is related to some particular fault surface. The writers regard the evidence as strongly suggestive but not conclusive.

As dolomitization is evidently a process related to ore deposition, the relationship between dolomitized zones and high-angle faults is pertinent. The data at hand do not provide a complete three-dimensional picture of the altered and unaltered zones. However, the local relations between high-angle faults and dolomite strongly suggest that the solutions responsible for the alteration were most effective in and around the high-angle fault zones. The rocks bordering the Vertical Shaft fault are altered throughout and are prevailingly more porous by the presence of vugs than are rocks seen elsewhere in the mine. On the 700 level, the normally dark beds of the Bullion are widely altered to coarse white dolomite in the zone of the K faults. The beds of the Yellowpine generally are more thoroughly altered to the northeast of the X–Y zone than to the southwest. Evidently the principal high-angle faults are older than either the dolomite or the mineral deposits.

High-angle faults as conduits.—Where ore ends against faults or in fault zones, and where there is evidence that fracturing occurred before ore formed, it is reasonable to assume that the faults together with their fringes of broken ground acted as conduits for mineralizing solutions. Even so, the more persistent of the high-angle faults did not serve as feeders except along relatively short segments. Thus the Strike fault is known for a distance of 430 feet along the 700 level, but ore of the Discovery body abuts against it for only 80 feet. The K zone, known for a distance of about 1,700 feet, is associated with ore for less than a third of the strike length. Likewise the Vertical Shaft, Como Dike, and other tear faults are associated with ore only for short distances. If the high-angle faults were the feeders, some explanation of the short length of the productive segments is required.

Along the 700 level the Discovery run consists of two pipes more than 100 feet apart, each of which abuts against the Strike fault at its lower terminus. The south pipe ends along that segment of the Strike fault between the junction of the A fault on the south and the junction of the B fault on the north (pl. 7). In the 600 level the A fault marks the southwest limit of Discovery ore, and on the 300 level the same fault lies scarcely 50 feet southwest of the stoped area around the South 300 ore bodies. Thus the supposed conduit for the south arm is in the area of junction between persistent faults of different trends. Similarly the north pipe ends in an area of junction between rifts and tears trending north, northeast, and northwest (pl. 7).

Comparison of the trend of the *K* zone underground and on the surface shows that although the zone is arcuate in strike throughout its known extent, the arc is not uniform. Its radius of curvature is about 1,800 feet along the surface, whereas underground the radius decreases, and is from 400 to 700 feet along the segment associated with ore. These relationships suggest that the *K* zone was a conduit where the arc of strike is most accentuated, or in other words where the radius of curvature is least.

If the main 700 run was fed through the arm that extends northwest between the *K* and *L* faults, the conduit might be related to the arc of the *K* fault, as are the Discovery and 200 ore bodies; or, since the mineralized zone extends down the south winze and along the *L* fault on the 1,000 level, the conduit may have been related to a zone of junction between the *K* and *L* faults, which appear to converge toward the northwest. If the feeding was largely along fractures bordering the Como dike, the geometry of the fault pattern offers no obvious explanation for the localization of conduits.

The ore bodies 958 and 964 may have been fed through conduits connected with openings along the Como dike, or more reasonably by fractures bordering the Vertical Shaft fault. The Vertical Shaft fault on the 900 level changes strike from west-northwest to northwest along an arc opposite the lower termini of the two pipes. A small steeply inclined pipe of ore has been mined from stope 1,100 between the 1,000 and 1,100 levels on the northeast side of the Vertical Shaft fault, suggesting further that the fault has been a feeder in this area.

Where the lower termini of the larger ore bodies have been determined by mining, the pipes end in areas where high-angle faults change strike along arcs that are either unusual for the known extent of the faults (Vertical Shaft fault) or are of lesser radius of curvature than the barren parts of the same zone (K_1–K_2 zone), or where rifts and tears interlink (lower arms of Discovery stope; possibly also the lower arm of stope 700).

Strike-slip movement along arcuate faults should provide zones of open ground along segments with the smallest radius of curvature. Junction of high-angle faults would presumably define steeply pitching zones within which ground was more brecciated and hence more permeable than the ground along any one of the individual faults.

SUMMARY

The following speculations agree with data gathered in the course of this investigation.

Mineralizing solutions responsible for ore of the Discovery body moved upward along the Strike fault and spread from the conduits up the dip of the Yellowpine member following and replacing thin-bedded zones of relatively high permeability. Where the solutions met the *E* fault they moved upward along it, then left the fault zone and moved eastward up the dip of the bedding approximately following the arch of a plunging anticlinal nose to about the horizon of the present 200 level; thence they moved northeast along a warp roughly parallel with the strike of the bedding.

Solutions rising along the *K* zone locally replaced the brecciated rock within the fault zone itself, but were most effective in depositing ore where they spread laterally to the northeast and southwest following flexures and warps. Thus the mineralizers progressing upward along the axis of a plunging anticlinal nose replaced the sheared ground below the *R* thrust to form the 200 and Little Copper ore bodies. Solutions feeding from a focus farther to the north also were channeled into this same structure to make ore of the Sin Nombre and possibly that of the northeast end of the overlying Discovery body. Northeast of the *K* zone the solutions moved along the zone of broken ground in the arch of a warp trending obliquely across the bedding and produced ore body 709.

Conduits along the *K* and *L* faults near the south winze fed solutions which rose to the sandstone of the Bird Spring formation and followed up the dip in the underlying Yellowpine member. Upon striking the zone of sheared and broken ground in the warp associated with ore body 709 the solutions spread laterally to the northeast and southwest, perhaps mingling with solutions from sources along the Como dike and the *K* zone, to produce ore body 700.

Along the Vertical Shaft fault the main conduit discharged through the arc along the strike above the 900 level. Through this were fed the solutions which migrated laterally and upward through brecciated zones related to minor thrusts and formed ore bodies 958, 964, and presumably the 970. The Como dike was a barrier to migration of solutions, and adjacent to this barrier the thickest deposit of ore was formed.

Features of the distribution of ore that remain unexplained are fairly numerous. It is not understood why ore body 700, large as it was, occupied only the downdip fringe of brecciated ground related to the flexure which presumably controls its axis. The axial trend of the ore body 958 appears to be controlled by the conjunction of the *R* thrust with bedding shears at the base of the sandstone of the Bird Spring (compare with ore bodies at the Green Monster mine, p. 88–89) but the data at hand do not offer a similar explanation for ore body 964. The localization of ore in pipes west of *E* fault is not explained. As a general rule, however, the ore appears to fit into a structural pattern wherever the geological information is adequate.

POTOSI MINE

By Arthur Richards, Arnold L. Brokaw, and David A. Phoenix

The Potosi mine is 11 miles northwest of Goodsprings and twice that distance from Arden, the nearest station on the Union Pacific Railroad. A side road off the old Death Valley–Las Vegas road leads to the campsite at Potosi Spring (fig. 2). From there a foot trail winds up a slope to the main portals half a mile from the camp and 700 feet higher.

The mine is the property of International Smelting and Refining Co. Although idle at present, and only intermittently active since 1927, its history dates from 1856.[14] Mining was begun along a cropping of galena ore that probably showed near the present portals at sites now largely covered by waste (pl. 8). A labyrinth of levels and stopes developed by subsequent work underground and to the east is in large part accessible (pl. 9). The mine is noteworthy not only for its long record of production but also because it contains the only bodies of sphalerite ore thus far discovered in the district.

ROCK UNITS

Characteristics of rock units mapped in the area are summarized in the columnar section on page 42.

The unconformity between the Monte Cristo and the Bird Spring is more pronounced around the Potosi mine than at any other mine examined. Only the lower beds of the Bird Spring are preserved; these occupy a channel so cut in the Monte Cristo that the basal shales of the Bird Spring rest on the upper beds of the Bullion along the deeper parts of the channel and on the Arrowhead and Yellowpine in the shallower parts. The shale locally extends downward into the Yellowpine members as irregular vermiform bodies several feet across. These bodies fill caves formed during an interval of subaerial erosion that began after the deposition of the Yellowpine and ended with the deposition of the basal beds of the Bird Spring. Cave fillings appear in various parts of the mine above the 1,000 level. The largest of these is exposed a few feet below the 1,072 level at mine coordinates 1,050 east and 1,425 south (pl. 10).

STRUCTURE

The mine is in the relatively flat eastern limb of a syncline trending south and plunging in the same direction at angles generally less than 20°. At most places the western limb dips eastward at moderate to high angles, but locally it is vertical or overturned. The eastern limb is broken by a thrust striking north and dipping east. As this

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[14] Hewett, D. F., op. cit., p. 69–70.

Summary of characteristics of rock units mapped in the area

Age	Formation	Member	Character	Thickness (feet)
Recent.			Landslide debris, with blocks of Bird Spring formation as much as 50 feet across partly embedded in shale. Slide apparently inactive.	(?)
	Unconformity			
Pennsylvanian.	Bird Spring formation.		Shale, basal, black, locally containing chert cobbles, grades upward into sandstone and sandy limestone overlain by thinly bedded limestone; one of the limestone beds, distinguished from others exposed in this area by its content of black calcareous concretions, is mapped separately on plate 8; base fills channel cut in underlying Monte Cristo limestone.	70+
	Unconformity			
Mississippian.	Monte Cristo limestone.	Yellowpine limestone.	Limestone, dark-gray to black, bedded in layers from 2 to 10 feet thick; largely altered to dolomite in zone of mine workings. Zones of prostrate zaphrentid corals 20 and 35 feet above base. Member eroded from section beneath deepest part of channel at base of the Bird Spring.	120 maximum
		Arrowhead limestone.	Limestone, fossiliferous black, in layers averaging 3 inches thick, separated by partings of black shale; only locally altered to dolomite.	13 average, 20 maximum
		Bullion dolomite.	Dolomite, predominantly coarsely crystalline cream, with scattered concretionary masses of chert. Unaltered zones of black limestone bedded in layers 1 to 5 feet thick common in upper 50 feet; bedding obliterated or obscure in dolomitized zones. Persistent bed of chert 20 feet below contact with Arrowhead member.	400–500

fault is the largest mapped in the mine it is designated the "Principal thrust." A parallel thrust shows along part of the eastern border of the area (pl. 8). Associated with these thrusts are a few high-angle tear faults that trend east.

Near the south end of the area a minor thrust striking east and dipping 18° south accounts for a separation of about 200 feet in the Arrowhead limestone member. This fault does not appear in the mine, but shears of similar attitude were mapped at many places underground (pls. 10, 11). A set of north-trending tears is associated with these thrusts. They are the predominant high-angle faults exposed in the mine, but they show at the surface only in the north part of the area as several fractures trending northwest.

In broader perspective the mine is in the footwall of the Keystone thrust, a master fault of the district. This thrust is concealed by alluvium in Potosi Wash 1 mile west of the mine, but the trend of the fault is known to be north-northeast and the dip is toward the west.[15] By projection the sole would lie probably less than 1,000 feet above the surface around the Potosi workings. The steep or overturned western limb of the syncline thus appears to reflect drag beneath a thrust block that moved relatively toward the east and is now eroded from the mine area. The Principal thrust and similar east-dipping thrusts are countershears in the footwall block of the Keystone thrust.

The mine workings are mostly in the footwall block of the Principal thrust, although the eastern parts of the main levels extend for short distances into the hanging-wall block. The bedding generally strikes east and dips south at angles mostly between 5° and 20°. Minor east-trending flexures account for local reversals in the dip along the west part of the 954 level (pl. 10), and there are irregularities related to drag along faults, but the structure of the footwall block within limits of exploration is broadly homoclinal.

The faults exposed in the mine are weaker and less numerous than in other mine areas of the district. Most faults can be classified in four groups: (1) east-dipping thrusts, of which the Principal thrust is the main example, (2) east-trending tears, (3) south-dipping thrusts, and (4) south-trending tears (pls. 10, 11). Striations indicate that slip along the thrusts has been predominantly with the dip of the fault surfaces, whereas the slip along the tears has been predominantly with the strike. Despite their differences in attitude the four groups of faults appear to have originated during the same stage of deformation. At most places where junctions between faults could be seen there was nothing to indicate that one fault had offset another.

The Principal thrust is exposed on the 954, 1,000, 1,072, 1,094, and 1,104 levels, as well as in several stopes between these levels. Net slip, as measured in the central part of the mine, is about 140 feet. The thrust surface is undulatory, but nothing suggests that the undulations were superimposed on an originally plane surface by later folding. Where exposed on the 954 level (pl. 10) the Principal thrust appears to be a single surface. On the 1,000 level it splits into two branches, and higher in the mine workings it is represented by several shears. These may unite before reaching the surface, as indicated by the map and structure section (pl. 8) but near its southern limit of exposure on the surface, the thrust again splits into several branches.

[15] Hewett, D. F., op. cit., pl. 1.

There are only a few easterly tears associated with the east-dipping thrusts. An example is the vertical fault mapped in the hanging-wall block of the Principal thrust on the eastern 1,072 level (pl. 10). Apparently this fault does not continue to the surface. Conversely, there are several faults of similar trend which show on the surface but which were not found underground.

The footwall block of the Principal thrust is broken into imbricate blocks by minor thrusts trending east and dipping south at angles generally steeper than the dip of the bedding. The most conspicuous zone of these faults is followed by the drift extending eastward from the portal of the 1,000 level. Similar thrusts show on all levels from near the northern to near the southern limits of mining.

Within the imbricate blocks the rocks are cut by tears, the most conspicuous of which trend north and dip at high angles either east or west. In many places the tears clearly terminate above or below against the thrusts. Although no single tear can be traced through the mine there is a conspicuous zone of such faults which bisects the mine area, extending from the south crosscut on the 1,000 level to beyond the north limits of the 1,072 level. Displacements along individual tears and thrusts could not be determined, but they are undoubtedly small and probably mostly of the order of a few feet.

DOLOMITIZATION

Alteration of limestone to dolomite was less widespread around the Potosi than around most other mines in the district. Alteration was more nearly complete in the zone explored by the mine workings than in rocks of the same age exposed at the surface. Even within the ore-producing zones, however, considerable quantities of limestone remain.

Dolomitization was generally attended by coarsening of the grain, by change in color from darker to lighter, and by obliteration of bedding surfaces. Most of the dolomite is of light-gray or creamy hue, whereas the unaltered rock is generally dark gray or black. Bleaching is also apparent in the black shale of the basal Bird Spring, which is locally light gray where present as cave filling in dolomitized zones.

The Arrowhead was less susceptible to alteration than either the Yellowpine or Bullion. So far as is known the Arrowhead remains a limestone, except along the surface near thrusts east of the mine and underground in the southeastern part of the 1,072 level.

ORE DEPOSITS

CHARACTER AND GRADE

The primary ore was predominantly sphalerite and galena in crystalline masses commonly associated with coarse white calcite. In most places the sulfides are in dolomite, but in a few places they are in limestone. Below the impervious canopy formed by the Principal thrust plane the sulfides remained essentially as formed. Toward the west the ore was progressively more oxidized, and along any level at distances beyond 100 feet below the thrust most of the sphalerite has been converted to hydrozincite, with which smaller amounts of calamine and smithsonite are associated. Most of the galena remains unaltered, and there is but little cerussite or anglesite in the ore.

Materials remaining in pillars and walls indicate that the ore varied considerably in composition and appearance along the main run of stopes from the east end of the 954 level to the top of the mine. Ore along the bottom of the run contained abundant galena associated with light-brown sphalerite. In the upper part of the run there was little galena, and the sphalerite was darker.

Reliable figures for average grade of the sulfide ore are not available although it is estimated that the crude sulfide ore has averaged from 10 to 20 percent zinc, with lead ranging from a fraction of a percent to several percent. Records of mining during the period 1914–17 show that the oxidized zinc ore contained from 30 to 35 percent zinc. Production records clearly indicate that the Potosi ore generally contains less lead as compared with ores from most other mines in the district; the lead-zinc ratio, considering all classes of ore, probably has ranged from 1:12 to 1:15.

In the central mine area, especially in the east-central part of the 1,042 level, the ground contains small percentages of copper as malachite.

DISTRIBUTION

It is estimated that 95 percent of the over-all production has been from the Yellowpine member, with the remaining 5 percent about equally divided between the Arrowhead and the upper 15 feet of the Bullion. The beds of the Bird Spring are essentially barren, although they too contain small amounts of sphalerite where in contact with mineralized zones in the Yellowpine.

If the fill were removed from all the stopes it is probable that they would interconnect in such a way as to indicate that nearly all the ore in the mine belonged to a single highly irregular body. The plan doubtless resembled the simplified border of mine workings superimposed on the areal map (pl. 8), but the solid geometry of such a deposit defies verbal description and is better left to the stope outlines of plate 9.

The conspicuous zone of north-trending tears divides the stoped areas into an eastern part within which the ore bodies were relatively large and continuous and a western part within which the bodies were smaller and less continuous. The eastern or principal ore zone begins near the 954 level at its lower southeast end and rises toward the northwest as a group of irregular bodies which cross the 1,000 level along the Smith lead stope and continue through the 1,042 level where the zone narrows and takes a northerly course, connecting through mine openings and pillars of mineralized ground with the Little Jack stope.

In the western part of the mine the ore extended downward 20 to 30 feet below the 1,000 level near the main portal. From this area two nearly horizontal pipes branched toward the east. A northeast branch, arcuate in plan, narrows toward the northeast and does not connect with bodies in the central part of the mine. The other branch is followed by the main adit at the 1,000 level and connects eastward with the exceedingly irregular bodies mined on the 1,042 level and above.

Ore was also mined at the western end of the 954 level and to an unknown depth below in stopes that are now backfilled.

GEOLOGIC CONTROLS OF ORE DEPOSITS

Sulfide minerals occur along certain fissures belonging to each of the four groups of faults recognized in the mine, indicating that these faults are presulfidation. As all the faults in the mine are regarded as essentially contemporaneous, it follows that all are probably older than the ore.

The primary ore was deposited by solutions which rose mainly along high-angle tears in the footwall of the Principal thrust. Where the conduits abutted upward against thrust faults, layers of clay gouge along the thrusts commonly prevented the solutions from passing into the hanging wall blocks. At such places the mineralizing fluids spread laterally, replacing the dolomite and limestone in the footwall blocks. The most effective and the only persistent barrier of this sort was the sole of the Principal thrust, which generally defines the upper and eastern border of the main zone of ore above the 958 level. The zone of junction between the most southerly belt of south-dipping thrusts and the Principal thrust is along an arch pitching southeast. Between the 954 and 1,072 levels the main run of ore lies beneath this arch.

There is no evidence that the ground replaced by the sulfides was brecciated, nor was it in all places dolomitized. The spacing of the fractures appears to have been the critical factor in mineralization. Favorable ground was apparently that in which the faults are closely spaced so as to define blocks that range from a few feet to a few tens of feet across. Ground in which the faults were more widely spaced was generally unfavorable for replacement.

Workings in the lower parts of ore bodies in the western part of the mine along the 1,000 level and below are largely inaccessible. However, as the long dimensions of these bodies parallel the trends of high- and low-angle faults mapped on the 1,000 level, it would appear that the ore here was largely controlled by the faults.

Mineralizing conduits along high-angle faults can be recognized with reasonable certainty in different parts of the mine, but some of the faults are known to disappear at depths above those explored in the lower workings. These must have been local conduits only, and their connection with the ultimate sources of the mineralizing solutions remains unknown. The zone of feeding fissures most likely to persist to depths considerably below those of present exploration is the group of north-tending tears that bisects the mine.

BEDDING

Near the portal of the 1,000 level the stope backs are in bedding surfaces of the Yellowpine member. Elsewhere the ore appears to have been laid with the bedding only where small parts of mineralized zones are considered. It seems reasonable that partings between strata locally guided movement of mineralizing solutions, but it is certain that these are not responsible for the general distribution of ore in the mine.

DOLOMITIZED ZONES

Probably a larger proportion of the dolomitized Yellowpine member is mineralized in the Potosi mine than in most other mines of the district. However, some of the limestone contains sulfide ore, whereas much of the dolomite does not, so that dolomitization cannot have been, strictly speaking, the limiting factor that determined positions of ore bodies.

