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GEOLOGY AND ORE DEPOSITS

OF THE

GOODSPRINGS QUADRANGLE, NEVADA

BY

D. F. HEWETT

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OUTLINE OF REPORT

Since 1907 the Goodsprings district has attained eminence as the principal source of zinc ores in Nevada. Production reached a peak during the World War, when the prices offered for zinc and lead ore were higher than for many years. Since then production has fluctuated widely in response to the prices of the metals. This is due to the fact that, viewed broadly in a comparison of American mining districts, costs of mine operation are high here, because the district lies in an arid region and there are few local sources of supplies. Also, the sulphide minerals originally formed have been almost completely altered to carbonate and silicate minerals, and these are not so readily amenable to concentration as the sulphides. Compared with many other western mining districts, this district has not benefited from a penetrating insight into the geologic problems surrounding the ore deposits. As mining is now regarded, the mines of the district have attained only moderate depths. Considering the known extent of the productive territory, it is reasonable to assume that with greater understanding of the geologic relations of the deposits and with improved mining and milling technique considerable ore will be found and the district will be a source of production for many years.

Stratigraphy.—The stratified rocks exposed in the Goodsprings quadrangle attain a thickness of about 13,000 feet and range in age from Upper Cambrian to Recent. Near Sheep Mountain, 10 miles east of the quadrangle border, about 500 feet of underlying beds, largely Middle Cambrian in age, are exposed, and these rest on pre-Cambrian gneissic granite. The systems of the Paleozoic are all represented in the 8,500 feet of beds exposed, and the beds of Devonian, Mississippian, Pennsylvanian, and Permian age are highly fossiliferous. Of the Paleozoic units, limestone and dolomite make up more than 7,000 feet. Beds of only the lower part of the Mesozoic system are present, and they attain more than 4,000 feet in thickness. Most of this thickness is made up of sandstone, shale, and conglomerate, but there is 600 feet of limestone near the base. No beds of Cretaceous age are known in this region. The Tertiary and Pleistocene stratified rocks include volcanic tuffs and flows and deposits of gravel.

Intrusive rocks.—Only three varieties of intrusive rocks are known in this district. The most abundant rock is granite porphyry, which forms a large sill 300 feet thick in the center of the district, two other large bodies, and numerous dikes. The three larger bodies lie near two of the principal thrust faults of this region, and the smaller dikes occur sporadically in a belt overlying one of these thrust faults. It is believed that the thrust faults have determined the distribution of the bodies of granite porphyry. In three mines small dikes of basic rocks have been encountered; these are here considered lamprophyres.

Extrusive rocks.—After a long lapse of time, during which the stratified rocks were folded and faulted, then intruded by granite porphyry and lamprophyric dikes, then subjected to considerable erosion, volcanic activity was renewed. This epoch of volcanism probably coincides with that of middle Tertiary age widely represented elsewhere in Nevada. At this time there were erupted from three or four centers tuffs and flows that are largely intermediate in composition, although they include rhyolite, latite, and basic andesite. In two localities dikes of basalt have been found.

Structural history.—The region reveals an amazing record of folding, thrust faulting, and normal faulting. At some time between the late Jurassic and the middle Tertiary, here concluded to have been early Tertiary, the bedded rocks were folded to different degrees, depending upon whether the beds were massive and thick or heterogeneous and thin. For the most part the massive limestones of the Devonian and Mississippian formations developed rather open folds, but the Pennsylvanian beds formed close folds. Toward the end of the epoch of folding, thrust faults began to form. This quadrangle displays four extensive thrust faults, which are shown by a further study of the surrounding region to be only part of a group of at least seven that may be traced many miles along the Spring Mountains. Near the end of the epoch of thrust faulting the sills and dikes of granite porphyry were intruded. Some of these intrusions are affected by minor thrust faults. After the thrust faulting a few normal faults of general northward strike and westward dip were developed. Some of these contain ore deposits and thus record the epoch of ore deposition in the structural history. These were followed by other normal faults that largely trend north and dip east and are known to be younger than the ore deposits but older than the middle Tertiary lavas. Since middle Tertiary time the region has undergone local tilting of the lavas and minor normal faulting. Much of the present relief appears to have been produced by the erosion that followed the latest faulting and tilting. The region is still in process of vigorous dissection by erosion.

Rock alterations.—The rocks of the region display a wide variety of alterations, but one kind—the dolomitization of limestone—is well shown in many localities and persists over a large area. Areal study shows that most of the 3,000 feet of beds below the base of the Devonian were laid down as magnesian limestone or dolomite, whereas most of the overlying 5,500 feet of Paleozoic beds were laid down as very pure limestone. At a much later period, probably after most of the thrust faults were formed and before ore deposition took place, large masses and thick layers of the limestone were altered to nearly pure dolomite. Dolomitized limestone is most widespread in beds of Devonian and lower Mississippian age but is sporadic in the pre-Devonian and Pennsylvanian rocks. Most of the ore deposits are found in breccia zones of dolomitized limestone, and the conclusion is reached that the alteration preceded ore deposition but that the solutions to which both processes were due rose from considerable depth along the same general channels. In one locality dolomitized limestone is altered to serpentine, and at another a block of dolomite nearly surrounded by granite porphyry is altered to garnet and quartz. The middle Tertiary intrusive rocks have produced minor dolomitization and hydration of earlier dolomite.

General features of the ore deposits.—The ore deposits of the district include those which have been exploited for gold, for copper with accessory cobalt, nickel, and silver, and for zinc and lead with accessory vanadium. The quantity and value of the material shipped as a source of zinc and lead far exceed those of the other metals. The deposits are not uniformly distributed throughout the district; most of them fall readily into several groups which are rather sporadically distributed. The deposits of several groups are clustered around bodies of granite porphyry that have been intruded on thrust faults, but several other groups lie from 5 to 10 miles from the nearest known outcrops of such rocks. All the ore deposits occur in rocks older than the Permian, but an astonishingly large part of the total number lie in a zone scarcely 500 feet thick, below the base of the Pennsylvanian. In a broad way the gold deposits occur in or very near the intrusive rocks, the copper deposits in Devonian or older beds, and the zinc and lead deposits in beds of lower Mississippian age. The sulphide minerals of all but a few of the deposits are completely altered to carbonates, sulphates, and silicates to the depths reached by mining, so that some problems of the deposition of the sulphides remain obscure.

Gold deposits.—Scarcely half a dozen deposits in the the district have been exploited for gold. The production from one mine, the Keystone, has probably exceeded $600,000, but that from the other mines has been small. The Keystone ores yielded considerable free gold by amalgamation, but the state of the gold in the unweathered product from this and the other mines of the district is not at all clear. Gold was rarely seen in the product of the Red Cloud mine, but it was readily dissolved in cyanide solutions. As it is reported that tellurium was present in the ore, the gold may have been present as a telluride in the unweathered material. Gold-bearing quartz veins, as they are known in many districts, have not been found here. The gold and minor associated sulphide minerals were either deposited in altered granite porphyry or replaced the adjacent carbonate rocks along minor fractures.

Copper deposits.—In several respects the copper deposits may be considered intermediate between the gold deposits and the zinc and lead deposits. Notable quantities of copper minerals are present in most of the gold deposits, and these minerals have been encountered sporadically in the zinc and lead deposits. Several of the larger bodies of copper minerals have been found near intrusive masses of granite porphyry (Columbia and Boss mines), but none have been found in such rocks. Several, however, are remote from known intrusive masses (Ninety-nine mine). The copper in these deposits is present largely in the form of malachite and azurite, but some chrysocolla is generally present, and two oxides are recorded, tenorite and cuprite. The evidence is quite clear that the original mineral was largely if not wholly chalcopyrite and that it was deposited with only small quantities of gangue minerals in breccia zones in dolomitized limestone. Some of the oxidized cobalt minerals are persistently associated with the copper minerals, and shipments of cobalt ore have been made from four mines.

Zinc and lead deposits.—Zinc and lead minerals are persistently associated in most of the ore deposits of the district, but a few zinc deposits are entirely free of lead minerals, and a few lead deposits contain no zinc minerals. Except for the Yellow Pine and Prairie Flower ore bodies, which underlie the Yellow Pine granite porphyry sill, most of the zinc and lead deposits are remote from outcropping bodies of intrusive rock, and if it were not for the regional relations of all the metalliferous deposits and the association of the widespread dolomitization of limestone and certain structural features, it would be difficult to prove a genetic relation of the intrusive rocks to the zinc and lead deposits.

Unweathered zinc sulphide has been observed in only two mines in the district, but lead sulphide is rather widespread. The commonest zinc mineral is earthy hydrozincite (hydrous carbonate of zinc), most of which has been formed through the replacement of dolomite by zinc sulphate. Smithsonite, the anhydrous zinc carbonate, is found in some of the mines, where it has been deposited in open fractures and watercourses. Locally, it has been altered to hydrozincite. A little calamine (hydrous silicate of zinc) is found in most of the mines. Experimental work has shown that anhydrous zinc carbonate tends to form where there is abundant excess of carbonic acid, and hydrous zinc carbonate where there is a deficiency of carbonic acid. The distribution of these two minerals in this district conforms with the conclusions of experimental work.

Although galena is widespread, probably most of the lead in the deposits is present as cerusite (lead carbonate); some anglesite (sulphate of lead) is found in most of the mines. The simple vanadate of lead, vanadinite, was recognized at only one mine, but small quantities of the mixed vanadates of lead, zinc, and copper are widespread.

Structural relations of the ore deposits.—The broad form of most of the deposits of the district, especially of the larger deposits, is distinctly tabular, although here and there some of the smaller bodies have simple or complex rounded forms. Most of these tabular forms lie nearly if not quite parallel to the bedding; a smaller number cut the bedding obliquely. The conclusion may be broadly stated that the deposits lie along fractures that have broken the beds, especially the massive beds of limestone. In several places the fractures that lie nearly parallel to the bedding have been interpreted as thrust faults which are slightly older than the fractures that cross the bedding. It seems here that the solutions bearing the sulphides of the metals have risen along the crosscutting fractures and spread out in the breccia zones along the earlier thrust faults. Probably this explanation applies to other deposits where the evidence is more obscure. The largest ore deposits have been found in the fractures and breccia zones that trend nearly parallel to the bedding. Two large ore deposits, those of the Potosi and Bonanza mines, lie in conical or domal breccia zones, where they are cut by later, nearly vertical fractures.

Many ore bodies in the district, especially in the southern part, are broken by minor postmineral faults, but the extent of these is not great.