THRUSTS

Thrust faults localized the primary ore in two ways. Locally the openings along thrust planes were conduits along which the mineralizing solutions moved. More generally the thrust soles, plastered with clay gouge or by impermeable shale, were barriers to the migration of solutions. The ore bodies formed along thrust conduits are insignificant, but those that backed against thrust baffles are the largest in the mine.

The only clear example of ore along a thrust conduit is above the 1,000 level at mine coordinates 1,000 east and 1,525 south. A thin ore seam, containing galena, largely follows a minor thrust dipping 18° toward the south.

Shears in the zone of the Principal thrust generally form the backs of stopes along the eastern side of the main run between the 954 level and the highest parts of the mine. One of these is spectacularly displayed in the Big Jack stope (1,094 level, pl. 10). Similarly the upper limit of mining in the Little Jack stope is in part along a thrust dipping southward from 30° to 45°. Along the main adit of the 1,000 level and above on the 1,042, the south-dipping thrusts locally form the backs of the stopes.

The south-dipping thrusts on the 1,000 level may be branches of the Principal thrust. If so, the main run of stopes above the 954 level backs against the arch of the Principal thrust where the fault changes strike from north to east. However, mapping of the surface geology favors the interpretation that the Principal thrust, despite conspicuous undulations, maintains a general northerly course through the mine. Thus by the simplest interpretation of the geology, the east-trending thrusts along the 1,000 and 1,042 levels join the Principal thrust as footwall structures. The effect is virtually the same as though the Principal thrust had changed strike as has been supposed. The southeastward pitch of the main run between the southern 1,072 and the 954 levels is now explained as controlled by the zone of junction between the Principal thrust and the most southerly as well as the most pronounced zone of east-trending thrusts in its footwall.

HIGH-ANGLE FAULTS

Tabular bodies of ore several feet thick have been mined from along the following high-angle faults:

a. Two north-trending faults dipping west at 78° and 80°, and crossing the eastern end of the Little Jack stope (pl. 10).

b. Two north-trending faults, one dipping 80° E., the other 75° W., both paralleling the western margin of stopes along and above the 1,094 level (pl. 10).

c. The east-trending fault dipping 85° S., together with subparallel faults crossing the southern end of the Smith lead stope on the 1,000 level (pl. 11).

d. The east-trending fault dipping 80° S., exposed 50 feet east of the main portal on the 1,000 level (pl. 11).

e. Arcuate faults dipping 72° and 77° SE. and following the curved stope in the northwest part of the 1,000 level (pl. 11).

f. An east-trending fault dipping 80° S. in the southeast part of the 1,042 level (pl. 11).

It is probable that each of these faults provided a conduit along which mineralizing solutions were channeled; and as each is associated with large stopes, it is also probable that these conduits were in some measure responsible for the ore bodies that lay adjacent to them as well as for the relatively narrow tabular bodies along them. This raises the question as to whether these fault-conduits persisted downward to depths at which mineralizing solutions originated, or whether they were merely local conduits linked at depth with others of the same or a different nature. The three east-trending faults (*c*, *d*, and *f*) must have been local conduits only, as none of them persists from the level on which it is mapped to the next levels above or below. The vertical extent of faults (*a*) and (*e*) remains unknown, as there is no access to levels below those on which they are mapped. The two north-trending faults of example (*b*) belong to the conspicuous zone of tears that bisects the mine workings, and this zone persists from above the 1,094 level at least to the 1,042 level, a vertical distance of about 70 feet. This is the most persistent zone of high-angle faults known in the area, and from the evidence at hand, the most likely to continue through the Bullion and into the Anchor below the mine.

SPACING OF SHEARS

The rocks are less broken in the Potosi mine than in the Yellow Pine and other mines in the district. No persistent zones of brecciated ground were observed. Most of the thrusts are tight shears as are many of the high-angle faults. Irregular masses of sulfides are commonly observed in rock which is, to all appearances, unbroken.

Granted that the mineralizing solutions moved upward into the mine area mostly along high-angle faults, and granted that this movement was locally retarded or blocked by layers of gouge along the thrusts, it remains to be determined why some zones below the thrusts and around the conduits were replaced by ore whereas others were not. There is no evidence that the favorable zones were lithologically different from the unfavorable zones, nor is there any reason to believe that the favorable ground was brecciated whereas the unfavorable ground was intact. There is, however, a geometrical relationship between the position of ore and the spacing of fracture surfaces. The ground around the stopes is crossed by many fractures spaced at intervals from a few feet to a few tens of feet; whereas the barren ground is crossed by few fractures spaced at wide intervals. The 908 level is the only one in the mine that is without ore showings; it is also the only level that does not cross conspicuous fractures; those shown on plates 10 and 11 are without exception minor shears. On the 1,000 level the ore zones are also zones of closely spaced shears, whereas the barren crosscuts between ore bodies or beyond the limits of productive zones cross few shears.

ANCHOR MINE

By CLAUDE C. ALBRITTON, JR., and ARTHUR RICHARDS

The Anchor mine is 7 miles west of Jean (fig. 2). A dirt road leads to the mill and from there a foot trail follows half a mile westward up a canyon and along a cliffy slope to the main portal at the head of an inclined shaft. The collar is at an altitude of about 4,250 feet,[16] 550 feet higher than the mill.

The Anchor group comprises seven patented and three unpatented claims held under option and in process of being acquired [17] by the

[16] Company maps use an assumed altitude of 5,000 feet, and this convention is followed on maps accompanying this report.

[17] In April, 1944.

Diamond Gold Mining Co.[18] The first location is said to have been made in 1893 by Richard Duncan, who later sold to S. E. Yount and George Fayle. In 1914 the property was sold to the Goodsprings Anchor Co. (S. W. Mudd, F. A. Keith, and associates). The company operated from 1914 to 1919, the interval of greatest productivity. When operations ceased in 1919, the mine was essentially the same as shown on Hewett's map.[19] During the years 1919–21 the ground was leased by Frederickson and Egger, and in 1922 the lease passed to J. J. and J. H. Smith. Operations by the Smith brothers continued until February 1932, and after closing the mine for lack of a market, they bought the property. It lay idle until June 1942, when the Diamond Gold Mining Co. acquired an option. From that time the mine operated until the summer of 1944. There was no activity when the writers revisited the property in September 1945.

Plate 13 shows the plan of workings. The main shaft, inclined west at 39°, is about normal to the profile of the steep hillside. Levels leave the shaft at altitudes 43, 84, and 125 feet below the collar. From the third level a winze leads downward at an average slope of 29° to the short fourth level which is the deepest part of the mine, 223 feet below the collar of the shaft. At the south end of this level a crooked raise has been driven westward for 270 feet at an average inclination of 50°. A short tunnel opens south of the hoist at the altitude of the first level underground.

ROCK UNITS

The workings expose 140 feet of the Anchor member of the Monte Cristo limestone, characterized in this area by its highly variable lithology. Originally there were three main types of rock: massive limestone, thinly bedded limestone with lentils of primary chert, and thinly bedded noncherty limestone. Preceding or during the general period of mineralization, all three types were locally altered to dolomite. The complex interfingering relations between the limy and dolomitic phases of the three facies are shown on plate 14.

The section is conveniently divided into three parts: footwall, intermediate, and hanging-wall beds, named in order from oldest to youngest. The intermediate beds, 20 to 25 feet thick, are thinly bedded and contain chert throughout the mine. The hanging-wall and footwall beds contain massive units of dolomite and limestone, although these may grade laterally or vertically into thinly stratified beds with or without chert.

Locally the entire intermediate part contains chert, but in most places the chert persists only in the upper 3 to 5 feet and in the lower

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[18] P. A. Simon, Jean, Nev., President.

[19] Hewett, D. F., 1931, Geology and ore deposits of the Goodspring quadrangle, Nevada: U. S. Geol. Survey Prof. Paper 162, pl. 40.

3 to 4 feet of the sequence. Both these zones carry from 25 percent to 50 percent of light-gray to almost white chert as lentils from a fraction of an inch to 8 inches thick interbedded with gray dolomite in beds of comparable thickness. The "lower" and "upper" cherty beds, as they are designated in this report, provide the necessary stratigraphic markers for defining local structures.

FLEXURES

The beds of the Anchor member strike generally north-northwest and dip west at an average of 33°. Superimposed across the homoclinal structure are minor flexures that are largely responsible for the sinuous patterns of the marker beds shown on plate 12.

The axis of a shallow synclinal trough roughly parallels the axis of the stoped zone below the third level (pl. 12). A broader trough is indicated by the pattern of cherty beds on the second level south of the shaft. An anticlinal nose is indicated by the attitude of marker beds along the northern part of the first level.

None of these or similar structures can be traced through the mine. Either they were originally discontinuous or their original continuity has been obscured by faulting. The flexures appear to be the oldest structures in the Anchor area. Their origin is unknown. In places they apparently coincide with zones in which the intermediate beds are cherty throughout. Conceivably they may have formed early in the sedimentary history by differential compaction of siliceous and limy muds. More probably they were formed later during stages of folding and faulting.

FAULTS

BEDDING SHEARS AND THRUST FAULTS

In the thinly layered sequences, surfaces of stratification are commonly striated or layered with seams of gouge, indicating that there has been shearing along the bedding. Where chert is lacking, the shears are generally inconspicuous and there has been little or no brecciation. Where the thinly bedded sequences contain chert, the shears are conspicuous, the ground along them is commonly brecciated, and the chert lentils are cracked and rotated out of their original positions. Thus the upper and lower cherty units of the intermediate sequence are generally broken to some degree even where adjacent noncherty beds are intact.

Twenty-seven minor thrust faults were mapped in the mine. The more persistent faults are numbered 5, 6, 7, 8, 12, and 13 on accompanying maps and sections. Although thrusts occur throughout the explored portion of the Anchor section, they appear to be more numerous in the intermediate and hanging-wall beds than in the footwall beds.

Most thrusts cross the strike of the bedding at acute angles of less than 30° and all except four insignificant ones are inclined westward with the regional dip. The dips of the faults range from a few degrees to about 45°; some thrusts are steeper than the bedding, others flatter. The persistent thrusts follow stratification in some places and cut across it at steeper or gentler angles in others. Many thrust surfaces appear to be undulatory, and as the bedding crossed by the thrusts is also wavy, a thrust may cut the same bedding horizon at more than one place along a line of section. Along section *D–D′* thrust 5 crosses the base of the upper cherty unit at four points between the first and fourth levels.

Most thrusts have net slips of only a few feet, and probably the slip does not exceed a few hundred feet for any thrust in the mine. Breccia and gouge zones along the thrusts may be as thin as a fraction of an inch or as thick as 3 feet, but the rocks are noticeably more closely jointed and broken along and adjacent to these faults than elsewhere. The effects of brecciation vary with the type of rock. There has been relatively little breaking where the thrusts cross thinly bedded noncherty units in the hanging wall and footwall sequences. In the massive hanging-wall beds the thrust breccias may be as much as 3 feet thick; they are sharply defined and are so friable that operators have referred to them as "sandy backs." The most conspicuous breccias are where thrusts cut thinly stratified cherty zones.

The sections (pl. 14) show that thrusts of higher inclination commonly terminate above or below on thrusts of lower inclination. It also appears that the thrusts as a group converge down-dip in the mine.

Bedding shears and thrusts are essentially contemporaneous and were formed during the stage of folding and thrusting which affected the district at some time between the Late Jurassic and the middle Tertiary.[20] Some of the thrusts clearly pass into bedding shears at inflections in the strike or dip of the stratification. Sections *A–A′* and *B–B′* both show a steepening of the bedding upward from the third level. Faults 7 and 8, essentially parallel with bedding at the third level, leave the beds at their points of upward inflection and cut across the stratification. Fault 7, which is in the hanging-wall beds at the third level, is in the footwall beds at the first level.

It is thus possible that a reason for the abundance of minor thrusts is to be found in the numerous irregular flexures already described. At least locally these had the effect of deflecting into thrusts many shears that in a homoclinal structure would doubtless have followed the bedding and produced breccias in narrow zones mostly confined to thinly bedded cherty sequences.

[20] Hewett, D. F., op. cit., p. vii.

HIGH-ANGLE FAULTS

WESTERLY DIP

Arcuate or sinuous fractures dipping west at angles averaging between 70° and 80° are more numerous in the lower than the upper levels. Where relative movement could be determined, it was found to be normal in all but one example.

The most conspicuous faults of this group are designated by nos. 2 and 3 (pl. 12; 4th level and stope 4,820.) Fault 2 has a minimum stratigraphic displacement of 30 feet; fault 3 a throw of 6 feet. Traces of both faults are convex toward the east with minimum radii of curvature between 100 and 120 feet.

Several west-dipping faults are crossed in the northern half of the third level. Near the stoped zone south of the shaft fault 9 arcs southwest, crossing the southern parts of stopes 4,830 and 4,845. Aggregate displacement for the faults on this level is not more than a few feet.

Where fault 14 crosses the second level south of the shaft, it shows a sharp convexity toward the north. The south side has apparently moved west from 15 to 20 feet. East of the arc the fault continues southeast and crosses the first level near the south end (pl. 12).

EASTERLY DIP

These are faults of sinuous trend that strike generally between north and northwest. Displacements are prevailingly normal, and for all but a few examples amount to only a few inches or a few feet. Measured displacements of 10 feet or more are confined to four faults and their branches.

Fault 4 crosses stope 4,830 trending northwest. The throw is 15 feet. As this fault does not appear in its projected position at the south end of the third level, it is likely that south of stope 4,830 the displacement is carried along the branch dipping 60° E.

Fault 10 trends north along the northern part of the third level. Striae on the slickensides are within 22° of the horizontal suggesting a predominant component of strike-slip movement with the west side displaced toward the north. The throw ranges from 15 to 20 feet. This fault was not recognized in stopes below the third level.

Fault 11 is the most conspicuous in the mine. Its dip ranges from 40° to 65°. The throw ranges from 10 to 20 feet, apparently decreasing slightly toward the south.

The fault with the largest apparent displacement is no. 18, mapped in the tunnel at the first level. The trace is broadly sigmoid. The dip ranges from 44° to 60° and the throw increases from 40 to 70 feet toward the south. Two branches (16 and 17) cross the first level to the west.

EASTERLY STRIKE

High-angle or vertical faults trending between east and northeast are most numerous in the northern part of the second level and at the south end of the first and second levels. Exact displacements could not be determined, but it is unlikely that the slip along any one of these faults exceeds 20 feet.

INTERRELATIONSHIP OF FAULTS

The bedding shears and thrust faults are displaced by and are clearly older than the high-angle faults dipping east and west. The high-angle faults of easterly and westerly dip apparently are contemporaneous, as examples of the two groups are seen to join in several places, whereas in no place does a fault of one group appear to offset one of the other.

The place of the east-trending faults in the chronology is not clear. Some, such as fault 15, are probably tears and hence related to the early stage of thrusting. However, at the south end of the second level, a member of this group cuts and slightly offsets a persistent east-dipping fault (no. 11). Tentatively the east-trending faults are regarded as tears along which there has been renewed movement since the development of the east-dipping group.

ORE DEPOSITS

GENERAL FEATURES

The ore is a replacement of dolomite of the Anchor member. Shoots have their longest dimensions along lines trending west or southwest and are inclined prevailingly westward at angles ranging from 20° to 30°. In form the bodies are flattened pipes 3 to 15 times as broad as they are high. Locally, as between the second and third levels, the pipes are almost cylindrical.

Although the ore is largely oxidized, enough galena remains to show that the shoots of oxidized ore occupy essentially the same positions as the primary ore bodies. This, combined with the fact that the shoots have been mined to near the point of depletion, indicates that the pattern and dimensions of stopes as shown on plate 13 give the approximate plan of the primary ore bodies.

Lead and zinc are intimately associated throughout the greater part of the mineralized zones. The average product of the mine is a mixed ore, which in the richer ground contains from 40 to 45 percent of lead and zinc combined. The normal lead-zinc ratio is about 1:3. Certain bedding seams—particularly those in the hanging-wall ore bodies—contained lead almost exclusively, in amounts from 50 to 70 percent. Crude lead ore, as mined in the past, commonly contained less than 10 percent zinc, and from 6 to 16 ounces of silver per ton of ore. Zinc ore, as sorted for shipment to the Jean stockpile, contains from 1 to 8 percent lead and from 14 to 32 percent zinc. In years past the zinc content has been higher; it averaged from 26 to 35 percent for shipments made in 1915, and from 35 to 42 percent for shipments made before 1915.[21]

MINERALS

Of the minerals commonly found in the mine, dolomite, calcite, and galena formed during the stage of ore deposition. Doubtless sphalerite also formed at this time, but it has since oxidized to calamine or hydrozincite. Black powdery manganese oxide is uncommon but it occurs with limonite along some otherwise barren fissures, and with galena in the hanging-wall bodies. Fine hairlike crystals, identified by Hewett as epsomite ($MgSO_4.7H_2O$), have grown on the walls of some of the older workings, as in the southern part of the third level.

The distribution of galena is shown on acompanying maps and sections (pls. 12, 14). Along faults it occurs as scattered crystals or in pods and veinlets as much as 6 inches across. In dolomite breccias, as west of the shaft on the second level, the mineral is in ellipsoidal masses as much as 1 foot across. It also forms irregular incrustations on dolomite along the irregular walls of cavernous zones around the stopes (fig. 3). Near the north end of the second level, the galena is altered wholly or in part to cerussite and anglesite; elsewhere it is a persistent constituent throughout the mineralized zone. Probably it was most abundant near the lower terminations of the ore shoots and along the back of the hanging-wall stope (pl. 12).

Association of galena with white calcite and dolomite is noteworthy. In the upper stopes above the first level, calcite fills irregular central portions of old channelways and vugs that were previously lined with galena (fig. 3). White dolomite shows the same relations in the opencut at the head of the shaft. Within the ore seams along bedding, calcite occurs in variable amounts up to 20 percent (fig. 3).

The most common zinc mineral is hydrozincite, generally dense and either brownish, pinkish, or white. Vuggy openings in massive hydrozincite are commonly lined with minute needles of the same mineral.

Calamine ordinarily occurs with the hydrozincite. In the open-textured ore it occurs as aggregates of small crystals, generally masked by limonite films.

ANCHOR ORE BODY

The principal ore body has been developed from the surface at the portal of the shaft to stope 4,820. It strikes N. 20° W., dips 20° W., and rakes southwest at slightly less than 20°. Measured along a line trending northeast, the stope is about 550 feet long. In plan

[21] Hewett, D. F., op. cit., p. 160.

it resembles an isosceles triangle, with a base 350 feet long defining the limits updip, and with sides converging downward toward a point near the south end of the fourth level. The triangular area is divided

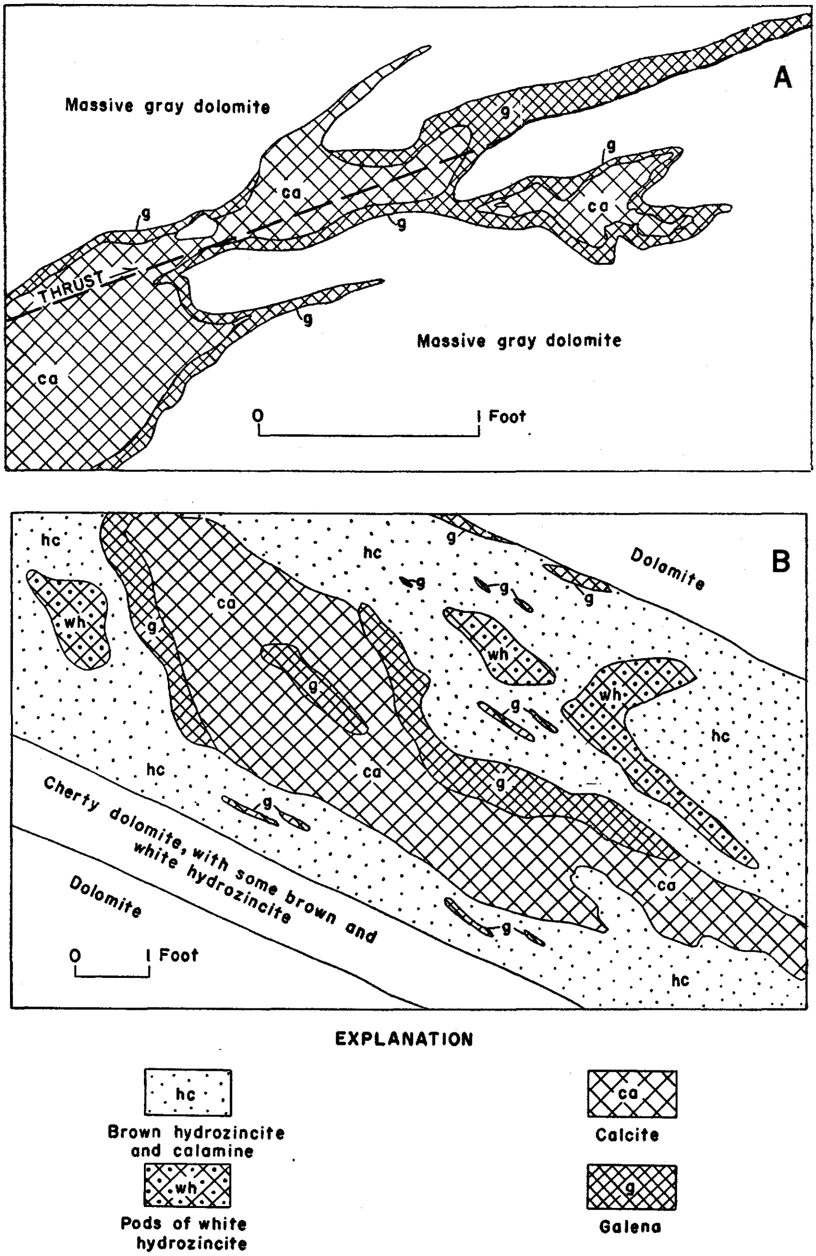

FIGURE 3.—Anchor mine. *A*, Sketch of galena and white calcite along thrust in hanging-wall stope, north of shaft above first level. *B*, Detail of mineralization in South ore body.

into roughly equal halves by the line of rake. Within this area there is only one large block that is barren or only slightly mineralized; this lies between the second and third levels along the south side of the triangle and lends definition to the southeastward arm of the ore body developed above the second and first levels (pl. 13).