Genesis of the ores.—In this district a thick section of limestone beds has been folded, broken by several major and numerous minor thrust faults, and then intruded by dikes and sills of a granular silicic igneous rock. After more minor thrust faulting and minor normal faulting, metalliferous sulphides and gold were deposited in breccia zones and fractures. In a broad way the gold deposits lie in fractures in or near the intrusive rock, the copper deposits are more remote from the intrusive bodies, and the zinc and lead deposits are most remote. Apart from a crude zonal distribution outward from the intrusive bodies, the presence of a little copper in both the gold deposits and the zinc and lead deposits tends to link them in a common origin. It is possible, though not certain, that a deeply buried mass of igneous rock was the actual source of the metals, and it seems probable that such a body caused the ascent and dispersal of the metals.

GEOLOGY AND ORE DEPOSITS OF THE GOODSPRINGS QUADRANGLE, NEVADA

By D. F. Hewett

INTRODUCTION

FIELD WORK AND ACKNOWLEDGMENTS

The field work on which this report is based was begun October 15, 1921, and continued until May 13, 1922. Charles H. Behre served effectively as a field assistant until April 1, 1922. Several of the mines were revisited by the writer in November and December, 1924, and December, 1926. Assistance was freely given by the Yellow Pine Mining Co. (J. F. Kent, president), Sultan Mining Co. (Henry Robbins, owner), Goodsprings Anchor Mining Co. (Seeley W. Mudd, vice president), Boss Mining Co. (S. E. Yount), Empire Zinc Co., Goodsprings Mining Co. (Alonzo Z. Hyde), J. R. Newberry (Tam o' Shanter mine), Nevada-Keystone Mining Co. (T. A. Johnson), S. E. Root, J. W. McFattridge (Azurite mine), and S. S. Arentz (Ingomar mine). Without exception the residents of Goodsprings as well as the watchmen at the mines cordially gave all assistance necessary from time to time in the areal work and the examination of mines. Special mention should be made of John Fredrickson, John Egger, Harvey Hardy, A. J. Robbins, R. Munzeberg, Fred Piehl, George Meacham, C. W. Price, A. O. Jacobsen, A. Munzbrook, George L. McIntyre, L. M. Benson, O. F. Schwartz, A. Buys, C. A. Beck, Joe Doran, Frank Miller, and F. Renaux. Nonresident mine owners or operators have also cooperated in many ways, especially in offering the use of mine maps and in supplying data of production.

The writer is indebted to G. F. Loughlin and H. G. Ferguson, of the United States Geological Survey, for critical reading of the manuscript and helpful suggestions.

The publications listed below contain information concerning the Goodsprings quadrangle and adjacent areas.

BIBLIOGRAPHY

1845. Frémont, J. C., Report of the exploring expedition to the Rocky Mountains, pp. 264–265, Washington. Frémont camped at Mountain Springs, May 1, 1844, and describes the appearance of the country.

1865. Whitney, J. D., Geological Survey of California, vol. 1, pp. 469–474. Quotes from the report of J. R. N. Owen, who explored the country along the California border in 1861.

1871. Raymond, R. W., Mineral resources of the States and Territories west of the Rocky Mountains, pp. 168–174. Quotes the report by C. A. Luckhardt, who examined the Comet (Potosi) mine about 1870.

1872. Gilbert, G. K., in Wheeler, G. M., Preliminary report concerning explorations and surveys in Nevada and Arizona, pp. 52–53. Describes the Comet (Potosi) mine, examined in 1871.

1875. Gilbert, G. K., Report on the geology of portions of Nevada, Utah, California, and Arizona: U. S. Geog. and Geol. Surveys W. 100th Mer. Rept., vol. 3, pp. 21–42, 166. Presents a description of the Spring Mountains and a structural cross section at Cottonwood Spring.

1882. Burchard, H. C., Report of the Director of the Mint, 1882, pp. 163–164. This and later reports refer briefly to the Yellow Pine district.

1893. Anonymous, Yellow Pine district, Nev.: Min. and Sci. Press, vol. 66, p. 260. Describes recent work at the Keystone, Boss, and Clementina mines.

1893. Anonymous, A promising district: Min. and Sci. Press, vol. 67, p. 113. Describes conditions in the Yellow Pine district.

1897. Anonymous, Eng. and Min. Jour., vol. 64, p. 677. Describes recent work by A. G. Campbell.

1901. Spurr, J. E., Origin and structure of the Basin Ranges: Geol. Soc. America Bull., vol. 12, pp. 235–236. Describes general structure of the Spring Mountains and concludes that the range is synclinal.

1902. Anonymous, Eng. and Min. Jour., vol. 74, pp. 446–447. Presents list of 24 active mines.

1903. Spurr, J. E., Descriptive geology of Nevada south of the fortieth parallel and adjacent portions of California: U. S. Geol. Survey Bull. 208, pp. 164–180. Presents descriptions of areal geology and structural features in the Spring Mountains, largely on the basis of work by R. B. Rowe in 1900–1901.

1906. Bain, H. F., A Nevada zinc deposit: U. S. Geol. Survey Bull. 285, pp. 166–169. Describes the Potosi ore body and concludes that, like those of the Mississippi Valley, it is not related to igneous rocks.