The ore thickens up the dip. In the area of the hanging-wall stope the mineralized zone is as much as 60 feet thick. In stope 4,820 near its downward termination the thickness is 3 feet. This downward thinning is not progressive but highly irregular, as indicated by figures for stope height on plate 13.

Below the third level the ore minerals were concentrated within a zone averaging 6 feet thick that followed thrust breccia in and around the upper cherty beds. According to J. J. Smith (personal communication), a former lessee, crude ore contained from 40 to 45 percent lead and zinc, with a lead-zinc ratio of 1:3. Southwest of the constriction in stope 4,830 the ore body was only 1 to 3 feet thick and consisted almost entirely of galena ore. In the west part of stope 4,830 the galena occurred as closely spaced round "boulders," some as much as 3 feet across. These were intact and could be picked from the breccia. Below, in stope 4,820, the galena was shattered and had to be extracted in granulated form.

Above the third level the body continues up the dip as two divergent pipes that expand and connect at the 4,905 level and also connect westward with the main run; this leads to the thickest zones of mineralized ground around the hanging-wall stope and in the southeastern arm above the first level. As the ore has been completely removed in the upper stopes, it is impossible to estimate the proportion of ore to waste extracted, or to ascertain the original attitudes and dimensions of the ore layers.

SOUTH ORE BODY

The stope of the South ore body is 220 feet long and extends from an altitude of 4,887 feet on the second level to one of 5,015 feet above the south end of the first level (pl. 13). The average strike of the ore is N. 10° W., and the dip is toward the west. The angle of dip increases upward by irregular stages. Below the second level the dip is 30°; between the second and first levels it is 40°, and at the first level it increases to 70°. In width the body expands irregularly up the dip from 20 feet near its lower terminus to 55 feet at the upper end.

From the lower end to the second level, the ore was a small pipe only 1.5 feet thick, in brecciated lower cherty beds. According to J. J. Smith (personal communication) the ore averaged 40 percent lead and zinc and the lead-zinc ratio 1:1. Concentrations of galena may still be seen, especially at the lower end of the stope. Above the second level the ore was 6 feet thick and the proportion of zinc was higher. Typical ore from here is said to have ranged from 30 to 35 percent zinc and from 12 to 15 percent lead. At the upper end, above the first level, the ore bed cannot be defined and the ore minerals are dispersed through a zone of about 30 feet within which are stringers of ore 2 inches or less thick.

OTHER ZONES OF MINERALIZED GROUND

Beyond the limits of profitable extraction there are zones of mineralized rock related to the Anchor ore body. Such, for example, are thin breccia bodies explored updip to the east from the fourth level (pls. 13, 14). An iron-stained breccia locally contains pods of galena. Zinc minerals are either lacking, or present in amounts estimated as not exceeding 2 percent.

The eastern tunnel at the general altitude of the first level explores the downfaulted segment of the Anchor ore zone east of fault 18. Galena is scattered throughout the sheared cherty intermediate beds. Local concentrations of zinc are in bedding seams that rarely exceed 1 foot in thickness. The grade (17 to 30 percent zinc) of individual seams is relatively high, but their wide spacing has discouraged mining.

Near the south end of the second level, a pipe of dolomite breccia has been explored by a short winze and raise (pl. 13). The pipe is about 5 feet across, roughly elliptical in section, and has a tortuous course with a general plunge toward the west. The interior is a breccia of dolomite pebbles cemented by milky calcite that forms masses as much as 1 foot long and 6 inches thick. Galena is in the calcite as discrete cubes and as pods as much as 6 inches long and 3 inches thick. Thin lentils of brown hydrozincite and limonite persist to distances from 2 to 10 feet away from the pipe in all directions. Wherever ore minerals are present the country rock is dolomitized; elsewhere in this part of the mine, the black crinoidal limestone is unaltered.

Along the north end of the third level the lower cherty unit is sporadically mineralized where broken by thrusts. Irregular workings extending to the west explore the broken cherty beds where they contain pods of galena and lenticular masses of brown hydrozincite. The mine operator estimated that the sorted material should contain from 35 to 40 percent zinc and from 4 to 5 percent lead. This same cherty zone is duplicated by faulting and again exposed near the entrance to the long crosscut east. Here the chert is bleached and the interstitial dolomite partly replaced with white hydrozincite. The material contains about 14 percent zinc. No galena was observed, and none was reported by the mine operator from a short inclined stope, now inaccessible, above the level.

Along the northern end of the second level the brecciated lower cherty unit is mineralized for about 50 feet north and south of fault 15. North of the fault this zone has been explored along the level and in an incline that follows the beds updip for 15 feet. South of the fault the zone was followed for 50 feet to the surface along a raise. The cherty breccia contains abundant limonite and scattered pods of galena as much as 6 inches across. Galena is partly altered to cerussite, and the exceptional degree of oxidization in this area may explain the apparent absence of zinc.

GEOLOGIC CONTROLS OF ORE DEPOSITS

Before formation of the ore bodies, the beds of the Anchor had been warped and tilted toward the west as a consequence of regional folding. Throughout the district this stage of deformation was marked by the development of westward dipping thrust faults, the larger of which had displacements of thousands of feet. Although none of the principal thrusts crosses the Anchor area, many subsidiary thrusts were formed and the rocks cut by these were brecciated in varying degrees. Crushing was most intense in thinly bedded cherty units. At flexures in the strata, bedding shears passed into thrusts extending the broken zones into adjacent units of massive rock.

After the thrusts had developed, the terrain was broken by high-angle strike-faults dipping east and west. Mineralizing solutions rose along some of these fissures and spread laterally and upward through thrust-breccias abutting against them. Effects of alteration were most widespread in the conversion of limestone to dolomite. During or following dolomitization the more open and broken zones to which the solutions had access were filled and replaced by sulfides, of which galena and sphalerite were the most common. Such openings as remained after the sulfides had been deposited were partly or wholly filled with white calcite and coarsely crystalline dolomite.

Renewed movement along some of the high-angle faults locally sheared galena veinlets along the faults and slightly displaced adjacent ore bodies. The problem of classifying the high-angle faults as premineralization and postmineralization is thus difficult. There are a few faults like the west branch of fault 4 that contain unsheared galena veinlets and along which all of the movement appears to have been presulfidation. There are a few other faults like fault 2, that contain unsheared galena veinlets in some places and sheared veinlets in others; and these may be reasonably interpreted as presulfidation faults along which there has been local postsulfidation movement. There are many others like fault 11 that are not followed by galena veinlets and which, so far as their geometrical relationships with the ore are concerned, might be either presulfidation or postsulfidation. Areal mapping between the Anchor and Fredrickson mines (pl. 1) suggests that the pattern of faults in the Anchor mine was probably established before mineralization and that the high-angle faults prob-

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ably originated as rifts and tears, but that there has been movement along many of the faults after mineralization.

The ore bodies have been oxidized, but their forms have been but slightly modified by transfer and redeposition of minerals. Galena remains generally unaltered, and although sphalerite is not found, its original presence is postulated to account for the large quantities of hydrozincite and calamine.

LITHOLOGY

Ore occurs only in dolomitized rock, and is more widespread in cherty than in chert-free zones.

The cherty intermediate beds are the most consistently mineralized in the mine. Where the ore is unusually thick, as near the hanging-wall stope and at the south end of the first level, the hanging-wall sequence has been mineralized in addition to the intermediate beds.

Only locally are the footwall beds mineralized They contain ore in the upper few feet on the east side of stope 4,845 and also in the lower part of the Anchor and South ore bodies along the second level south of the shaft.

The cherty beds generally are the most favorable for ore and where ore is in the massive hanging-wall beds the underlying cherty sequence is also mineralized. Furthermore the cherty units have been more susceptible to dolomitization than chert-free units. At the south end of the mine, where the section is less dolomitic and locally grades into unaltered limestone, the upper and lower cherty units are dolomitized throughout. Hewett [22] has shown that for the district as a whole dolomitization is to be regarded as a phase in the process of mineralization. Thus the fact that cherty units are dolomitized where chertless units are not altered provides supporting evidence for the belief that mineralizing solutions were most widely dispersed in the cherty beds.

Yet it does not follow that distribution of ore is directly determined by lithology. South of the Anchor stope on the third level, the cherty beds are dolomitized but otherwise unmineralized. It is only where they are brecciated that they contain ore. As noted previously, the cherty units have been extensively shattered by bedding shears and thrusts. The chert is relatively brittle and breaks into angular fragments, making the breccia highly permeable and relatively insoluble. Because of this the cherty beds are locally significant as the common carriers of mineralizing solutions.

BEDDING SHEARS AND THRUSTS

Ore bodies occur in broken zones along bedding shears and thrusts. Bedding shears produced breccia only in the relatively brittle cherty beds. Locally, as at bends in the bedding, shears broke across the

[22] Hewett, D. F., op. cit., p. 57–67.

bedding. In thin-bedded units the thrusts discordant to the beds produced brecciation beyond that produced by bedding shears in the same ground. In massive rock, as in the hanging-wall sequence, the thrusts are largely responsible for brecciation.

In the Anchor ore body the intermediate beds are everywhere fractured, but are most broken along the belt where they contain chert throughout. The extent of this belt is reflected in the pattern of stopes below the third level along the line of section *C–C′* (pl. 13), and in the southern arm of the stope at the first level. Brecciated rock that made permeable zones in the otherwise dense hanging-wall beds was due to movement along the thrusts shown in sections *D*, *E*, and *F*.

The South ore body begins east of an upward bend in the bedding, and follows a zone of brecciated ground related to faults 7, 8, and associated thrusts (sec. *B–B′*).

HIGH-ANGLE FAULTS

Mineralizing solutions fed up and into the permeable thrust zones from conduits along high-angle faults. If only those faults along which there is abundant galena are to be designated as conduits, then the probable feeders of the Anchor ore body include the west-dipping faults 2, 3, and 9 and the east-dipping fault 4 (pl. 12). Each has a significant relationship with the geometry of the stopes or with the type of mineralization in the ore bodies themselves. Fault 2 lies at the apparent lower end of the Anchor ore body. Positions of faults 3, 4, and 9 are reflected in local widenings of the ore zone along the strike. It is noteworthy that west of fault 4 the metal content of the ore was almost entirely lead with only small amounts of zinc, whereas east of the fault both zinc and lead were present.

The South ore body begins along a vertical fault that carries abundant galena (sec. *B–B′*.) East (updip) of this fault the rocks are dolomitized; to the west they are unaltered.

The breccia pipe at the south end of the second level apparently is a mineralizing conduit that produced but little effect on the adjacent beds.

Other faults possibly acted as local feeders. These are bordered by mineralized ground containing galena, but do not have sulfide veinlets between the fault walls. Examples include the west-dipping strike faults along the north third level, similar shears in the main stoped zones on the second level, and faults 14 and 15.

Even these questionable examples of conduits are concentrated in the lower levels of the mine. None were mapped on the first level in the Anchor ore zone and fault 14 was the only one mapped on the first level in the South ore zone. It appears therefore that the weakening of mineralization updip in the case of both ore bodies is a function of distance from source of feeding.

ARGENTENA MINE

By Arthur Richards and Claude C. Albritton, Jr.

The Argentena mine is near the crest of a ridge extending southward from Columbia Pass (fig. 2). A dirt road connects the camp with the graveled highway leading over the pass and to Goodsprings. Owned and operated by the Argentena Consolidated Mining Co.,[23] the property includes two patented claims, three unpatented claims, and a millsite. A. G. Campbell and A. E. Thomas located two of these claims as early as 1887, but most of the work has been done since 1926, the year in which Fred Piehl took the property under lease and option. The Argentena Mining Co. was organized early in 1927 and reorganized as the present company late in the same year. With the construction of a 60-ton flotation gravity concentration mill in 1927, the Argentena became one of the best equipped mines in the district. Although its principal products have been lead and zinc, there have also been small shipments of vanadium ore. (A shipment of 27 tons made in 1928 contained 7.8 percent V_2O_5. In 1942–43 the Metals Reserve Co. purchased 705 tons containing 0.88 percent V_2O_5.)

ROCK UNITS

The rock units that crop out in the area include about 300 feet of upper Paleozoic limestone, dolomite, and sandstone, overlain unconformably to the west by Tertiary tuff and andesite and by Recent alluvium. The exposed Paleozoic section is given below.

As indicated, most of the Paleozoic limestone has been dolomitized in the Argentena area. Limestone remains mostly as irregular residuals in the Bird Spring formation, but in the extreme south of the map area (pl. 15) there are also patches of limestone in the Yellowpine.

Although dolomitization is regarded as a process related to ore deposition, it should be emphasized that the pattern of alteration observed in the basal beds of the Bird Spring is unlike the pattern of dolomitized and mineralized rock in the Yellowpine. Locally unaltered beds of the Bird Spring overlie dolomitized and mineralized ground in the Yellowpine, and the largest limestone cropping in the area is directly above the stopes of the No. 1 workings.

STRUCTURE

BEDDING

The Paleozoic rocks strike prevailingly northward, and dip at low angles toward the east in the eastern part of the area and toward the west in the western part. Dips are mostly less than 10°, and

[23] H. L. Martin, president; Fred Piehl, vice-president and general manager.

Age	Formation	Member	Character	Thickness (feet)
Pennsylvanian.	Bird Spring formation.		Top not exposed.	
			Limestone, shaly dark-gray, largely altered to tan dolomite.	30
			Dolomite, sandy gray to tan, containing lentils of brown chert.	15
			Dolomite, light-gray to white, interbedded with tan chert in beds as much as 6 inches thick; unit is two-thirds dolomite and one-third chert.	8
			Limestone, dark-gray thinly bedded, containing a few lentils of dark-gray chert; rock altered to dolomite over most of area.	25
			Dolomite, banded fine-grained gray and white, contains abundant slightly curved and concentric openings an inch long and a fraction of an inch across.	8
			Limestone, dark-gray to black fossiliferous, altered to dolomite in most of the area.	50
			Sandstone, gray to tan fine-grained, containing dolomite lentils as much as 3 feet thick.	10
			Total exposed thickness	146
Mississippian.	Monte Cristo limestone.	Yellowpine limestone.	Dolomite, cream to light-gray, obscurely bedded or massive, parted in middle by 6 inches of shaly dolomite, and by scattered lentils of primary chert; horn corals from 3 to 14 inches long, locally abundant.	80–85
		Arrowhead limestone.	Dolomite, fine-grained, in beds from 2 to 6 inches thick separated by wavy seams of shale.	10
		Bullion dolomite.	Dolomite, cream to light-gray coarse-grained. Base not exposed; thickness of exposed section.	50+
			Total exposed thickness	140–145

exceed 15° in relatively few places. Opposed dips in the east and west are interpreted as defining a broad anticline, the axis of which would bear from north to north-northwest and would trend from near the southeast corner of the map area to near the road directly east of tunnel 2. However, the terrain is broken by so many faults that it would be difficult to determine whether there is a fold dislocated by faults or whether the dislocation by faulting of originally flatlying beds has produced a fold or the semblance of one.

RIFTS

Many high-angle faults trending from northeast and northwest are linked to form a complex anastomosing pattern (pl. 16). All the principal faults and many of the subsidiary ones are marked by reefs of breccia. Fragments range in size from chips a fraction of an inch thick to "horses" several tens of feet across. In fresh exposures underground the breccias show many closely spaced shears (pl. 17), but these are not generally apparent on weathered slopes. The striae on slickensides are within a few degrees of the horizontal, indicating strike-slip movement. Even without the evidence of striae the fact that the thickness of a fault breccia commonly equals or exceeds the throw of the fault would in itself suggest rifting.

It is not necessary, however, to rely on local evidence for an understanding of the fault movements. The principal fault in the mine area is no. 1, marked by a belt of breccia that has a maximum exposed width of 225 feet. Beyond the limits of mapping, about 1,500 feet northwest of Argentena camp, a north-trending fault joins no. 1 and the single large fault formed by the junction of the two continues northwest as the Fredrickson fault. Where high-angle faults with predominant strike-slip displacement cut gently inclined beds that show local reversals in directions of dip, it is sometimes difficult to classify the faults as rifts or tears. The Fredrickson is an example. At its northern end it is strictly speaking a tear; farther south it is a rift. In this report it is classed as a rift, because its strike is near the regional strike of beds in the district. West of the Fredrickson mine, the fault continues as a bedding thrust that strikes northeast and dips southeast. The areal relationships, considered with the near-horizontal slickensides preserved on fault walls near the Fredrickson mine (fig. 2), led Hewett to conclude that the Fredrickson fault was formed during the thrust epoch and that the movement along it has been essentially horizontal, with the southwest side displaced relatively toward the northwest (pl. 1).[24]

On plates 15 and 16, where the principal faults are designated by numbers, it is apparent that faults 2 and 3 are branches of fault 1, and that the no. 4 is a branch of the no. 2. By branching and junction all the persistent and most of the subsidiary high-angle faults in the map area are linked with no. 1. Therefore, the mine is in the Fredrickson rift zone.

A structural peculiarity noted in connection with several of the minor faults is that the apparent displacement reverses along the strike, with the result that the upthrown side along one segment becomes the downthrown side along another segment. For example, along a vertical fault near the northeast corner of the area (pl. 15),

[24] Hewett, D. F., op. cit., p. 49.

the Yellowpine is dropped on the west against the Arrowhead on the east, whereas only a hundred feet to the southeast the Bird Spring is dropped on the east against the Yellowpine on the west.

The largest faults crossed in the mine are those numbered 2 and 4. Displacement along fault 2 is normal and the throw measures about 60 feet. Displacement along fault 4 is reverse, and the throw is about 45 feet along the line of section *C–C′*. The wedge-shaped block between the faults is structurally higher than the blocks adjacent.

Many minor high-angle faults are exposed underground. Most trend between north and northwest and the majority dip west at angles from 60° to vertical. Commonly the faults appear as crevices several inches wide. The throws are measured mostly in inches. Some of these faults terminate upward against the sheared Bird Spring contact, and as few of them persist to the surface, most are probably nonpersistent shears in the upper beds of the Monte Cristo.

THRUSTS

Minor thrusts are fairly common underground, especially in the No. 1 and No. 3 workings, but few can be traced for as much as 50 feet along the strike. It is generally impossible to measure displacements, but probably none of the faults mapped has a slip exceeding a few feet. Although the strikes bear in all directions, two-thirds of them are east-northeast and north-northeast. These thrusts dip southeast and northwest in about equal numbers, at angles from a few degrees to 45°. It is generally impossible to see minor fractures of this sort on weathered slopes; only two thrusts were mapped on the surface as compared with about 70 mapped underground.