1909. White, Douglas, The zinc mines of southern Nevada, Am. Min. Cong. Twelfth Ann. Rept. Proc., pp. 401–411. Describes briefly Monte Cristo, Bonanza, Mobile, Green Monster, and other mines.

1910. Gregory, N. B., The Yellow Pine district of Nevada: Eng. and Min. Jour., vol. 90, pp. 1308–1309. Describes briefly principal mines.

1914. Hill, J. M., The Yellow Pine mining district, Clark County, Nev.: U. S. Geol. Survey Bull. 540, pp. 223–274. Describes areal geology, general structure, and features of principal mines.

1915. Knopf, Adolph, A gold-platinum-palladium lode in southern Nevada: U. S. Geol. Survey Bull. 620, pp. 1–18. Describes the Boss mine and its minerals.

1915. Kennedy, J. C., Occurrence of platinum at Boss mine, Nevada: Min. World, vol. 42, pp. 939–940.
1915. Nevius, J. N., Reconnaissance of the Goodsprings district, Nevada: Min. World, vol. 42, pp. 897–899.
1916. Palmer, L. A., The Yellow Pine district, Nevada: Eng. and Min. Jour., vol. 102, pp. 123–125. Describes the principal mines and mills.
1918. Hale, F. A., jr., Ore deposits of the Yellow Pine mining district, Clark County, Nev.: Am. Inst. Min. and Met. Eng. Trans., vol. 59, pp. 93–111. Describes areal geology and principal mines.
1920. Waring, G. A., Ground water in Pahrump, Mesquite, and Ivanpah Valleys, Nev. and Calif.: U. S. Geol. Survey Water-Supply Paper 450, pp. 51–86. A summary of existing data concerning ground water in wells or springs in these valleys.
1921. Longwell, C. R., Geology of the Muddy Mountains, Nevada: Am. Jour. Sci., 4th ser., vol. 50, pp. 39–62.
1926. Longwell, C. R., Structural studies in southern Nevada and western Arizona: Geol. Soc. America Bull., vol. 37, pp. 551–584.
1927. Glock, W. S., Geology of the east-central part of the Spring Mountain Range, Nevada: Am. Jour. Sci., 5th ser., vol. 17, pp. 326–341.
1928. Longwell, C. R., Geology of the Muddy Mountains, Nevada: U. S. Geol. Survey Bull. 798, pp. 1–149.
1929. Nolan, T. B., Notes on the stratigraphy and structure of the northwest portion of Spring Mountain, Nevada: Am. Jour. Sci., 5th ser., vol. 17, pp. 461–472.

GEOGRAPHY

LOCATION OF THE AREA

The Goodsprings quadrangle lies in the extreme southern part of Nevada, in the angle of Clark County that is bounded on the east by the Colorado River and on the west by the State line. (See fig. 1 and pl. 3.) The width of the quadrangle is 10.25 miles and the length 21.9 miles, so that the area is 224.5 square miles. Of this area 12.4 square miles in the southwest corner lies in the State of California.

The district is accessible from Jean, on the Los Angeles & Salt Lake branch of the Union Pacific Railroad, which lies in 8 miles southeast of Goodsprings, the principal settlement in the quadrangle. This railroad was built in 1905, and previously the district was accessible from Ivanpah, Calif., 34 miles south of Jean, and the terminal of a branch line of the Atchison, Topeka & Santa Fe Railway. The Arrowhead automobile highway between Barstow, Calif., and Las Vegas, Nev., passes through Jean. At an earlier period the district was reached from the Spanish trail between Los Angeles and Salt Lake City, which crosses the Spring Mountains 2 miles north of Potosi Mountain. The ore produced by the Yellow Pine mine is shipped to Jean, and the heavy supplies for that mine are brought into the district over a narrow-gage railway built in 1910 by the Yellow Pine Mining Co.

SURFACE FEATURES

The Goodsprings quadrangle covers the southern third of the Spring Mountains—a range which is, in several ways, one of the most unusual and interesting in southern Nevada. Unlike the near-by ranges, which trend generally north, this range forms a broad arc convex to the northeast. It is clearly defined for 70 miles, extending from the Amargosa Desert on the northwest to State Line Pass on the southeast. The greatest width is about 24 miles, at the place where it culminates in Charleston Peak, 11,910 feet above sea level. Although there are several slightly higher peaks in Nevada (such as Boundary Peak, Esmeralda County, 13,145 feet, and Wheeler Peak, White Pine County, 13,047 feet), it is interesting that one of the highest peaks in the State lies adjacent to the lowest valley, Las Vegas, scarcely 1,600 feet above sea level. The rugged mountain mass of which Charleston Peak is the highest point rises abruptly from the valley, and the two extremes of surface features are presented in striking contrast. The climate and therefore the plant life reflect this contrast. There is a heavy snowfall on the peak, some of which survives the summer, and there are large areas of a vigorous growth of pine trees. By contrast, snow is very uncommon in Las Vegas Valley and many semitropical plants thrive.