RELATIONSHIP BETWEEN RIFTS AND THRUSTS

Locally the high-angle faults terminate against thrusts, as in the middle of the No. 3 workings. Elsewhere, as at the north end of the No. 1 workings, the thrusts are displaced by the high-angle faults. Relationships indicate that some of the thrusts and rifts developed contemporaneously, and that other thrusts developed before the rifts displaced them. It is reasonable to assume that the differences in age thus suggested are negligible as geologic time is measured, and that all the faults in the mine developed during a single stage of deformation.

ORE DEPOSITS

The ore forms tabular bodies from 5 to 30 feet thick lying generally with the bedding and replacing dolomite in the upper 40 feet of the Yellowpine member. The pattern of stopes, as they were in the early summer of 1944, is shown on plate 16. No special significance is attached to the alinement of stopes toward the north-northeast. The limits of rock with lead and zinc have been reached in relatively few faces and the present pattern may well reflect more a method of mining than some underlying control of ore deposition.

Calamine is the most abundant zinc mineral, and hydrozincite the next most abundant. Faces of ore generally show pockets and bands of high-grade ore, 1 foot or less across, set in masses of low-grade ore. The rich ore is largely calamine and hydrozincite and the low-grade ore contains smaller amounts of these minerals in a gangue of tan or pink dolomite. Smithsonite and sphalerite are comparatively rare, but were observed in small quantities in the No. 1 and No. 3 workings.

Cerussite in dark-gray granular masses is generally present; commonly it contains nuclei of galena and anglesite. Although the carbonate of lead is more abundant than the sulfide, galena is scattered throughout the productive zones. It was abundant in the 1*A*, 1*B*, and 1*C* workings and in the small tunnels off the north end of No. 3 workings. The sulfide was also mined from the opencut 200 feet east of Argentena camp (pl. 15). Thin reddish films of cinnabar are commonly found on the galena.

Veins of gray or white barite as much as 1 foot thick, are locally so abundant in the No. 1 workings that it is unprofitable to mine the associated zinc ore. In places the barite has been partially leached, leaving bladed molds that contain crystals of calamine.

A yellowish-brown earthy vanadate found in the No. 3 and in the north end of the No. 1 workings is probably descloizite $(Pb,Zn)(VO_4)_2(Pb,Zn)(OH)_2$. Locally it forms only thin coatings on fragments in dolomite breccia, but at one point near the south end of the No. 3 workings 27 tons of ore containing 7.8 percent V_2O_5 was mined. In some pockets of earthy vanadium ore the horn corals typical of the Yellowpine are coated with powdery descloizite. At one locality in the northeast corner of the No. 3 workings, dolomite breccia is coated with minute greenish-black crystals that are probably cuprodescloizite $(Pb,Zn,Cu)(VO_4)_2(Pb,Zn,Cu)(OH)_2$.

Selective mining coupled with milling or hand sorting has at times yielded lead and oxidized-zinc concentrates. By careful mining in selected areas, crude ore with a zinc-lead ratio of 7 : 1 may be obtained. Normally the ratio ranges from 3 : 1 to 4 : 1. Ore mined in recent years has averaged about 23 percent combined lead and zinc.

GEOLOGIC CONTROLS OF ORE DEPOSITS

FAVORABLE ZONE

As of September, 1945, all the ore taken from the mine had come from the upper 40 feet of the Yellowpine. Mineralized croppings prospected in the map area are also largely in this upper zone. The main adit, driven near the base of the member, is barren. The evidence consistently indicates that the upper part of the Yellowpine was more favorable for replacement than the lower.

Insofar as is known, the productive and unproductive parts of the section are lithologically similar. Chert occurs in sparing amounts throughout the section. Horn corals appear to be locally more abundant in the upper beds than in the lower; their presence in large numbers might conceivably increase the porosity of the rock, but there is nothing to indicate that the lead-zinc ore was localized in fossil coral reefs.

Favorableness of the upper part of the Yellowpine as the host for ore appears to be due to the fact that it is the highest zone of thoroughly fractured ground beneath the less permeable capping of the Bird Spring, which here as elsewhere in the district was generally unfavorable for replacement. Along the belt between the Fredrickson and Argentena mines the unconformity between the Bird Spring and the Yellowpine played an important role in ore deposition. In many places, both underground and on the surface, the Yellowpine is intricately fractured and dolomitized, whereas the thinly layered Bird Spring directly above is unbroken and unaltered. It has already been noted that a number of shears in the Argentena mine terminate upward against the basal sandstone of the Bird Spring. In this connection it is instructive to observe the generally wider spacing of fractures in that part of tunnel 2 which is in the Bird Spring as compared with the close spacing of fractures along adjoining parts of the same tunnel in the upper part of the Yellowpine (pl. 17). To say that the unconformity is structurally important in localizing ore is not to deny that the Bird Spring is broken by all the master faults that cross the area; the difference in fracturing of these beds as compared with the underlying Yellowpine is one of degree. There must be innumerable minor shears in the upper part of the Yellowpine which either end at the base of the Bird Spring or disappear within the lower few feet of the Pennsylvanian section.

FAULTS

Concentrations of galena are found along many thrust faults and several high-angle faults in the productive parts of the mine. Locally, but uncommonly, the breccia reefs along the more conspicuous high-angle faults are mineralized. Considering all evidence, it is reasonably certain that all the faults mapped are presulfidation, although some of the gaping fractures with smooth walls may have been opened since the ore was formed.

The mineralizing solutions doubtless rose along broken rocks bordering the larger fractures of the Fredrickson fault zone, which presumably persist to greater depths than the subsidiary fractures.

However, there is no local evidence to indicate the positions of conduits connecting with ore bodies mined to date. If breccias along the more persistent faults (as the nos. 2 and 4) are regarded as feeding channels it must be concluded that ground favorable for feeding was generally unfavorable for replacement; because these breccias, though commonly bordered by ore, are only locally mineralized. If present conditions reflect the conditions that prevailed during the mineralizing epoch, however, the fissured ground bordering the fault breccias was more permeable than the breccia itself. Thus the conduits may have been peripheral to rather than within the breccia reefs.

MONTE CRISTO MINE ("COMBINATION LODE")

By DAVID A. PHOENIX and ARTHUR RICHARDS

The Monte Cristo mine is on the west side of Porter Wash, 8 miles by road from Jean (pl. 1). From 1908, a year after the claim had been located by William Kennedy, there was continuous production through 1919. Since that time there has been but little activity, and the mine remains essentially as described by Hewett.[25] In 1924 the claim was restaked by the present owners, P. S. McClanahan and J. W. Wilson. Small tonnages of ore marketed at Jean during 1943–44 are recorded under the name "Combination lode". The plan of workings is shown on plate 19.

GEOLOGY

Workings are in limestone and dolomite of the Anchor member of the Monte Cristo limestone. The normal rock is a dark-gray limestone in beds from half a foot to several feet thick containing lentils of chert. Generally the chert lentils are scattered through the section, but locally they are closely spaced and account for a third of the rock. Near the main ore body the limestone grades into dolomite, within which the bedding is generally obscure. Narrow bands of silicified ground are locally present in the dolomitized zones.

In the vicinity of the Monte Cristo mine the average strike of the bedding is N. 30° W. and the dip is southwest from 15° to 30°. Throughout the greater part of the mine the beds show this attitude, but locally the strike curves to between north and east-northeast. Abnormalities in attitude of bedding appear to be related to flexures, of which the two most conspicuous—an anticlinal nose plunging west and a synclinal trough plunging southwest—are indicated on plate 19.

The hills near the mine are crossed by many faults, most of which trend northwest and dip at high angles either toward the northeast or

[25] Hewett, D. F., op. ct., p. 156–158.

southwest. The two most conspicuous high-angle faults in the mine belong to this group. One is a rift, of unknown but probably small displacement, dipping southwest and crossing near the south end of the main stope. The other, a vertical fault followed by a long drift from the north portal, has a throw of only 6 feet.

High-angle joints are especially numerous in the southern half of the main workings, and a zone of these fractures may be traced along the back of the stope between the south and north portals.

East-dipping low-angle faults of unknown but probably small displacement were mapped along the east side of the main stope. Presumably these are thrust faults. At the south portal the most conspicuous shear of this group trends north; near the north portal a zone of these faults trends northeast. At several place it appears that the base of the slope wash follows the soles of the faults.

Age relationships of structural elements in the mine are uncertain. At no place was one fault observed to offset another, although there are several places where high-angle faults branch or join, and where low-angle and high-angle faults join without apparent offset. By the simplest interpretation consistent with evidence gathered from the study of the mine and from areal mapping between the Fredrickson and Anchor mines, all the structures are contemporaneous. The northwest-trending high-angle faults originated as rifts; thrusts and flexures developed by stresses acting as horizontal couples within fault blocks bounded by rifts.

ORE DEPOSITS

In plan the main ore body resembles the letter "*J*", with the short terminal hook about 140 feet long, and the longer stem trending northeast and about twice as long. The form of the stope and the glory hole connecting with it at the north indicate the ore body had an average width of 40 feet and increased in thickness from about 8 feet at the south to 20 feet at the north. The axis was essentially horizontal except at the south end where the ore plunged 15° west.

Only small patches of ore remain along the sides of the stope and in the backs. These contain smithsonite, pink and white hydrozincite, and calamine, with which are associated minor amounts of quartz, calcite and iron oxide. Masses of coarsely crystalline white calcite from a few inches to several feet across are common along the walls of the glory hole and in places underground.

In 1912, Hill [26] observed mining in the area of the present glory hole. He reported that the ore was nearly pure white smithsonite.

[26] Hill, J. M., 1914, The Yellow Pine mining district, Clark County, Nev.: U. S. Geol. Survey Bull. 540, p. 271.

That some hydrozincite was mined in this area was, however, assumed by Hill, who noted the mineral in croppings around the stope. This assumption was later substantiated when appreciable tonnages of the hydrozincite ore were sorted from the dump.[27] Nevertheless the reports seem to agree that the ore was largely made of smithsonite at the north and of calamine and hydrozincite at the south. Whether there was any zonal arrangement of the calamine and hydrozincite is uncertain.

No lead minerals and no sulfide of any species were observed in the principal workings. There is no record to indicate that lead has ever been produced. Until 1920 the ore mined averaged about 37 percent zinc; the ore marketed more recently was about 10 percent lower in grade. The occurrence of straight zinc ore is unusual for the district, and finds its closest parallel in the smaller Houghton ore body. However, there are bodies of sphalerite ore in the upper stopes of the Potosi mine, which if oxidized in place would probably resemble the Monte Cristo ore body in composition and grade as well as in form.

From two prospects, a short distance up the slope from the main workings, 12 to 15 tons of galena have been mined (pl. 19). The galena is in crystals averaging an inch across and set in a bedding seam of milky calcite 1 to 2 feet thick. There is no record of shipment and the deposits appear to be small and unpromising, but the occurrence of galena in such close proximity to the main body of oxidized zinc ore is noteworthy.

GEOLOGIC CONTROLS OF ORE DEPOSITS

The southern end of the main ore body lies along the south flank of an anticlinal nose and plunges west with the plunge of the fold. The ore lies in and a few feet above a 4-foot zone of thinly bedded dolomite which is in most places conspicuously more cherty than the rocks above or below it. North of the south portal the axis of the shoot parallels the strike of east-dipping thrusts, and the ore lies mainly in the footwall of the thrust zone. Between the two portals the axis of the shoot follows a swarm of high-angle joints. It is not known whether the plunging synclinal warp shown on plate 19 has any relationship to the ore mined from the glory hole, as the bedrock is covered with waste or alluvium in the area where the axis of the structure should project.

In summary, the ore lay in a zone of dolomitized and locally silicified ground, which in many places grades into unaltered limestone

[27] Hewett, D. F., p. 157.

at distances of a few feet away from the mineralized rock. Locally the shoot follows favorable beds that are thinly stratified and cherty, but for the greater part of its length it occupies the footwall of a thrust zone along a belt of ground broken by near-vertical joints. Flexures parallel or cross the productive parts of the mine, but it is not clear that these are genetically related to the deposits.

It could be postulated that the ore has been derived from a parent sulfide body that lay above the oxidized shoot at a level higher than the present surface of erosion. On the other hand the alteration of rocks in and around the ore, as well as the geometrical relationships of the ore to flexures and fractures, are phenomena characteristic of many primary ore bodies in other parts of the district. The question of origin remains undecided, but the evidence seems to favor oxidation in place of a sphalerite ore body. By this interpretation the zone of near-vertical joints in the central part of the mine would likely be regarded as local feeding fissures, and the soles of the thrusts—possibly silicified before mineralization—as baffles or impermeable barriers.

SULTAN MINE

By John A. Reinemund and Arnold L. Brokaw

The Sultan mine, 6.5 miles southwest of Goodsprings, is easily accessible by a branch of the Columbia Pass road (fig. 2). W. R. Sloane staked a claim here in 1896, although no shipments were made until 1910. Henry Robbins owned and operated the property from 1915–19, the interval of greatest productivity. Since 1919 the mine has been intermittently active. In 1920 it was operated by Dawson, and in 1925–26 the superintendent of the Yellow Pine mill processed Sultan tailings and shipped the lead concentrate. R. J. Robbins operated the mine in 1935–36, but there is no record of the several shipments said to have been made during this interval. Roy Jacobson acquired a lease in 1938, and the following year sold to Las Vegas Development Co., which relinquished title after a few months of work. In 1941 Jacobson resumed operations, and since 1943 he and Ralph Hamilton have held the property under lease from Mary E. Robbins, the present owner. Total shipments of ore represent about 1,800 tons of zinc and lead.

Topography of the mine area is shown on plate 20 and the plan of workings on plate 21.

ROCK UNITS

Characteristics of rock units identified in the area are summarized in the following columnar section:

Age	Formation	Member	Character	Thickness (feet)
Quaternary.			Slope wash; gravel and conglomerate of local origin.	0-15±
	Unconformity.			
Tertiary (Miocene?).			Latite, banded reddish-brown glassy rock.	(?)
			Latite breccia, weakly indurated reddish-brown tuff enclosing fragments and bombs of glass as much as a foot across.	35
			Tuff, light-gray stratified; pyroclastic particles generally less than an inch across.	35-40
	Unconformity.			
Pennsylvanian.	Bird Spring formation.		Dolomite breccia, light-gray to buff, commonly cemented with milky calcite, and locally enclosing relatively intact horses of cherty dolomite.	(?)
	Unconformity.			
Mississippian.	Monte Cristo limestone.	Anchor(?).	Limestone, dark gray to black fine-grained in beds as much as 10 feet thick, containing scattered lentils of dark chert. Tabulate corals and crinoid columnals common. Unit possibly belongs to Anchor member.	50±
Devonian.	Sultan limestone.	Valentine.	Limestone, gray, in beds from 1 to 10 feet thick, with nodules of ferruginous chert in indistinct zones within thicker units. Locally altered to buff dolomite.	[1]
		Ironside.	Dolomite, black coarsely crystalline, in beds from 2 to 7 feet thick. Locally mottled light and dark gray.	30

[1] Not determined.

The generally fractured and brecciated character of the Paleozoic rocks makes it difficult to classify the local section according to formations and members recognized elsewhere in the district. It is probable, as the table suggests, that some members of the Monte Cristo and Sultan formations are locally missing from the section. On the other hand the identification of the ore-bearing breccia in and around the mine as the Bird Spring is tentative, and it is therefore possible that some of the missing members may actually be represented in the breccia.

STRUCTURE

ATTITUDE OF BEDS

Where the bedding in the Paleozoic section is not obliterated by brecciation, the strikes are between northwest and northeast and the dips are northeast to east at low to moderate angles. In the southern part of the area the rocks strike prevailingly northeast and dip northwest between 10° and 30°. In the north the strikes are mostly northwest and the dips are northeast at angles between 30° and 45°. For ground as intricately broken as this the attitudes of bedding are remarkably consistent over areas that are large in comparison with the size of individual fault blocks.

The volcanic rocks resting unconformably on the Paleozoic rocks strike northwest and dip northeast at an average of about 20°.

HIGH-ANGLE FAULTS IN PALEOZOIC ROCKS

Faults trending between north and northwest and dipping east at moderate to high angles are the predominant structural features in the Paleozoic rocks. Together they form a belt at least 600 feet across trending about N. 40° W. and extending from fault 4 on the west to an undetermined distance beneath volcanic rocks and alluvium to the east (pl. 20). In the mine this zone has been explored to a depth of 300 feet, through which the ground is generally brecciated.

Fault 1 lies near the western limit of brecciated ground. According to the interpretation given on plate 20, the displacement is normal, with younger Bird Spring rocks on the east faulted down against the older beds of the Sultan on the west. Minimum stratigraphic throw would thus equal the thickness of the Monte Cristo limestone—about 750 feet.[28] Faults 3 and 4 appear to be branches of fault 1. All three show slickensides oriented parallel with the dips of the fault planes. The evidence suggests, therefore, that considering only the most recent movement, the three are dip-slip faults, and that no. 1 is a gravity fault.

East of fault 1, the pattern is that of an anastomosing network in which the fault traces are commonly sinuous or arcuate. The principal break is fault 2, and the slickensides along this and all other conspicuous faults are either horizontal or within a few degrees of the horizontal. Classified according to the most recent movement for which there is evidence in the grooves and striations, these are clearly strike-slip faults.

Within the limits of mining exploration the displacements of faults in the brecciated ground cannot generally be measured. Correlation between faults seen on the surface and those mapped underground, as well as between faults along different levels or different parts of the same level must therefore rely principally on projection of observed dips and strikes. Although the attitudes of faults are generally easily measured within narrow limits, the projection of these observed attitudes for distances of more than a few tens of feet is bound to introduce errors of unknown amount in this area where the faults are so variable in dip and strike. Reference to the geologic map of the main tunnel (pl. 21) shows that, with the exception of the faults 1 and 2, the

[28] Hewett, D. F., op. cit., p. 17.

faults crossed by the radiating arms of the level cannot be connected with any certainty by projection of strikes. Although an effort has been made to complete the fracture pattern by connecting fault lines between points of observation, it should be emphasized that correlations are in many cases doubtful.

LOW-ANGLE SHEARS

In the brecciated ground in and near the mine there are many minor shears dipping at low angles toward the east and the west. Locally these are parallel with the bedding in horses of relatively unbroken ground; thus at least some are to be classed as bedding shears. The others are probably minor thrusts.

HIGH-ANGLE FAULTS IN TERTIARY VOLCANIC ROCKS

In contrast to the Paleozoic rocks, the Tertiary volcanic rocks are relatively intact and are cut by only a few minor high-angle faults. Those mapped strike between northeast and northwest; displacements amount to only a few feet. Several of the faults are vertical and most of the others dip west at moderate to high angles. The more persistent examples trend parallel with fault 2 and by projection would almost tie with some of the west-dipping faults mapped underground.

RELATIONSHIP BETWEEN FAULTS

In several places underground the low-angle faults are offset by the high-angle strike-slip faults, which are therefore the younger, although they were probably formed during the same general period of deformation. Clearly the stage of intense faulting in the Paleozoic rocks had come to an end long before the volcanic rocks were laid down; thus the faults in the volcanic rocks must be younger than those in the Paleozoic. Similarity in strike and dip of persistent faults in the volcanic rocks with faults mapped underground in the Paleozoic breccia may indicate recurrent postvolcanic movement along prevolcanic faults.

The relationship between the high-angle faults along the western margin of brecciated ground (nos. 1, 3, and 4) and the high-angle faults to the east is not certain. The integrated pattern of faulting suggests that both groups developed contemporaneously. A reasonable interpretation would have all the high-angle faults in the Paleozoic rocks originate as a single rift zone (similar in magnitude and pattern with the parallel Fredrickson rift zone) which has subsequently been downfaulted at the west along fault 1 and its branches.