The southern part of the Spring Mountains presents a similar contrast to the near-by valleys but in less degree. This part of the range trends nearly north, is very irregular in outline, and 4 to 6 miles wide. The highest point in the Goodsprings quadrangle is Potosi Mountain (Olcott Peak), 8,504 feet, in the northern part; the lowest altitude is at Mesquite Dry Lake, in the southwest corner, about 2,545 feet. The surface features of these two parts of the region stand in striking contrast. Viewed from the southwest or south along gently rising ridges, Potosi Mountain is not particularly impressive, but viewed from northwest, east, or southeast (pls. 4, *A*; 13, *A*), the northeast face presents an impressive escarpment that can be ascended only with difficulty. The summit and northeast slopes are well covered with piñon and cedar, 15 to 25 feet high, and there are sporadic groves of spruce on the north side. This high area receives a heavy snowfall, and drifts survive locally into the early summer. By contrast, the flat valleys have only a sparse growth of desert shrubs, and their lowest parts are utterly bare. Thus, the lowest part of Mesquite Dry Lake is devoid of vegetation and is covered with a veneer of gypsum crystals and salt. The bordering zone contains sparse groves of mesquite trees, but the most abundant shrub is creosote bush (*Covillea tridentata*). In Goodsprings Valley and the border of Ivanpah Valley this is the commonest shrub up to an altitude of about 4,250 feet, and mesquite trees are unknown. There are few other shrubs in the valleys except greasewood (*Atriplex canescens*) and several varieties of yucca.

The areas containing abundant creosote bush merge with a higher zone in which a small shrub, coleogyne

(*Coleogyne ramosissima*), is abundant, and another, locally called Mormon tea (*Ephedra viridis*), is common. The range in altitude of these areas is a thousand feet or more, and they merge with a higher zone in which common sage (*Artemisia tridentata*) predominates. This is the most abundant shrub in the higher smooth slopes such as Table Mountain. The "cedar" (*Juniperus utahensis*) appears at about 5,000 feet in the northern half of the quadrangle, at first 5 to 8 feet high, and then, at higher altitudes, more abundant and larger. It is almost absent in the southern half of the quadrangle. The picturesque Joshua tree (*Yucca arborescens*) is abundant in Goodsprings Valley, largely above an altitude of 4,250 feet, but is sparsely distributed elsewhere.

The views included in this report should give the impression that the rocks are uncommonly free from soil or débris and that their relations are exceptionally well revealed for study. The continuity of many of the stratigraphic boundaries and of some of the structural features may be traced with much more confidence than is customary in more humid regions or those of low relief.