ORE DEPOSITS

The ore replaces and fills cavities in shattered and brecciated dolomite. Primary ore presumably consisted of sphalerite and galena lenses dipping mostly at low angles toward the northeast, and of irregular tabular bodies of sulfides along high-angle faults. By oxidation the sphalerite has been converted almost entirely to hydrozincite and calamine, and migration of zinc during this process has altered the form of the ore bodies. However, the richer deposits are where the primary lenses were most closely spaced, and the largest stopes are where groups of lenses were extracted.

As ore remains in many faces and the limits of mineralization have been reached in relatively few places, the overall shape of ore bodies is unknown. For purposes of description, however, the ore is considered as divided into three pipes or shoots that plunge eastward at angles from 30° to 60°. Their horizontal cross sections are generally elliptical and elongate toward the north or northwest.

MINERALOGY

In order of relative abundance the principal ore minerals are hydrozincite, cerussite, calamine, and galena. Small patches of fine-grained sphalerite were found in the stope adjacent to opencut 3 (fig. 4).

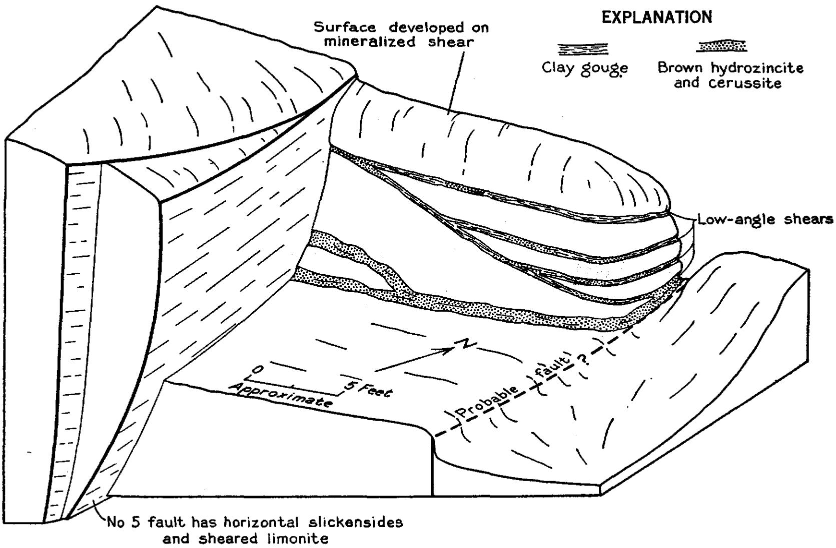

FIGURE 4.—Diagram of northwest corner of opencut 3, Sultan mine.

Hydrozincite accounts for at least 70 percent of the volume of ore minerals. It is brown, white, or purple. The brown variety forms lenses as much as 3 feet thick and 15 feet long, and consists of acicular crystals a few millimeters long that are stained brown and weakly cemented by limonite. Irregular pods also occur in the breccia adjacent to high-angle faults.

White hydrozincite is the common variety in some small stopes and opencuts. An alteration product of the brown, it represents material that has migrated a few tens of feet from original sites of deposition. In and beneath some ore bodies it cements the breccia fragments. Along open fractures and in cavities, it is commonly in hairlike crystals as much as half an inch long.

Purplish or bluish hydrozincite is a minor constituent that occurs with the white variety in association with lead minerals.

Cerussite, like the brown hydrozincite with which it is generally associated, occurs near high-angle faults. Crystals as much as half an inch long form friable aggregates that are either embedded in brown hydrozincite or—less commonly—joined together to form whole pods and lenses.

Calamine is found in fractures and as coatings on other minerals. Commonly in crystals as much as a quarter of an inch long, it is a widespread minor constituent in and near the ore bodies.

Galena occurs most commonly as unaltered cores in masses of cerussite, but it also forms isolated cubes scattered through the dolomite between ore lenses. The isolated crystals are generally fresh and unsheared, but much of the galena in ore lenses and along fractures is broken.

Limonite abounds in the ore lenses and along surfaces of fractures. Plumbojarosite is locally present, and copper stains were noted in several places.

Breccia in which the ore occurs is dolomitized, and white crystalline dolomite commonly forms the gangue in ore lenses. Locally, as in stopes below the main level, there are lenses of the white dolomite that are similar in size and attitude to the associated lenses of ore. In many places the dolomite fills the central parts of cavities, which are lined with galena, cerussite, and brown hydrozincite (figs. 5 and 6). Relationships indicate that the dolomite formed during the stage of primary mineralization, and was in most places deposited later than the sulfides.

FORM AND GRADE

East shoot.—The east shoot is explored by the opencuts 1 and 2 and by one large and several smaller stopes underground (pl. 21). The main tunnel level intersects the largest stope 20 feet below the back. From this level a shaft extends downward at 63° at the lower levels, all of which are in or adjacent to the main stope.

From the tunnel level the main stope extends downward as two pipelike arms on either side of the shaft. These join below the first level and plunge eastward to the intermediate level as a single stope. Directly below the intermediate level (altitude 3,900 feet) the stope ends along the smooth surface of fault *A* (pl. 22). The stope length is greater than average along fault *C*, where the two arms merge, and along fault *B* near the lower end of the stope (pl. 21; second and intermediate levels). Sections *H–H′* and *I–I′* show the plunge and dimensions of the stope as viewed in vertical section.

Concentrations of galena, cerussite, and brown hydrozincite have been partly extracted from along fault *B* down to the third level and

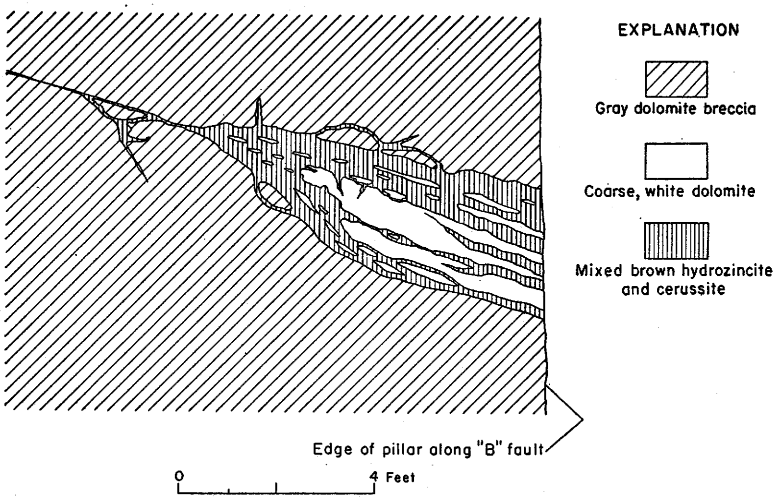

FIGURE 5.—Mineralized low-angle shear in pillar of main stope, intermediate level, Sultan mine.

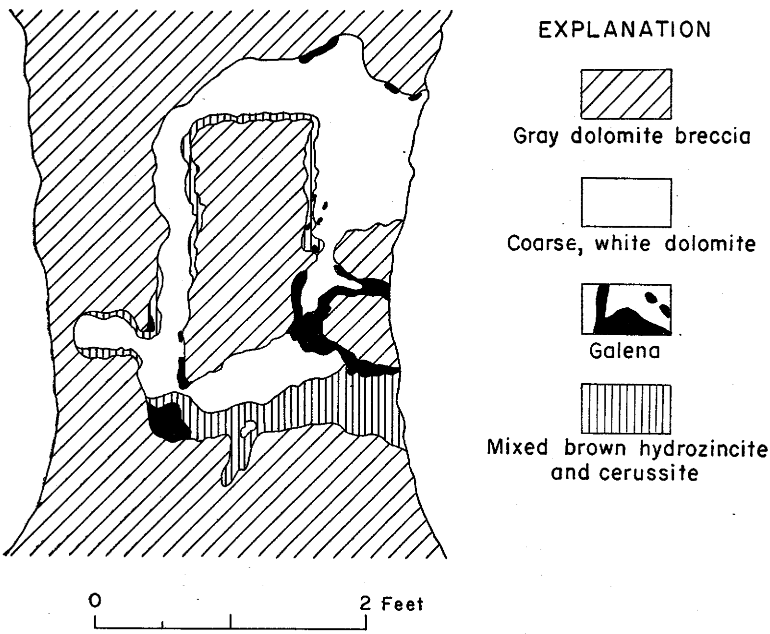

FIGURE 6.—Relation of white dolomite to ore minerals in pillar of main stope, first level, Sultan mine.

from a lens on that level. As on the intermediate level above, mineralized ground terminates abruptly along fault A (pl. 21, sec. *D–D′*).

Above the main tunnel the two arms of the stope give way to irregular and disconnected stopes following small tabular bodies of ore that dipped northeast at 30° to 40°. Those ore bodies above the shaft collar lie above the most easterly arm of the main stope and below opencut 1. Their position is shown in plan on plate 21, and in section on plate 22. A similar small stope that leads to a vertical pipe connecting upward with opencut 2 lies directly above the main level and may be considered as forming the upper western arm of the stope below (pl. 22, sec. *I–I′*). Opencut 2, bordered by fault 2, is the surface expression of the western arm just as opencut 1 is of the eastern.

Most of the ore taken from the Sultan mine has come from the east shoot. Measurements made in connection with this survey indicate an approximate total volume of 275,000 cubic feet. Records kept by the operators show that the grade ranged from 12 percent to 40 percent, and that most of the ore contained about five times as much zinc as lead. The grade is higher here than for other parts of the mine, probably because most of the ore in the east shoot was in lenses or irregular masses that could be mined selectively.

These lenses are chiefly brown hydrozincite, cerussite, and galena. Those mapped on the levels trend between west and N. 30° W. and dip between 10° and 50° northeast. There are many more lenses in the stopes than could be shown on maps and sections, and apparently many more have been removed during mining. Sections *G–G′*, *H–H′*, and *I–I′* show that the stope plunges more steeply than the lenses. The small stopes above the main one were in single lenses or small groups of lenses; section *B–B′* shows a stope developed along such a lens. However, not all the ore was in the lenses; irregular concentrations of ore occur also near and along the high-angle faults.

Ore from the east shoot runs relatively high in lead. Also there is an increase in the grade of ore with depth, a fact noted by Hewett.[29] For example, the grade increases from opencut 2 to the small stope immediately below, and from stopes above the main level to the large stope below. A similar change is apparent within the lower part of the shoot. The lower main stope in 1941 yielded about 500 tons of ore, most of which assayed more than 40 percent lead and zinc, and all of which contained more than 10 percent lead. The best ore found on the first level, higher up in the same ore body, was being mined in April 1944; this contained between 30 and 35 percent lead and zinc with the lead between 3.5 and 10 percent. Increase of zinc with depth may be explained in part by the migration and deposition in second-

[29] Hewett, D. F., op. cit., p. 155.

ary compounds, but no similar explanation accounts for the increase in lead.

Center shoot.—The center shoot has been mined from opencut 3 (pl. 20) as well as from stopes to the west. Measurements indicate a volume of about 160,000 cubic feet of ore for stopes in the center shoot. Ore ranged from 12 to 15 percent zinc, without appreciable lead.

Opencut 3 is deepest at the east edge where it abuts against fault 2. There it bottoms at an altitude of 4,088 feet, 37 feet below the surface. White hydrozincite occurs almost to the exclusion of other ore minerals, although remnants of galena and thick lenses of brown hydrozincite and cerussite are locally abundant in the upper part of the opencut. The west portion is a bench developed by stripping along one of these lenses (fig. 4). The opencut is bounded on this side by fault 5.

Twenty-five feet west of opencut 3, an ore body has been mined from within a few feet of the surface to a depth slightly below the altitude of the bottom of the cut. It is accessible by a tunnel (altitude 4,131, pl. 21). In April, 1944, the stope was being rapidly enlarged by mining, and its bottom was 65 feet vertically below its top. Its cross section was greatest on the 4,131 level, where the diameter was 50 feet. White hydrozincite was the only abundant ore mineral, but traces of lead minerals were scattered throughout, and a little sphalerite was found in a lens near the bottom.

The high proportion of white hydrozincite, much of it probably having migrated from higher bodies now eroded, distinguishes this from the larger east shoot. The greater irregularity is doubtless also a result of migration.

Three small ore bodies lie near this shoot but are not connected with it. Two, near the main level, abut against fault 2 and have yielded mostly zinc. A third, near opencut 3, consisted of three lenses containing abundant galena and extending to fault 5 (pl. 21, sec. *E–E′*).

West shoot.—Opencut 4 marks the position of ore bodies that constitute the smallest and most westerly shoot. The ore extended to within a few feet of the surface. Mining has been on three levels accessible from tunnels at altitudes of 4,072, 4,102, and 4,118 feet (pl. 21). Total stope volume at the time of the survey was about 13,000 cubic feet. The average grade of ore was estimated at 18 to 25 percent lead and zinc, with the lead-zinc ratio ranging from 1:7 to 1:17.

At the lowest level, where fault 5 is exposed, the stope is 25 feet wide, but it narrows in its tortuous course upward. Lenses of ore containing galena were characteristic of mineralized ground in the lower part, where there was also a concentration of galena and hydrozincite along fault 5. The upper part of the stope contained mostly white hydrozincite with accessory lead minerals.

GEOLOGIC CONTROLS OF ORE DEPOSITS

Evidence at hand suggests the following relationships between ore and other geologic features:

1. East-trending shoots lie within zones of maximum inflection of high-angle feeding fissures.
2. Ore deposition was more concentrated and more widespread along the feeding high-angle faults than at distances away from them. Thus the largest cross sections of ore shoots are parallel to such faults.
3. Faults which bound shoots, like faults 2 and *A*, also bound structural blocks. Structures favorable for migration of mineralizing solutions would not ordinarily be expected to persist directly across one of these major faults.
4. Lenses of ore developed along bedding shears and minor thrusts, that provided tabular zones of high permeability.
5. The apparent plunge of the ore shoots is probably a result of incomplete exploration.

POSITION OF ORE BODIES IN TECTONIC PATTERN

Fault 2, dominant structural feature in the mine, is one in a system of high-angle fractures forming the pattern shown on plates 20 and 21. These fractures trend between north and northwest and dip steeply either east or west. Their arcuate or sinuous traces, branching habit, and near-horizontal slickensides have already been noted. Only a few faults of the group are persistent. In zones of inflection most individual faults either link with others or disappear within short distances laterally and vertically. The more important examples are shown on plate 21 and are designated by numbers and capital letters.

Faults of this system are believed to be older than the ore because:

1. Concentrations of ore minerals and of coarse white dolomite occur along some of them.
2. Stopes commonly widen and ore lenses thicken adjacent to them.
3. They are the only faults present in the ore bodies, and are favorably situated for feeders. Minor faults trend roughly normal to these, but are not persistent and exert no apparent control on ore distribution.

The dominant high-angle faults have noticeable changes of strike within the ore bodies. Their tendency to merge and to give rise to spurs in these areas of inflection is also apparent. With respect to the position of the three ore shoots in the structural pattern, three relationships are suggested.

1. The three ore shoots lie in zones of inflection, both in strike and dip, of high-angle faults.

2. These appear to be zones of maximum inflection.
3. Inflections in subsidiary faults are roughly opposite inflections in fault 2.

The inflections in the faults associated with the east ore shoot do not persist to the north nor do they appear in the main tunnel.

ORE LENSES

Ore lenses on the third level and in stopes above the shaft pass into unmineralized shears containing 1 or 2 inches of clay gouge. The ore minerals are commonly sheared indicating that there was renewed movement along some of the faults after the sulfides had been deposited. Not all lenses appear to follow crosscutting fractures; a small number run into barren dolomite along what appear to be surfaces of bedding. Some shears, steeper than average, branch across to connect shears of lower inclination (sec. *C–C′*). Many, however, are roughly parallel to such traces of bedding as remain in the breccia.

These facts suggest that many of the lenses follow incipient bedding shears, or shears that began in bedding and developed at steeper angles to join surfaces of movement at higher levels. Displacements along most of these probably do not exceed a few inches or a few feet. Very likely the fractures originated during the period of thrusting described by Hewett.[30] Evidently they offered permeable zones along which the mineralizing solutions moved upward and away from high-angle feeding faults.

PLUNGE OF SHOOTS

The eastward plunge of the largest (East) shoot is only partly explained by the northeast dip of ore lenses. As shown on sections *H–H′* and *I–I′* the plunge of the stope is steeper than the inclination of the lenses. It is believed, however, that the plunge is more apparent than real. Exploration has not been sufficient to show whether or not mineralized ground persists vertically along the high-angle feeders. A single exception is provided by a crosscut driven on the first level in the spring of 1944. Behind faults *D*, *E*, and *F* in the footwall of the main stope, the crosscut was in lead-rich ore. There is nothing to preclude the possibility of finding additional ore along major high-angle faults below the present stope, for if feeding has been localized by inflections, the conduits provided by inflections should continue some distance downward.

No uniform plunge is to be observed in the center shoot. Erosion of the ore and migration of zinc have obscured the original form of the body. In the west shoot, the apparent eastward plunge may be explained by reference to fault 1 and adjacent low-angle shears, or again by lack of exploration below the ore bodies.

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[30] Hewett, D. F., op. cit., p. 42 ff.

BULLION MINE

By Arthur Richards and David A. Phoenix

The Bullion mine is 5 miles south of Goodsprings and 7 miles west of Jean, the nearest station on the Union Pacific Railroad. A dirt road leads from Jean to the millsite (fig. 2), and from there a foot trail winds up rocky slopes to the main workings, which are about 300 feet above the floor of Porter Wash.

Ore was discovered in 1900, but most of the production was from 1913 to 1927. Little work has been done during the past two decades, and the mine remains essentially as shown on Hewett's map, dated 1931.[31]

The north and south tunnels (pl. 23) lead directly into a maze of stopes that may be followed downward and westward to their lower termination along the second level. The stopes are divided into an upper set mapped with the north tunnel and a lower set mapped with the south tunnel. The two sets are distinct only in the eastern part of the mine; toward the west they converge in a single zone of stoping, the subdivision of which is artificial but nevertheless useful in describing the geology.

From the north tunnel a winze inclined at an average of 27° and bearing north-northwest connects with a level about 100 feet lower than the tunnel. Below the second level the main shaft, which was largely destroyed in the course of mining at higher levels, steepens and continues westward at an inclination near 68°. It connects with three short levels, the lowest of which is 60 feet below the second level and about 115 feet below the portal of the north tunnel.

Stopes and lateral workings were accessible in 1945.

ROCK UNITS

The workings are in dolomite of the Anchor member of the Monte Cristo limestone. In the zone of the stopes the rock is massive with only scattered interbeds of thinly stratified dolomite. Peripheral to the stoped zone the rock is thin bedded and cherty. Bedding surfaces are spaced from 4 inches to a foot apart. Chert lentils lie parallel with the bedding, and compose 20 percent to 60 percent of the rock.

Massive and thinly bedded facies are intergradational both laterally and vertically. The productive part of the mine generally is within an irregular lens of massive rock surrounded by thinly bedded cherty rock.

STRUCTURE

The regional structure is that of a homocline within which the beds strike north and dip west at an average of 20°. Within the mine area

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[31] Hewett, D. F., op. cit., pl. 39.

the strikes range predominantly from N. 40° W. to N. 40° E., and the dips range from 10° to 30° west. Flexures are therefore indicated, but in the absence of marker beds, it is impossible to map them with reference to a single horizon. However, determinations of strike and dip along and above the second level show that the variation in attitude of bedding is systematic and that the central stoped zone occupies the arch and flanks of an anticlinal nose plunging west. The northern and southern limits of stoping are in parts of two synclinal warps that also plunge west roughly parallel with the anticlinal nose. Workings below the second level do not reveal whether these flexures persist down the dip and west of the stoped zone.

High-angle faults are fairly numerous, but no individual fracture persists across the relatively narrow width of the workings. The prevailing trend is northwest and the dip is toward the northeast or southwest at angles mostly greater than 55°. The more conspicuous faults are numbered 1, 2, 3, 3A, 4, and 5 on plate 23. The throw is probably less than 3 feet except along fault 3, which has a throw of 15 feet. Displacements are normal along most faults and reverse along a few; slickensides indicate that regardless of the relative movement the latest movement has been predominantly with the dips of the fault surfaces.

Minor thrust faults are present, but structurally they are less impressive than the high-angle faults. Their significance lies in their relationship to the ore, as discussed in the following section.

ORE DEPOSITS

The productive zone is approximately elliptical in plan, having a long axis of 200 feet alined with the projection of the main shaft, and a short axis about 180 feet in length (pl. 23). The ore was distributed through 80 feet of the local section, although at any given place the beds that contained ore measured not more than 45 to 55 feet. The form of the stopes indicates that the ore lay as a series of superimposed tabular bodies dipping west or northwest. Individual bodies probably ranged from a few feet to 20 feet in thickness, and the superimposed bodies were separated by irregular ribs of barren dolomite. Where the ore bodies lay close together the dolomite partings were evidently removed along with the ore; this probably accounts for the fact that some of the stopes in the central part of the mine are higher than wide.

In the small patches and stringers of mineralized rock remaining around the stopes, galena is the only abundant mineral, although pink earthy hydrozincite is locally present. Records indicate that about six and one-half times more lead has been produced than zinc. Hewett states that most of the product shipped contained from 50 percent to 75 percent lead, 2 to 15 ounces of silver to the ton, and a few percent of zinc.[32]

[32] Hewett, D. F., op. cit., p. 159.

GEOLOGIC CONTROLS OF ORE DEPOSITS

Distribution of stopes clearly indicates that the massive facies of the Anchor member was more favorable for replacement by sulfides than the thinly bedded cherty facies. Moreover it was the massive rock within the plunging anticlinal nose that was the host for most of the ore. The ore ends down the dip against fault 5, and does not extend northward for more than a few feet beyond fault 3. Galena is abundant along fault 5 in and near the shaft along and below the second level. Galena is also present along fault 3 near the head of the winze in the north part of the mine, where striking hydrothermal effects can be seen in the bleached and banded dolomite bordering this fault.

Probably the mineralizing solutions rose along fault 5 and spread laterally and up the dip, replacing the massive dolomite within the plunging anticlinal nose. Other high-angle faults may have been local feeders as, for example, fault 3, and also fault 1, which has galena along it and appears to determine the position of ore in upper stopes south of the shaft. All the faults in the mine are probably older than the ore, but evidently only a few provided conduits for mineralizing solutions.

In the stoped zone there are many tabular bodies of breccia, most of which dip westward at angles slightly greater than the dip of the bedding. Collectively they tend to follow the strike of the dolomite around the anticlinal nose, describing an arc with a shorter radius than the arc of the bedding. Because these breccias are commonly replaced by galena, most have been removed by stoping.

Thirty feet north of the shaft on the second level one of these ore layers clearly follows a thrust dipping west at 27° with the slickensides paralleling the dip. The writers believe that most if not all of the tabular breccias are along minor thrusts. None could be traced for more than a few tens of feet, but if the breccias that are peripheral to the northern parts of the stoped areas are considered as a single fault zone, they could be broadly regarded as forming a composite hanging wall for the ore.

Ingress of mineralizing solutions into the massive dolomites was thus largely along thrust breccia, which was more permeable than the unbroken massive rock adjacent or than the thinly bedded cherty dolomite surrounding the massive facies.

The geologic controls of ore deposition were therefore partly lithologic and partly structural. Mineralizing fluids rising in the conduits along high-angle fractures were diverted up the dip of the bedding where thrust breccias abutted against the feeders. The thrust breccias were confined, insofar as is known, to the massive dolomite that became the host for the ore deposits.

GREEN MONSTER MINE

By Arnold L. Brokaw

The Green Monster mine, about 13 miles west of Goodsprings, is near the end of a long spur extending westward from the Spring Mountains into Mesquite Valley.[33] Access is by a graveled road branching from the Wilson Pass road near the Keystone mill. Plates 24 and 25 show the topography and geology of the mine area and the geology of the underground workings.

The claims were first located in 1894 and were soon afterward acquired by the Hearst Estate, which has retained the title until the present. In 1919 John Darington leased the ground and sank a winze in ore from near the southern end of the 200 level. The development was unprofitable, and there is no record that any shipments were made. The property was idle until Roy Jacobson leased it in 1942. In that year two carloads of zinc ore was shipped to Coffeyville, Kans. Shipments to the stockpile of the Metals Reserve Co. at Jean during the following 2 years amounted to 2,496.4 tons averaging about 19 percent zinc and 1 percent lead.

ROCK UNITS

The stratigraphic section includes several hundred feet of dolomite, limestone, and quartzite of Carboniferous age, locally covered by Quaternary terrace gravel and slope wash. Characteristics of the Paleozoic beds are summarized in the following columnar section:

Age	Formation	Member	Character	Thickness (feet)
Pennsylvanian.	Bird Spring formation.		Limestone, dark gray, coarsely crystalline, dolomitic, in beds 2 to 5 feet thick; locally with small masses of fossiliferous chert. Top not exposed in mapped area; exposed thickness.	120–140
			Quartzite, cream-colored fine-grained, in beds 6 to 15 inches thick; weathers light gray.	25–30
	Unconformity.			
Mississippian.	Monte Cristo limestone.	Yellowpine limestone.	Limestone, predominantly coarse grained; obscurely bedded in massive beds 5 to 10 feet thick; contains abundant large horn corals. Locally altered to light gray or buff coarsely crystalline dolomite.	75±
		Arrowhead limestone.	Limestone, predominantly fine grained dark gray, in beds 2 to 5 inches thick; contains half-inch partings of clayey shale; abundantly fossiliferous. Locally altered to light gray coarsely crystalline dolomite.	8-12
		Bullion dolomite.	Limestone, dark gray, in beds 5 to 10 feet thick and containing scattered nodules of ferurginous chert; mostly altered in mine area to light gray or buff dolomite. Base not exposed.	150

[33] U. S. Geol. Survey, Ivanpah topographic quadrangle map.

STRUCTURE

The beds strike generally northwest and dip southwest at moderate to high angles. In the Monte Cristo limestone the dip averages about 55°. The homoclinal structure thus indicated belongs to the limb of a sharp syncline plunging southeast. The opposite limb of this fold has been thrust northeastward along the fault mapped south of shaft No. 1 (pl. 25). This thrust is the principal fault in the area, and the faults in and near the ore bodies, which are below the footwall of this thrust, all appear to be related to it.

The contact between the Bird Spring formation and the Yellowpine limestone member of the Monte Cristo limestone is locally sheared, but the most conspicuous bedding shears are in the Arrowhead limestone member, especially along its contact with the Bullion dolomite member. Planes of movement in the thin beds are commonly marked by conspicuous seams of gouge, but the bedding is not ordinarily obliterated by brecciation.

Several minor thrusts in the upper part of the Bullion converge with the bedding shears along the base of the Arrowhead. These faults strike about parallel to the bedding and dip in the same direction, but at slightly smaller angles. One is exposed at the surface northeast of the inclined shaft. Several others mapped underground were not recognized on the surface. Movement along individual faults does not exceed a few feet, and brecciation along isolated thrusts is generally negligible. However, the rocks at or near the junction of bedding shears and thrusts are brecciated and were favorable for the development of ore bodies.

Several tear faults strike nearly at right angles to the strike of the bedding and dip toward the southeast or northwest at angles of 60° or more. The offset along these tears is only a few feet, and the direction of relative movement is variable. The striations along the tear faults are inclined with the dip of the associated thrusts. As shown on plate 25 some tears are within imbricate blocks bounded by thrusts or by bedding shears at the top and bottom of the Yellowpine limestone member. Other tear faults displace thrusts and bedding shears, but none appears to offset the principal thrust in the Bird Spring.

ORE DEPOSITS

The ore replaces dolomite breccia in the upper few feet of the Bullion dolomite member and the lower part of the Arrowhead limestone member. Most ore has been mined from tabular bodies elongated in the plane of the bedding. The ore, which originally was composed of sphalerite with accessory galena, is now oxidized to depths below the deepest level of exploration, or more than 400 feet below the surface. However, the persistence of residual sulfides in small quantities throughout most of the mineralized ground indicates that the forms of primary ore bodies have not been appreciably altered by migration of oxidized substances.

Most recent shipments of crude ore contained from 15 percent to 25 percent of combined metals, with lead averaging about 1 percent. An increase in the proportion of lead with depth is suggested by the fact that the deepest development is in ground containing 10 percent or more lead.

MINERALOGY

The ore is predominantly a mixture of hydrozincite and calamine in a gangue of white dolomite and ocherous limonite. Earthy hydrozincite stained brown by iron oxides is widespread in the shoots. A purer white variety that forms veinlets along fractures below the ore bodies represents zinc that has migrated beyond the original boundaries of the mineralized ground. Most calamine forms friable aggregates of iron-stained crystals associated with brown hydrozincite. In some stope areas it is the principal ore mineral.

Smithsonite, in pale-gray botryoidal masses, locally forms veinlets in fractures crossing the ore zones, but it has not been an appreciable source of zinc. Aurichalcite, the basic carbonate of zinc and copper, is a minor constituent that accounts for the traces of copper commonly reported in assays. Small residual pods and lenses of dark-brown to black sphalerite locally occur in the dolomite gangue where they are surrounded by masses of brown hydrozincite.

The lead minerals include cerussite, anglesite, and galena. Cerussite is the most abundant mineral and appears as brown or gray granular masses; the largest concentration was found near the bottom of the Darington winze (sec. *D–D′*). Lenses and kernels of galena, rarely more than 3 inches across, are commonly surrounded by thin rinds of anglesite.

The occurrence of uranium-bearing material was first noted during the mine mapping program in 1944. Samples submitted to the laboratory were examined by W. T. Schaller of the U. S. Geological Survey. Schaller established the presence of two or more uranium minerals, intimately associated with the oxidized lead and zinc ores. Subsequently, material collected by M. H. Staatz was identified by the Trace Elements laboratory in Washington as a mixture of kasolite ($PbO \cdot UO_3 \cdot SiO_2 \cdot H_2O$) and another uranium-bearing mineral, which was identified by the U. S. Bureau of Mines as dumontite

$$(PbO \cdot 3\ UO_3 \cdot P_2O_5 \cdot 5H_2O).$$

An examination of the ore deposits with special reference to the uranium minerals was made by the U. S. Geological Survey in 1951 for the Defense Minerals Administration. This examination revealed that the highest grade uranium-bearing material occurs immediately below the discovery pit where ore shoot *A* intersects the surface. The mineralogy is typically supergene: either kasolite or dumontite or both are found intermixed with the oxidized lead and zinc minerals. The ore zone is roughly parallel to the Arrowhead and Bullion contact and ranges from 1 to 12 feet in thickness and is probably not more than 100 feet long. Some kasolite and dumontite are found in fractures extending 2 or 3 feet into the Bullion dolomite member.

The grade of the uranium ore is variable; small patches of oxidized material may contain 9.0 percent uranium but the adjacent rock will be practically barren. The uranium content decreases rapidly with depth, and the lower levels of the mine contain only a negligible amount of radioactive ore. The source of the uranium minerals is not known.

SHOOTS

Shoot A.—The largest ore body mined to 1944 extended from the surface to the 200 level. This was a tabular body that lay essentially parallel to the bedding and plunged 30° to 40° to the southeast. On the average it was 5 to 8 feet thick, though locally it was as much as 15 feet. Masses of cerussite were mined from along fault *A*; elsewhere the ore was predominantly brown hydrozincite and calamine.

Shoot B.—An ore body, which was cylindrical for the greater part of its length, was mined from a short distance above the 200 level to 77 feet below the 300 level. The bottom was not reached in the winze from the 300 level. At its upper limit the pipe expands into a tabular body merging with shoot *A*. The principal ore mineral was brown and white hydrozincite, but lead minerals are more abundant at depth.

Shoot C.—A tabular body of brown hydrozincite ore, 50 feet wide and 10 feet thick, has been mined near the southeast end of the 200 level to a depth of 73 feet below the level by the Darington winze. The downward limit has not been determined. Below the level the ore contained 10 percent or more lead in the form of galena. This is the largest concentration of galena yet found in the mine. Sphalerite also is more common here than elsewhere.

GEOLOGIC CONTROLS OF ORE DEPOSITS

The location of the ore is governed by the interrelationships of (1) the sheared contact between the Arrowhead and Bullion, (2) the minor thrusts that branch from this sheared contact and cut across the upper beds of the Bullion, and (3) local conduits along tear faults.

Unsheared sulfides occur along several of the tears and thrusts, and as all the faults in the mine are believed to be contemporaneous, they are all probably older than the ore minerals. Tear faults that cross the stopes are marked by concentrations of galena or cerussite; hence these are regarded as the local conduits along which the mineralizing solutions rose. There is nothing to indicate why some of the high-angle faults should have been local feeders, whereas others evidently were not, nor is it known whether the supposed feeding fissures connected directly or indirectly with the sources of the mineralizing fluids.

It is fairly clear, however, that the beds in the Arrowhead were not only generally unfavorable for replacement by sulfides, but that they acted as a barrier to upward movements of hydrothermal solutions. Over most of the area the base of the Arrowhead is also the contact between dolomitized ground below the unaltered limestone above; and all the ore bodies mined to date have hanging walls along this same contact, which is sheared and layered with clay gouge.

Branching from the shears along the Arrowhead and Bullion contact are the minor thrusts in the upper part of the Bullion. Near the junction of the bedding shears and the thrusts the ground is brecciated, and the ore occurs mainly in this breccia. The southeastern plunge of the main shoots appears to follow generally the lines of intersection between the thrusts and the bedding shears, although in some places the ore occurs in broken ground paralleling the mineralized tear faults.

ROOT MINE

By Arnold L. Brokaw and John A. Reinemund

The Root mine is near the crest of Bonanza Hill, 7 miles southwest of Goodsprings (fig. 2, pl. 26). A foot trail leads to the portal from a camp at the base of the hill, and there are several roads connecting the camp with the Columbia Pass road.

Five claims are owned by the Root Zinc Mining Co.[34] These were staked between 1893 and 1901, and although there is a record of intermittent production since 1893, the details of mining history were not learned. Since 1937 the property has been leased and operated by Roy Jacobson and Ralph Hamilton of Goodsprings.

Plate 27 shows the plan of the principal workings. There are several additional workings on the Root claims, but there was no opportunity to study them in detail.

ROCK UNITS

Rocks exposed on the surface and to the limits of exploration underground belong to the upper 70 feet of the Yellowpine limestone member of the Monte Cristo limestone and to the lower 200 feet of the Bird Spring formation.

The Yellowpine is predominantly dark gray limestone bedded in units ranging from a few inches to several feet in thickness—hence more thinly stratified than in many other parts of the district. Fossils are abundant, particularly the large horn corals typical of the Yellow-

[34] W. J. Wilson of Las Vegas, principal stock holder.

pine. Locally the rock is altered to coarse-grained light-gray dolomite.

The lowest unit in the overlying Bird Spring is thinly bedded sandy limestone 10 to 15 feet thick. It is poorly exposed on the surface but well exposed underground. This is succeeded by about 200 feet of limestone and dolomite. The limestone is uniformly fine grained and thinly bedded, whereas the dolomite is in coarse-grained massive units. From 120 to 125 feet above the base is a light-gray limestone containing abundant fossils, some of which are silicified. As this unit is persistent it was mapped as a marker (pl. 27).

STRUCTURE

The prevailing strike of the beds in the vicinity of the mine is northeast, and the dip is southeast at low to moderate angles. This pattern is followed in some parts of the mapped area, but in other parts the beds are gently tilted in different directions along faint flexures without apparent systematic arrangement. Stope *B* follows an east-trending anticline.

The contact between the Yellowpine and Bird Spring is clearly faulted, as it is marked by a gouge of sand and clay ranging from a fraction of an inch to a foot in thickness. Upper beds of the Yellowpine are broken, and there are many smooth surfaces exposed in the mine that are probably bedding shears and minor thrusts. As the buff sandstone normally found at the base of the Bird Spring is missing in this area, it may be that this formation rests upon a bedding thrust of considerable magnitude, and that the low-angle shears in the subjacent Yellowpine are subsidiary to this fault. Further studies in outlying areas would doubtless settle the point, but a major thrust is not required to explain the relationships observed. Lithology of the basal Bird Spring is known to be variable, and the sandy limestone exposed in the Root mine could be a limy phase of the predominantly sandy facies. Moreover there is evidence from many parts of the district that the Bird Spring and Yellowpine contact marks a zone of structural weakness along which there has been considerable shearing.

The contact is displaced by many high-angle normal and reverse faults. Throws are mostly in the order of a few feet, except along faults *A* and *B* where displacements probably exceed 100 feet for each fault.

The mine is in a triangular block which has been uplifted relative to adjacent blocks. The northeastern margin is formed by fault *A*, the southeastern margin by fault *B*, and the western margin is along a fault of similar magnitude trending north-northeast and located beyond the western limits of mapping. Within the mine area there are many subsidiary breaks trending with each of the major faults. Thus in the southeast (pl. 27) the prevailing trend is roughly parallel with fault *B*; in the northeast, with fault *A*; and in the west, with the unmapped western fault. In the central area there are few fractures and those present trend in several directions. In some places faults that trend northeast offset faults trending northwest; elsewhere the relationship is the reverse. The high-angle faults cannot, therefore, be strictly contemporaneous, but they probably developed during the same stage of deformation.

Areal coverage is broad enough to reveal a curious pattern of faulting, but is too limited to show how the pattern fits into the fault mosaic of Bonanza Hill and thus into the regional framework. Nature of movement along most of the faults is also uncertain. In the mine, striations along fault walls that trend northeast are inclined from horizontal to 45°, and along several faults of northerly trend from 45° to vertical. There is not sufficient evidence, however, to classify one group of faults as rifts or tears and another as gravity or reverse faults.

ORE DEPOSITS

The ore forms tabular bodies that average 6 feet in thickness and replace dolomite and limestone in the upper 15 feet of the Yellowpine. Largely oxidized, it is typically a mixture of hydrozincite, calamine, and cerussite. Loosely coherent aggregates of iron-stained hydrozincite and calamine account for most of the production in stopes *A*, *B*, and *C*. White and purplish hydrozincite are locally abundant in stopes *B* and *D*, where barite is said to have been common in the gangue. Brown earthy cerussite has been the source of most of the lead. Galena occurs as residual pods in masses of cerussite and white or purplish hydrozincite, and as irregular concentrations near some high-angle faults. White coarsely crystalline dolomite forms veinlets and pods in and around the ore zones, and was probably deposited during the stage of primary mineralization.

Although the ore bodies are small, their grade is unusually high. Sizable bodies contain as much as 42 percent zinc, and the average grade of ore for the mine has been about 37 percent zinc and 5 percent lead.

GEOLOGIC CONTROLS OF ORE DEPOSITS

Distribution of galena and cerussite throughout the productive zones indicates that the oxidized ore bodies formed in place by the alteration of primary sulfide bodies. All the ore is in fractured ground within the upper 15 feet of the Yellowpine, and the upper limit of mineralization is the sheared Bird Spring and Yellowpine contact. Here as at the Argentena mine the ground below the contact is relatively more broken than that above, and there are many fractures in the upper Yellowpine that do not persist through the capping of Bird Spring. It would therefore appear that the uppermost Yellowpine was the favorable zone owing to the presence of breccia formed by shearing along and near the base of the Bird Spring. Capping the broken ground is the layer of sandy clay gouge that probably retarded the upward migration of solutions.

High-angle faults in and near the ore bodies are commonly marked by concentrations of brown hydrozincite and cerussite and locally by galena. Mineralizing solutions most likely moved along these fissures into the favorable zone at the top of the Yellowpine.

As the area of favorable ground that is barren or only slightly mineralized is apparently large in comparison with that which contains ore, it is possible that the position of ore bodies was largely determined by the position of feeding conduits. Stopes *A* and *C* are in zones characterized by the intersection and junction of faults trending in different directions. Possibly the conduits in these areas were along lines of linkage and intersection between high-angle fissures. Such an hypothesis would not, however, account for the position of stope *D*. Nor would it explain the position of stope *B*, which trends more nearly with the axis of a minor anticline than with any of the fractures that cross it.

LOOKOUT AND MOUNTAIN TOP MINES

By David A. Phoenix and Arthur Richards

These mines are along the crest of the same spur on which the Argentena mine is located, and are reached by a road south from Argentena camp (fig. 2). A. G. Campbell located the Mountain Top claim before 1893 and the Lookout several years later. In 1945 the Mountain Top was operated by P. A. Simon of Jean, Nev., under lease from the Campbell estate. Most of the mining and exploration has been at the six small workings or groups designated by claim and number on figure 7, and shown in plan on plate 28.