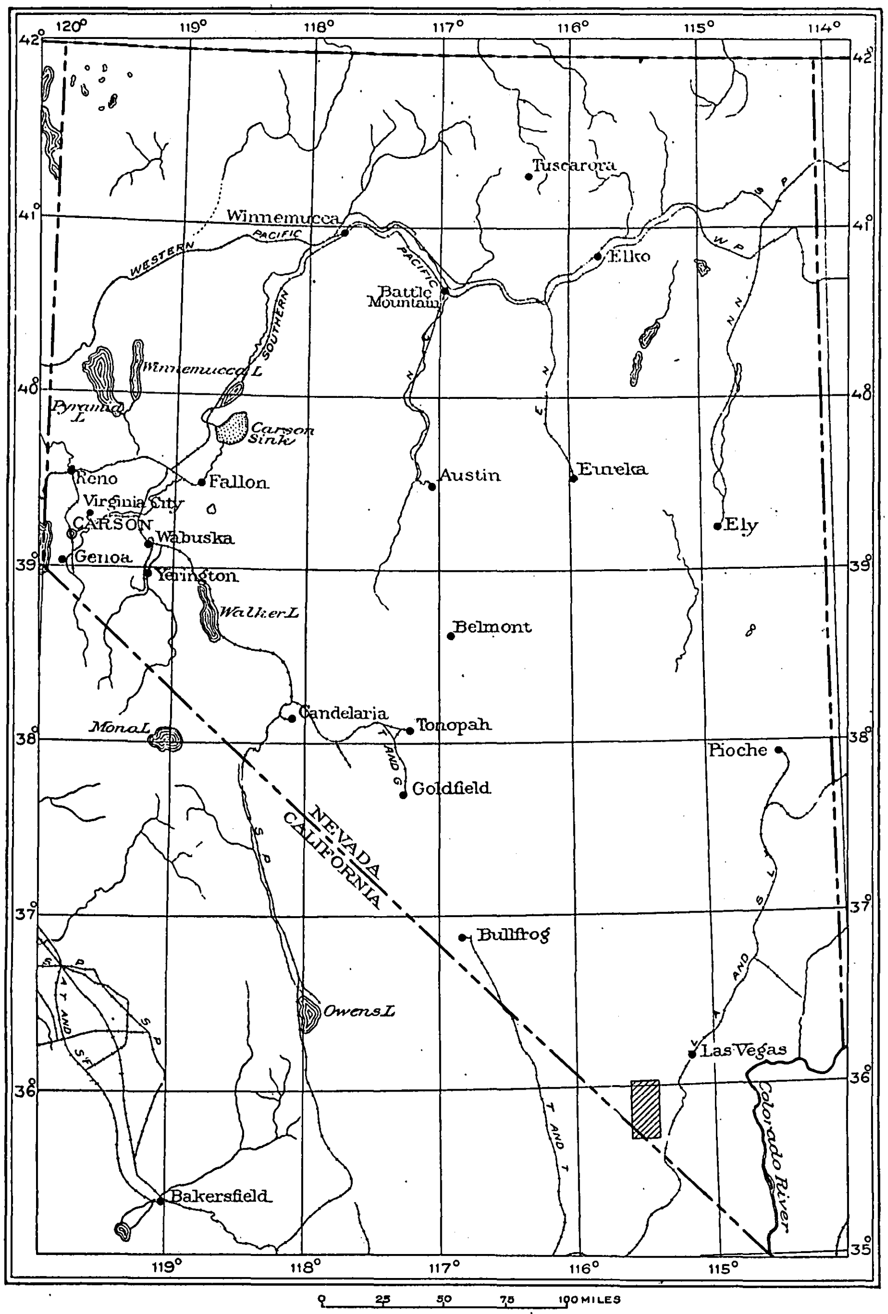


FIGURE 1.—Index map showing location of Goodsprings quadrangle

Compared with most landscapes in more humid regions or at higher altitudes, the hills of this area have a forbidding, even though extremely interesting aspect during most seasons of the year. However, the traveler can scarcely imagine the abundance of flowers and gayety of color that appear over large areas of the hills and washes during March and April after a few showers.

Physiographically, the region is divisible into two parts—the hills, which are being eroded, and the valleys, which are receiving the waste. The processes of erosion under the local climatic conditions offer the chance for much interesting observation and speculation, but the purposes of this inquiry did not permit much time for either. The waste from the hills discharges into three major basins, only one of which, Cottonwood Valley, in the northeast corner of the quadrangle, leads to through-flowing drainage to the sea. This valley is tributary to Las Vegas Valley, which is drained eastward to the Colorado River. The drainage of Goodsprings Valley and those farther south is carried southeastward to one of the dry lakes in Ivanpah Valley. All the drainage on the west side of the range is tributary either to Pahrump Valley or to Mesquite Valley, both of which are parts of a single closed basin.

The rock waste of these drainages is uncommonly coarse but shows a wide range in size. The total area underlain by silt is only a few square miles, and most of this lies in Mesquite Valley. A small area lies north of Goodsprings. Most of the wash is underlain by ill-assorted subangular gravel, made up largely of limestone and dolomite. Most of the material ranges from half an inch to 10 inches in diameter, but here and there boulders as much as 3 feet in diameter lie 4 to 6 miles from their sources in the hills. As shown by the contours, there is a broad fan of débris at the mouth of every ravine in the hills, and it is trenched here and there by radially disposed channels 5 to 10 feet deep, representing the successive paths of the latest floods whose waters passed through to the major basins. In only one locality, secs. 23 and 26, T. 23 S., R. 57 E., is there evidence of a smooth rock surface or pediment,[1] with only a thin or sparse cover of wash.

The hills assume many forms, depending upon the local nature and succession of the rocks and their proximity to major drainage channels and to structural features. The region illustrates well the conclusion, drawn from many dry regions, that the carbonate rocks, such as limestone and dolomite, resist disintegration better than other sediments, such as sandstone and shales, or than igneous rocks. Furthermore, thick, massive layers of limestone resist better than thin beds. The massive beds that make up the Monte Cristo limestone form the crest of the long homoclinal ridge that extends from Potosi Wash northward to Mountain Springs and beyond. The same beds, warped into a westward-plunging syncline, sustain impressive cliffs in the region of the Mobile and Smithsonite mines. Similarly the massive Kaibab limestone, which overlies sandstone and shale of the Supai formation, forms the crest of Mule Spring Mountain and the north end of the Bird Spring Range. The highest mountain, Potosi Mountain, coincides with the outcrop of the Anchor limestone member of the Monte Cristo limestone, and the steep northeast face includes the duplicated section caused by the Potosi thrust. (See pl. 13, *A*.) The actual position of the escarpment however, is determined by the younger Ninty-nine fault. Here and there, as along the cliffs northeastward from the Potosi mine to Potosi Mountain and the Ninety-nine mine, the Crystal Pass limestone member of the Sultan limestone does not show its common tendency to weather into thin laminae but, like the overlying limestones of the Monte Cristo formation, forms a single massive bed which weathers to a steep scarp.

Many of the intricately dissected areas in the southern part of the quadrangle coincide with areas of the Bird Spring formation or the Goodsprings dolomite, each of which is characteristically thin-bedded. (See pl. 7, *B*.) The impressive cliffs that limit the range at the north edge of the quadrangle appear not to be related to a fault but to be due to the rapid disintegration of the thick sandstone under a thin cover of resistant dolomite. (See p. 44.)

The effect of faults on the surface features depends upon the lithology and structure of the beds brought into contact, the dip of the faults, and the size of the fault breccia. Most of the flat thrusts have slight surface expression unless resistant limestone or dolomite is brought to rest on sandstone. For most of its length in this quadrangle the Keystone fault, which dips 45° or less, coincides either with a valley (Potosi Wash) or a deep ravine (Keystone and Lavina Washes). The steeper Potosi, Wilson, and Puelz faults, which dip in large part 45° to 55°, are scarcely reflected in local surface features. Erosion processes have sought out most of the steep faults, however, regardless of their age and the rocks brought into contact. The Ninety-nine and related Cottonwood faults, the Fredrickson fault, and the group of persistent faults near Devil Canyon may be cited as examples. Simple monoclines, whether exhibited in the overlying or underlying blocks adjacent to faults, form persistent prominent ridges, whereas highly folded beds are eroded to lower areas of more irregular pattern. It is scarcely an exaggeration to say that all the local ravines and small depressions throughout the entire area follow minor faults and fractures, generally too small to justify record on the map.