The spur is made up of flat-lying dolomite of the Yellowpine member, capped by the basal sandstone and the overlying thinly bedded limestone and dolomite in the lower part of the Bird Spring formation (pl. 1). All production has been from a wedge-shaped fault block. On the west this block is bounded by a persistent fault trending northwest and dipping steeply west. The eastern boundary is a similar fault trending north. The eastern fault passes about 50 feet east of the Mountain Top workings, and the western fault passes near the fork in the road leading to the Lookout No. 1 workings (fig. 7). Branches of these faults cross the block and displace the beds from a few inches to 20 feet.

Zinc-lead ores almost completely oxidized replace dolomite of the Yellowpine in the form of tabular bodies either steeply inclined along faults or lying flat with the bedding. Calamine and hydrozincite are

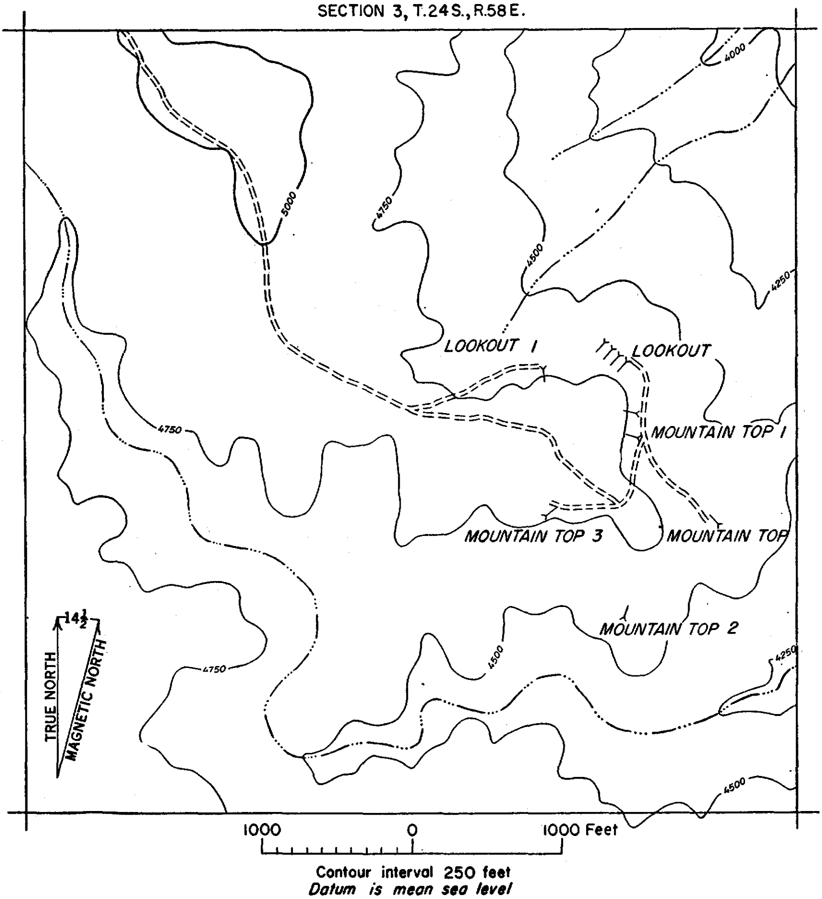

FIGURE 7.—Approximate location of the Mountain Top and Lookout mine workings.

the most common zinc minerals, and galena is the source of most of the lead. Material screened from dumps at the Mountain Top mine in 1944 contained 19 percent zinc and 11.5 percent lead. Distribution of galena throughout the mineralized zones indicates that there has been little migration of oxidized zinc from the sites of primary deposition.

The deposits range from 1 to 6 feet in thickness, and the richer shoots have longest dimensions of only a few tens of feet. Ore is found at several horizons throughout the Yellowpine member. Workings at the north (including the Lookout, Lookout No. 1, and the more northerly of the two prospects designated as Mountain Top No. 1) derive their ore from the upper 20 feet of the Yellowpine. At the south, the Mountain Top and Mountain Top No. 2 are in the lower part of the Yellowpine, and at the Mountain Top the thin beds of the Arrowhead member are also mineralized. The intermediate workings

(Mountain Top No. 1 and No. 3) are in the middle part of the Yellowpine, about 40 to 50 feet below the base of the Bird Spring.

Rise in the stratigraphic position of the productive horizons from south to the north suggests that the scattered deposits might be related to some simple controlling structure such as a thrust zone dipping south. However, there is nothing to indicate that such is the case, as the following brief reviews of the several mines and prospects show.

Ore in the Lookout No. 1 was in a bedding seam averaging about 2 feet in thickness. The seam dips gently southward, ending at the west along a reverse fault that trends north and dips 60° E. Ore was of the highest grade adjacent to the fault, and it becomes lower in grade as it thins toward the east. Probably the fault served as a conduit for mineralizing solutions. The rock in the walls of the stope is locally brecciated and everywhere fractured, owing to shearing along the bedding.

Similar conditions are found at the Lookout, to the east of the Lookout No. 1. Five workings explore mineralized ground for about 300 feet along a near-vertical shear zone trending northwest. On this fault the southwest side has been thrown down about 6 feet. The ore was taken mainly from the southeastern workings, where it occurred in the form of a flat tabular body in the upper 12 feet of Yellowpine. Basal sandstone of the Bird Spring shows in the back of the stope, and the favorable zone was in underlying dolomite fractured by bedding shears. Here the productive ground is northeast of the high-angle shear zone. Prospects to the northwest exposed thin bedding seams of ore on both sides of the same zone of shearing and 10 to 20 feet below the basal Bird Spring. Evidently the mineralizing solutions rose along the fault and spread laterally along bedding surfaces and flat zones of ground broken by bedding shears.

In the north prospect of the Mountain Top No. 1 small amounts of oxidized lead, zinc, and copper minerals are found in thin bedding seams from 12 to 20 feet below the base of the Bird Spring. In the south prospect of this same group, galena and oxidized zinc minerals are found in thinly bedded dolomite sandwiched between blocks of massive dolomite of the middle part of the Yellowpine. The favorable rocks are 1 foot thick and consist of layers averaging 2 inches in thickness separated by clay partings. Several high-angle faults show minor displacements, but it is not evident whether movement was before or after mineralization. The ore at Mountain Top No. 3 is found at about this same horizon. The galena and calamine in part follow a bedding seam ranging from 1 to 2 feet in thickness, and in part occur along several low-angle faults dipping east. A persistent high-angle fault dipping southwest crosses the ore zone a few feet from the portal.

The glory hole at the Mountain Top workings exposes galena and calamine in rubbly dolomite along a mineralized shear striking east and dipping steeply toward the south. Fractured rock bordering the fault belongs to the lower few feet of the Yellowpine member and to the underlying thin beds of the Arrowhead member.

At the Mountain Top No. 2, croppings of malachite and greenish descloizite(?) were prospected. Largest concentrations of ore minerals apparently have been at the surface and near the portals. Although a bedding seam 1 foot thick containing limonite and scattered galena was followed underground toward the north, no appreciable amount of ore appears to have been mined.

In summary, the three largest deposits, Mountain Top, Lookout, and Lookout No. 1, give evidence of the mineralizing solutions having been introduced along high-angle faults. At the Mountain Top the fractured rocks along the fault were hosts for most of the ore. In the other two mines the favorable ground lay with the bedding of the upper part of the Yellowpine in zones where the rocks were fractured by bedding shears.

FREDRICKSON MINE

By David A. Phoenix and Arthur Richards

The Fredrickson mine, 3 miles west of Goodsprings, is easily accessible by the Columbia Pass road (fig. 2). The two claims that have been worked are now owned by C. A. Beck and Mrs. O. S. Boggs of Las Vegas, Nev. Locations were first made in 1897, but the earliest recorded production dates from 1909. Nearly all the lead and zinc were produced during the interval 1912–20, and although there was activity again in 1926, the mine has been idle for the past two decades.

A crooked incline leading from small stopes opening at the surface slants southward for 380 feet at an average of 15° to the deepest level of exploration about 110 feet below the surface. Six short levels connect with the incline at the altitudes indicated on plate 29.

The mine explores the upper beds of the Yellowpine member of the Monte Cristo limestone and the lower beds of the overlying Bird Spring formation. All the stopes and most of the exploratory workings are in the upper 15 feet of the Yellowpine member, here a coarsely crystalline light-gray dolomite veined with coarse white dolomite. Basal beds of the Bird Spring formation are crossbedded fine-grained sandstone in which there are scattered lentils of sandy dolomite and quartzite.

The beds strike prevailingly northeast and dip southeast at angles averaging between 20° and 30°. Undulations along the Bird Spring and Yellowpine contact indicate minor flexures tending roughly with the dip of the bedding. The axis of an anticlinal nose appears to run between the west end of the 4,409 level and the south end of the main incline, and there are suggestions of wrinkles east of this axis.

A persistent fault trending northwest and dipping southwest between 35° and 55° is exposed at the western end of the 4,409 level and near the eastern end of the 4,312 level, as well as in the stopes and levels between. Where this fault cuts the Yellowpine and Bird Spring contact the horizontal separation as measured along the strike of the fault ranges from a few feet to nearly 30 feet, with the southwest side displaced to the northwest. This fault is similar in trend, direction of dip, and direction of horizontal separation to the large Fredrickson fault, which is exposed at the surface in the wash directly east of the portals, and it is probably a subsidiary rift in the Fredrickson fault zone (pl. 1). In the mine there are several other small faults, as well as many joints having this same trend; and although slickensides are not commonly present, a few of these have the horizontal striae characteristic of the rifts and tears in this region.

In addition there are several strike faults dipping southward more steeply than the dip of the bedding and trending almost at right angles to the tears. One of these, exposed in the incline between the 4,409 and 4,380 levels, is a thrust having a net slip of about 2½ feet. Striations parallel the dip of the fault surface. Doubtless the other strike faults of similar dip are also minor thrusts.

On the level directly below the 4,409 level, a strike fault is slightly offset by a minor tear. Elsewhere in the district thrusts and tears have developed during a single stage of folding and thrust faulting. This suggests that in the Fredrickson mine area the thrusts developed early in a stage of deformation that culminated with the development of tears.

Although many of the smallest faults in the mine displace the Yellowpine and Bird Spring contact by a few inches, there are many fractures in the Yellowpine that end upward against the contact. Several of the more conspicuous examples are shown on plate 29 as joints, but all are regarded as shear surfaces related in origin to the tears. This is also the case on the surface, along the slopes above the mine and to the west. Here the Bird Spring and Yellowpine contact crosses a bluff fronting the Columbia Pass road. The coarse-grained almost white dolomite of the Yellowpine beds is cut by an intricate network of high-angle and low-angle shears. By contrast the overlying unaltered dark limestone beds of the Bird Spring are virtually intact, although cut by a few widely spaced high-angle shears. The contact has been a surface of movement—a bedding thrust with many tears ending against its sole—and hence a place of structural discontinuity dividing broken and altered rocks below from generally intact beds above.

In the mine, all the ore bodies end against this surface. Oxidation has converted the primary zinc sulfides to brown hydrozincite and calamine, but most of the galena has remained as scattered crystals and pods within the zinc ore. Coatings of cinnabar are generally found on the galena, but where the galena has entirely altered to anglesite and cerussite, the cinnabar occurs as tiny crystals disseminated through the oxidized lead minerals. Cerargyrite, in minute waxy crystals lining vugs and cracks in sandstone and dolomite, locally enhances the value of the ore. Malachite, descloizite, cuprodescloizite are accessory minerals. Unsuccessful efforts have been made to concentrate the vanadates. Little ore remains in the stopes but production records show that the average product of the mine has run about 25 percent combined metals, with the zinc-lead ratio about 3 : 1, and with values in silver ranging from 3 to 4 ounces to the ton of ore.

The stopes form an almost continuous belt trending northwest. Their shapes indicate that the ore lay as tabular bodies replacing dolomite of the uppermost Yellowpine and backing against or within a few feet of the Bird Spring and Yellowpine contact. Productive zones were generally from 2 to 10 feet thick. The lower stopes are generally elongated with the dip of the bedding and the upper stopes more with the strike.

The persistent west-dipping fault in the mine is marked by concentrations of galena in the stope east of the incline and above the 4,312 level. It is clearly a premineralization fault, and as it either passes through or along the borders of stopes in the main run from the lowest to the highest levels, it was probably the principal feeding fissure. Evidently the mineralizing solutions rose along this fault and spread laterally in the more broken rocks below the base of the Bird Spring, replacing the dolomite. Where the fault crosses the anticlinal nose in the western part of the mine, the mineralized rock is largely in the arch of this flexure.

ACCIDENT MINE

By Arthur Richards and David A. Phoenix

The Accident mine is a quarter of a mile north-northwest of the Bullion mine (pl. 1). A branch of the dirt road connecting the mines in this vicinity with the highway at Jean leads to the campsite on the west side of Porter Wash. From there a pack trail follows up a spur to the portals, which are in the face of a cliff at a level about 400 feet above the floor of the wash.

The mine was idle when it was examined in 1945, but the workings were about twice as extensive then as when Hewett mapped the property in 1922.[35] According to local residents the more recent work was done by Sam McClanahan and associates of Las Vegas.

[35] Hewett, D. F., 1931, Geology and ore deposits of the Goodsprings quadrangle, Nevada: U. S. Geol. Survey Prof. Paper, p. 158.

Plate 30 shows the plan of the irregular underground workings. Except where the connection between the workings from the main tunnel and those from the lower tunnel is blocked by fill, there is easy access to all parts of the mine.

GEOLOGY

The mine is in the middle part of the Yellowpine member of the Monte Cristo limestone. Around the north portal the Yellowpine member is divisible into upper and lower massive limestones separated by 3 to 6 feet of thinly bedded limestone. The thinly bedded rock is in beds ranging from 3 inches to 1½ feet in thickness, separated by seams of shale. Workings underground largely follow the thin beds, but locally extend for short distances into the massive limestones above or below. The total thickness of the Yellowpine section exposed in the mine is about 30 feet.

Basal sandy beds of the Bird Spring formation are exposed in a bench above the cliff of Yellowpine. Stratigraphically these beds are about 50 feet above the thinly bedded unit and are not reached by the underground workings. Within the Yellowpine are vermiform channel fillings of clayey sandstone that the workings commonly follow. These are interpreted as cave fillings marking the positions of watercourses dissolved during the Yellowpine and Bird Spring interval of erosion and later filled when the basal beds of the Bird Spring were deposited. The fillings are mostly of sand, clay, or mixed sand and clay, except in the vicinity of the "corkscrew stope" where they are pebbly. Most of the pebbles are less than an inch across and are rounded or subrounded. Surfaces are smooth and many are highly polished. Most pebbles are of dolomite or chert, but some are made of quartzite.

The beds strike between north and northeast, and dip west at angles from 10° to 26°. A few high-angle faults are exposed by the mine workings. The prevailing trend is northerly and the dips are either east or west at angles between 55° and the vertical. Throws are less than 10 feet, and the effects of brecciation along individual shears are confined to zones within a few inches of the fault walls. No thrust faults were observed.

ORE DEPOSITS

The ore occurs as a branching network of pipes. Compared with other ore bodies in the district, those at the Accident mine were unusually long in relation to their dimensions in cross section; as a rule they were only 3 to 10 feet across but several tens or scores of feet long (pl. 30). The workings followed the ore, and what appear in plan to be irregular drifts are in reality tubular stopes along the courses of crooked shoots.

Along the sides of the stopes thin ore seams remain, and from these the character of the deposits may be inferred. The ore consists largely of pods and lentils of galena or anglesite, in masses ranging from a fraction of an inch to a few inches across. In places there were irregular streaks of ore as much as 3 inches thick and 6 feet long. The gangue is principally iron-stained montmorillonite and quartz sand. In the vicinity of the corkscrew stope the matrix is conglomeratic.

In most places the pipes are in the thinly bedded zone of the Yellowpine, but in the corkscrew stope, the ore was followed upward along a nearly vertical chimney for about 30 feet into the hanging wall of the thin beds. Rocks near the pipes show effects of hydrothermal alteration. The backs of most of the stopes are made of silicified limestone that averages 2 feet in thickness and grades upward into unaltered limestone. Below and along the sides of the ore pipes the rock is commonly altered to a dolomite so friable that it superficially resembles disintegrated igneous rock.

Although the only ore minerals observed were those of lead, the records indicate that zinc has been produced in amounts about equal to one-fifth of the lead. The source of the zinc cannot be explained in terms of the ore that remains, and it is possible that the zinc ore marketed under the name of this property actually originated elsewhere.

The lead minerals separate readily from the clay-sand gangue, and concentrates were doubtless easily obtained.

CHRONOLOGY OF GEOLOGIC EVENTS

The following is the simplest interpretation of the geologic history of the deposits.

After the deposition of the Yellowpine member, watercourses developed in the limestone by the solvent action of ground water. The waters followed the thinly bedded unit, which evidently was more permeable than the massive rocks above and below. Locally vertical solution openings connected the surface of the land with the watercourses along the thin beds. During deposition of the basal beds of the Bird Spring, the watercourses were filled with sand, mud and pebbles.

After several thousand feet of Paleozoic and Mesozoic sediments had been deposited above the unconformity at the base of the Bird Spring, the area was broken by meridional high-angle faults. At this or a later time the mineralizing solutions, rising from unknown sources, followed the permeable fillings in the old watercourses. Limestone surrounding these was silicified or dolomitized and the shaly partings as well as the mudstone in the fillings were converted to montmorillonite. Galena formed in the fillings and along their walls.

This account leaves unanswered the question as to why the original watercourses in the thinly bedded units developed along the lines they did. Nor is any indication given as to the sources from which the mineralizing fluids were fed into the channel fillings.

Neither is the relationship between ore and the high-angle faults understood. Only one fault, located near the western margin of the workings, shows concentrations of galena which conclusively mark it as presulfidation. However, all the faults belong to a zone which is assuredly premineralization in prospects to the north and in the Bullion mine to the south. The elongation of several of the narrow stopes with the strike of the faults suggests that the fractures locally guided solutions that were in the main following the cave fillings; but there is nothing to indicate that any one of the faults was a feeding fissure responsible for the ascent of solutions from their sources into the mine area.

PORTER MINE

By Claude C. Albritton, Jr. and Arthur Richards

The Porter claim covers slopes along the north side of a ravine that opens into Porter Wash at the Monte Cristo property, one-half mile east (fig. 2). No road or well-marked trail exists beyond the Monte Cristo, but the narrow floor of the ravine is an easy and direct path to the mine. Apparently no work has been done on this claim or on the adjoining Palace claim on the opposite side of the ravine since Hewett examined the area in 1922.[36] Both claims belong to the Yellow Pine Mining Co., and in 1945 were held under lease and option by the Coronado Copper and Zinc. Co. The plan of the three principal workings is shown on figure 8.

GEOLOGY

Workings explore the upper 30 feet of the Yellowpine member of the Monte Cristo limestone. In this area these upper beds range from 3 inches to 1 foot in thickness, and contain scattered lentils of chert up to 1 foot thick. By contrast, the lower part of the Yellowpine member is largely massive limestone.

The beds dip prevailingly westward at angles about 10°, but locally they are flat or tilted a few degrees eastward. They are broken by faults trending between north-northwest and northwest, most of which dip west at angles ranging from 60° to 85°. Striae or slickensides along three of the faults indicate that the slip has been predominantly with the strikes of two of the faults, and with the dip of the third. The throw ranges from a few inches to a few feet for all examples mapped, with the exception of the Porter fault, exposed directly west of the No. 3 workings. The minimum stratigraphic displacement here

[36] Hewett, D. F., op. cit., p. 158.