This part of the Spring Mountains shows no traces of flat uplands or high smooth slopes which might suggest that they represent remnants of surfaces, once widespread, formed in an earlier stage of erosion,

[1] Bryan, Kirk, Erosion and sedimentation in the Papago country, Ariz.: U. S. Geol. Survey Bull. 730, pp. 52-65, 1923.

interrupted by local uplift. At several places in the quadrangle there are flat depressions less than a mile in diameter in the higher central parts of the mountains which are covered with wash but drain outward to the valleys through narrow rock-walled canyons. On the north, Mountain Springs lies at the north edge of a flat wash-covered basin which drains westward to Pahrump Valley through a narrow canyon, at one part of the floor of which bedrock crops out. A similar basin lies 2 miles south, but it drains eastward to Cottonwood Valley, and bedrock does not outcrop in the bed of the canyon. There is a smaller basin at the head of Keystone Wash, but it contains only a sparse cover of wash. The most southern of these basins lies at the head of Devil Canyon east of Little Devil Peak. The area of wash is about 1,500 feet in diameter, but not far to the east the valley narrows and for a short distance the road in the canyon lies on bedrock.

An examination of the contours in these basins and the narrow canyons through which they drain shows that there is local steepening of the gradient in the canyons, such as would be expected if there had been rather recent uplift of the mountain mass or subsidence of the valleys. In the opinion of the writer, one of these has taken place, although it is not at all clear whether the movement was localized along faults near the present mountain fronts or was merely warping. Faults in the outer alluvial fans have not been found, although several large faults limit a part of Ivanpah Valley beyond the limits of the Goodsprings quadrangle. As stated elsewhere (p. 4), none of the outstanding ridges of this area appear to be limited by recent faults. These as well as many minor features appear to be produced by rapid erosion along old faults.

CLIMATE

The area under consideration lies within the Nevada Basin, which forms the largest part of the Basin and Range province.[2] Throughout this region the rainfall is low and the annual as well as daily range in temperature is high. No comprehensive continuous record of the weather has been kept at any place within the quadrangle, so that any statement must be based upon the record at places near by. For a few years (1908–1915) observations were recorded [3] at Jean (2,866 feet), 8 miles southeast of Goodsprings and 829 feet lower, but records at Las Vegas (2,033 feet), 28 miles northeast; the Pahrump ranch (2,667 feet), 48 miles northwest; and Searchlight (3,600 feet), 38 miles southeast, have been kept for 20 years or more.[4] According to these records it is clear that the rainfall commonly ranges from 3 to 10 inches a year. For seven years the range at Jean was 1.33 inches in 1913 to 6.15 inches in 1909. Most of the rain commonly falls between December 15 and March 1, but there are also local heavy showers now and then in the summer. Apparently the rainfall depends largely upon the local altitude, for the total annual fall, as well as that during each storm, is about half as much more at 3,600 feet as at 2,000 to 2,500 feet. Doubtless this tendency continues with increase of altitude, and the high parts of the range, 6,000 to 8,500 feet above sea level, may receive 12 to even 18 inches a year.

The maximum and minimum temperature throughout the year also depend largely upon altitude. At Las Vegas (altitude, 2,033 feet), the daily maxima during the summer commonly range from 100° to 115° F., and the daily range is 30° to 45°. The daily minima during the winter range from 15° to 40°. On the other hand, at Searchlight (3,600 feet), the daily maximum in summer is commonly 90° to 105° and the daily range 20° to 30°. The winter temperatures are slightly lower than at Las Vegas.

WATER SUPPLY

Springs.—There are only a few places in the quadrangle where water issues at the surface throughout the year, and all of these lie north of Goodsprings.

The Mountain Springs lie on the west slope of the range, in the NW. ¼ sec. 20, T. 22 S., R. 58 E. When visited in March, 1922, water issued from six openings in an area of several acres. Estimates of the flow range from 1 to 10 gallons a minute for each spring, and the total flow was estimated at 40 gallons a minute. The water from one spring is piped to a trough, but that from the rest sinks into the ground within 1,000 feet. The geologic relations of the spring are obscure, for the ground near by is covered with soil, which supports a growth of grass and moss.

Mule Spring lies at the head of a ravine in an isolated mountain in the W. ½ sec. 15, T. 22 S., R. 57 E. Water issues from several minor fractures in the lower bed of the Kaibab limestone but sinks into the adjacent wash, from which it issues at a lower level at several places in an area 50 by 100 feet. A pipe is driven into the wash and delivers water to a steel tank 200 feet distant. In March, 1922, the flow was estimated at 75 gallons an hour, or 40 barrels a day. By improving the equipment, more water could be recovered. The water was clear and tasteless.

Potosi Spring lies along the east side of Potosi Wash, in the SW. ¼ sec. 1, T. 23 S., R. 57 E. It has been improved for use at the Potosi mine camp by leading the water from the principal seep to a concrete tank, from which it is distributed to several outlets. In March, 1922, the flow was estimated at 75 gallons an hour, or 40 barrels a day. Although the water appears in wash that covers bedrock, probably its local appearance is largely determined by the Keystone thrust fault, which lies near by.