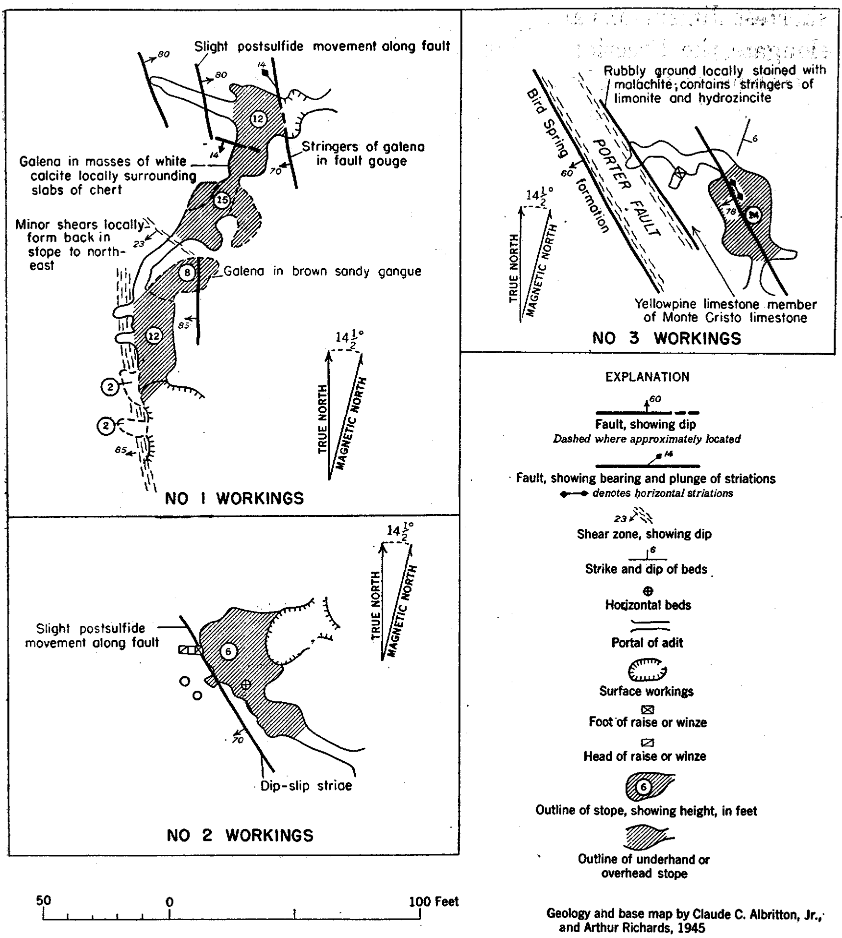

FIGURE 8.—Geologic map of the principal workings of the Porter mine.

is about 50 feet, with Bird Spring on the west downthrown against Yellowpine on the east.

Two low-angle shears, mapped in the No. 1 workings, trend from northwest to west and dip south. These are probably minor thrusts.

The rocks are brecciated and rubbly for 20 feet on either side of the Porter fault, but elsewhere rocks bordering faults are unbroken. Dolomitized limestone is limited to narrow zones immediately surrounding the stopes, but limestone adjacent to the dolomite is of lighter color and coarser texture than is normal for the Yellowpine rock. In parts of the No. 1 workings the limestone is silicified.

ORE DEPOSITS

The shape of stopes indicates that the ore lay as irregular lenses or pipes with the longest dimensions paralleling the bedding and the shortest dimensions at right angles to bedding. Where the bodies are elongate, the direction of elongation bears from northeast to northwest.

Galena is the only abundant ore mineral remaining, and records of production indicate that lead has been the principal product. Iron-stained hydrozincite occurs with the galena in the No. 3 workings, but zinc minerals appear to be lacking elsewhere. The galena is commonly in pods and irregular stringers in gangue of white calcite or iron-stained sand. In the No. 1 workings much of the white calcite associated with the galena fills solution cavities or watercourses in the thinly bedded Yellowpine, or cements open-textured breccia where slabs of chert were left in the watercourses as insoluble residue. Some of these slabs are rotated as much as 45° from their original positions. Much of the galena has been deposited along the sides of the chert slabs, although crystals are scattered through the dolomite and limestone adjacent to the calcite filling (fig. 9). Where the gangue is sandy, it may be assumed that, as at the Accident mine, the sand

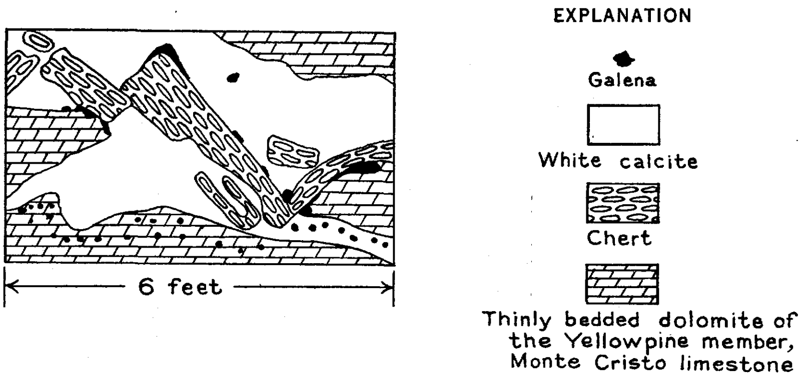

FIGURE 9.—Sketch of stope wall in northern part of No. 1 workings, Porter mine. Shows white calcite and galena filling small watercourse in the thin cherty beds of Yellowpine limestone member.

washed into watercourses developed during the interval of erosion preceding deposition of the Bird Spring.

In a few places galena is concentrated along the high-angle faults, indicating that the faults existed before mineralization. Along some faults, however, the galena and associated calcite are cracked, reflecting slight postmineralization movement along premineralization faults. Such is the case, for example, along the fault with dip-slip striae that crosses the western edge of the No. 2 workings.

VALENTINE MINE

By ARTHUR RICHARDS and DAVID A. PHOENIX

The Valentine mine is a quarter of a mile south of the Anchor mill near the top of a steep slope overlooking Porter Wash (fig. 2). A foot trail leads to the portal of the main workings, about 500 feet higher than the wash. No work has been done here since Hewett examined the property in 1922. As the investigation of 1945 added nothing of especial interest to what is already known,[36] the following account is brief, and the reader is referred to Hewett's paper for further details.

Figure 10 shows the plan of the main workings and the principal geological features. Two small ore bodies have been mined, one below the collar of the shaft to a depth of about 50 feet, the other near the western end of the mine. Workings connecting the stopes are barren as are the short lateral drifts and crosscuts near the ore. Both ore bodies are in thinly layered cherty dolomite of the Anchor member of the Monte Cristo limestone. The mineralized ground around the stopes consists principally of hydrozincite inclosing small amounts of galena. In the eastern stope the ore forms thin streaks parallel with the bedding.

Several faults trending northwest are exposed in the mine. All dip east except three, which dip west at 70°–72°. One of these westward-dipping faults clearly controls the ore in the western slope, and another crosses the western edge of the eastern stope. These faults probably were conduits along which the mineralizing solutions moved.

HOUGHTON (VICTORY) MINE

By Claude C. Albritton, Jr. and Arthur Richards

The Houghton mine is in the lower slopes bordering the west side of Porter Wash, and is easily accessible by a branch of the dirt road that follows the wash. The claim is registered in the names of T. B. Keeler, P. S. McClanahan, and M. T. Schwartz. In 1917 about 80 tons of ore containing 37 percent zinc was shipped by Dick Duncan (personal communication, 1945). In 1943–44 slightly more than 200 tons ranging from 19 percent to 23 percent zinc was marketed at the Metals Reserve Co. stockpile by Hammond and Reed of Goodsprings.

Ore has been mined from an opencut to a maximum depth of 35 feet below the surface (fig. 11). Country rock is limestone of the Anchor member, locally altered to dolomite. Along the lower and eastern parts of the pit the rock is thinly bedded and contains many lentils of chert ranging from a few inches to 1 foot in thickness. The western part of the pit is in massive gray chertless dolomite.

Bedding strikes northwest and dips 25° southwest. Several vertical or near-vertical fractures cross the workings trending from northwest to northeast. These are conspicuous only in the deeper western part of the pit where they appear as narrow crevices, some of which contain angular pebbles and cobbles of dolomite. The fractures are either joints or faults along which the movement was slight.

[36] Hewett, D. F., op. cit., p. 162.

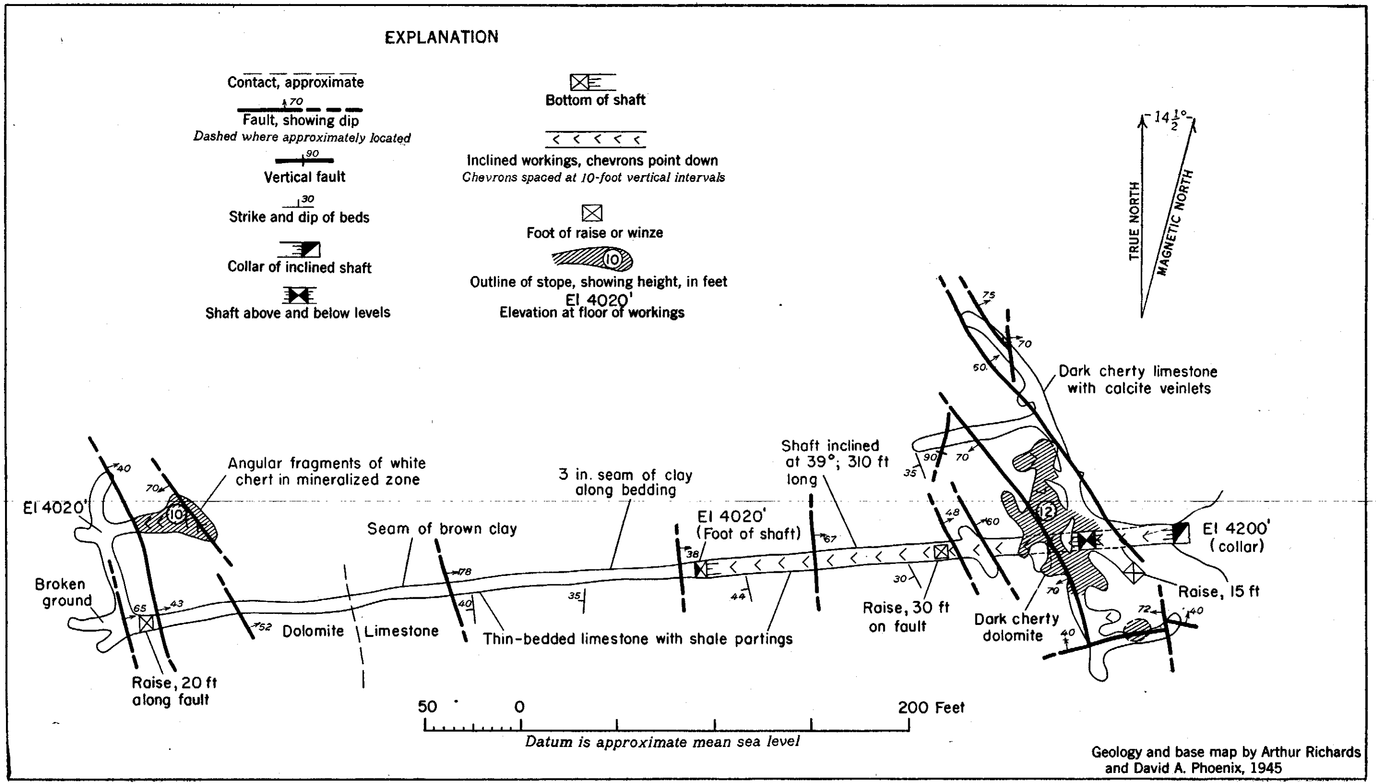

FIGURE 10.—Geologic map of the mine workings in the Valentine mine,

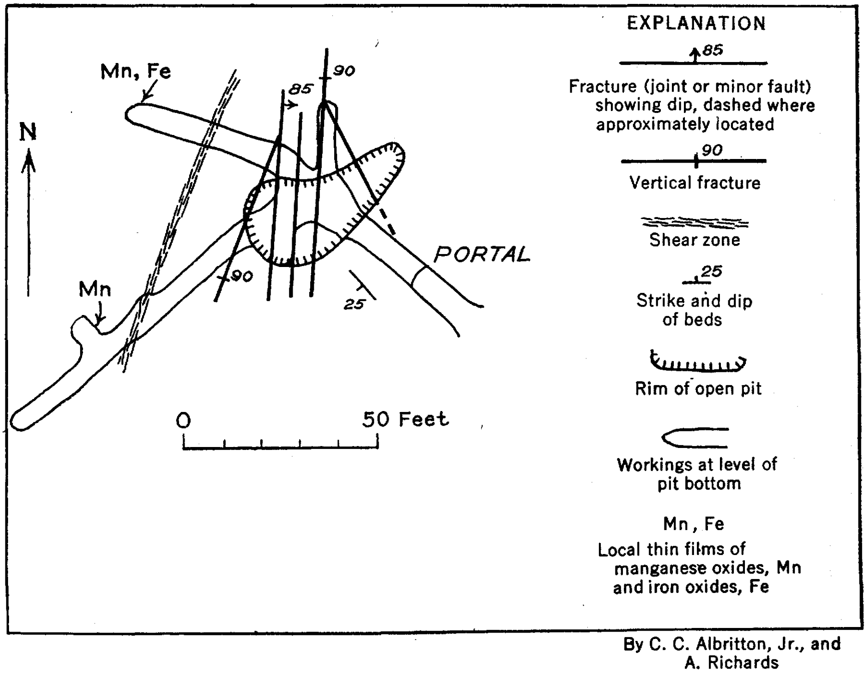

FIGURE 11.—Map of underground and surface workings, Houghton (Victory) mine.

As the lateral workings are barren and the bottom of the pit is only sparsely mineralized, the shape of the ore body must have been similar to that of the pit. Incrustations of smithsonite cover some dolomite fragments in the crevices. Vugs in the dolomite around the walls of the pit contain smithsonite, calamine, and needles of hydrozincite. No sulfide minerals were observed. As there is no record of any lead production the ore was presumably an aggregate of the oxidized zinc minerals named above.

Possibly the ore formed by oxidation in place of an unusually pure body of sphalerite. More probably the primary ore lay somewhere above the present surface of erosion, and the oxidized ore has migrated downward along and adjacent to the high-angle fissures.

STAR PROSPECT

By CLAUDE C. ALBRITTON, JR. and ARTHUR RICHARDS

The Star prospect is along the sides of a ravine 0.3 mile southwest of the Houghton mine (fig. 2). Figure 12 shows the plan and geologic features of the main tunnel, which is on the south side of the ravine. The country rock is Monte Cristo limestone, which strikes northwest and dips southwest at an average of 25°.

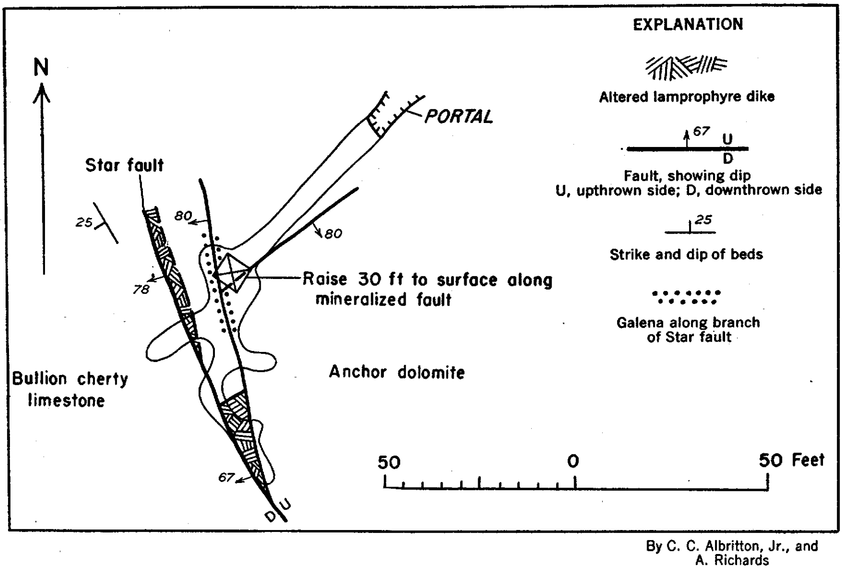

FIGURE 12.—Map of main tunnel, Star prospect, showing geology.

Prospecting has been along the Star fault, a persistent fracture that may be traced a quarter of a mile north and south to places where it links with other persistent faults. It dips west at angles from 65° to vertical. In the prospect mapped, gray dolomite of the Bullion member forms the hanging wall; the thinly layered cherty beds of the Anchor are in the footwall. The displacement is thus normal, and according to Hewett's estimate the stratigraphic throw is about 300 feet. Along a drift at the southwest end of the prospect the fault is followed by tabular masses of clay containing flecks of biotite. The micaceous clay originated by decomposition of a lamprophyre dike. This and similar dikes in other parts of the district have already been noted by Hewett. The clay is sheared and locally appears as iron-stained gouge. The Star fault existed before the dike was intruded, but there has also been movement along the fault since the dike was formed.

A high-angle branch of the fault is followed for a few feet by an irregular drift and by a raise for 30 feet to the surface. Walls and fractured ground along this fault are generally iron stained and are locally replaced by galena, which forms scattered crystals and pods coated with cinnabar. Small amounts of ore were mined along this fault.

The prospect is interesting more for the sequence of geologic events it suggests than for the small tonnage of ore it produced. A quarter of a mile to the south the Star fault joins a larger fault, which is also followed in part by a lamprophyre dike. The walls are scored with horizontal striae, suggesting that this fault is a rift similar in origin if not identical with the Fredrickson fault zone north of Table Mountain.[37] As the Star fault is a branch of this rift the two are probably contemporaneous, and it is likely that the Star also originated as a rift. The probable sequence of geologic events was as follows:

1. Strike-slip movement along the Star fault.
2. Intrusion of lamprophyre dike.
3. Normal movement along Star fault followed or accompanied by ascent of hydrothermal solutions responsible for dolomitization of adjacent rocks, alteration of dike, and introduction of sulfide minerals along branch fault.
4. Oxidation of sulfide minerals.

GENERAL RECOMMENDATIONS AND OUTLOOK

By Claude C. Albritton, Jr.

Broad areas of fractured dolomite and most of the innumerable pre-mineralization faults in the district are barren at the outcrop. Compared with the expanse of barren rock the volume of mineralized ground is small; much more ground was prepared for mineralization than was mineralized.

The Goodsprings district, with its numerous mines and prospects, scattered over an area of several hundred square miles, may be compared to a blotter dotted with tiny spots of ink. In seeking to understand the origin of the spotted pattern it is not much to the point to investigate variations in the absorptive qualities of the blotter; it is necessary to reconstruct the train of circumstances by which the ink from the well reached the points of absorption. Similarly, in order to understand the distribution of mines it is necessary to know what determined the path of ore-forming solutions from the depths upward and into the ground prepared for mineralization.

The district as a whole is located where several sets of fractures intersect. Strong lineaments trend northeast and northwest through the heart of the mining area, whereas to the north and to the south the structural grain is northwest. The largest mine in the district, the Yellow Pine, is developed along the junction between northwest-trending tears and northeast-trending rifts. On a smaller scale, the Discovery ore body in this mine is located in a zone where subsidiary rifts and tears come together. The same reticulate pattern found in the heart of the district is duplicated by minor faults in the central area of the Potosi mine, and at the Root mine. The anastomosing pattern of faults found in the principal rift zones, such as the Fredrickson and Sultan, is another type of linkage that is characteristic of the district.

[37] Hewett, D. F., op. cit., pl. 1.

Optimum conditions for the development of conduits existed in areas where high-angle fractures of more than one trend divided the terrain into relatively small fault blocks. In the Goodsprings district, the places where the principal conduits cut the exposed parts of the favorable beds should have already been discovered: they are the mine areas that were located on mineralized croppings. On a broader scale, using as leads the mines rather than ore croppings, it follows that a favorable place to test deeper horizons, such as the Yellowpine limestone member, is in the conduit zone below a mine in the lower part of the Bird Spring formation, and, similarly, the favorable place to prospect the Anchor limestone member is below a mine in the Yellowpine. Although superposed stopes are known in the favorable beds at the two largest mines in the district, no mine has yet explored the favorable zones in both the Yellowpine limestone member and the Anchor limestone member. Such exploration has already been recommended by Hewett, and the writers claim no originality in suggesting it again.[38] It is repeated and expanded to emphasize that the future of the district depends in large part on whether further exploration proves the existence of superposed ore bodies beneath the exposed conduit areas.

[38] Hewett, D. F., op. cit., p. 103.

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