[2] Assoc. Am. Geographers Annals, vol. 6, pl. 1, 1917.
[3] Waring, G. A., Ground water in Pahrump, Mesquite, and Ivanpah Valleys, Nev. and Calif.: U. S. Geol. Survey Water-Supply Paper 450, p. 54, 1920.
[4] U. S. Weather Bur. reports.

Rose Tank lies along the Potosi-Arden road in the E. ½ sec. 26, T. 22 S., R. 58 E. In 1922 water was piped to the tank from a seep 8,000 feet to the northwest, at the base of the sandstone cliffs. The cliffs above the talus are cut by a group of fractures of small displacement which trend N. 45° W. and which may aid in supplying the water. In March, 1922, the flow at the tank was estimated at 4½ gallons an hour, or about 2½ barrels a day, but in November, 1924, the tank was abandoned. The water was poor in quality and was used only by cattle.

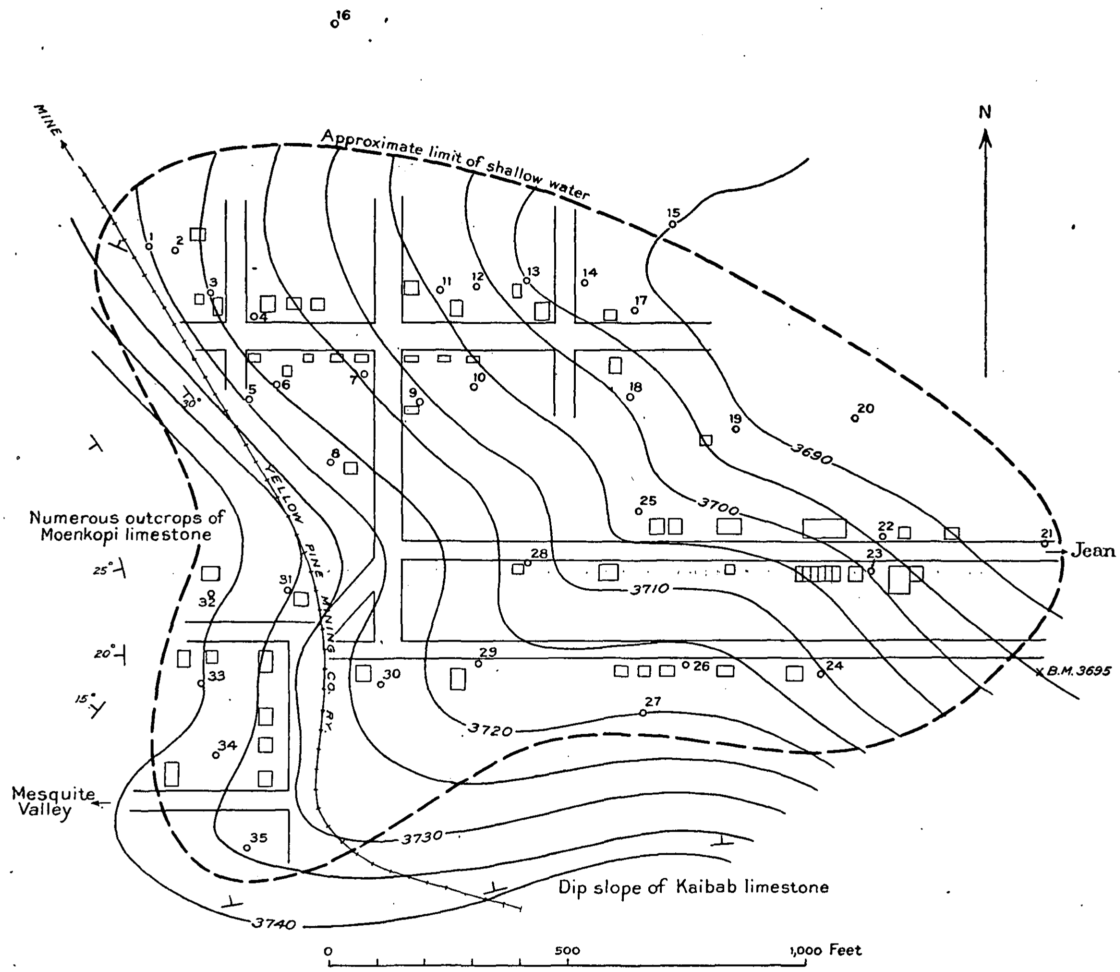


FIGURE 2.—Map of Goodsprings area, showing location of wells, April, 1922. (See p. 7.)

There is a spring in the W. ½ sec. 24, T. 23 S., R. 58 E., that has been improved by a tank to supply water to cattle. A tunnel is driven about 50 feet in the wash to bedrock, the Moenkopi formation, and a mud dam impounds the water that accumulates. It is then piped to the tank. In October, 1921, the flow was estimated at 1½ gallons an hour, but in November, 1924, it was even less. The water was clear and tasteless. The Cottonwood fault passes close to the tunnel and probably aids in accumulating water at this place.

Ninety-nine Spring lies on the south side of the principal ravine in the NE. ¼ sec. 8, T. 23 S., R. 58 E. The water accumulates in a pool 6 by 12 feet, on the floor of a shallow hole dug in cemented wash. The Ninety-nine fault passes scarcely 50 feet southwest of the pool and doubtless has considerable effect on the accumulation of the water. In April, 1922, the discharge was estimated at 1 gallon a minute, or about 35 barrels a day. When the Ninety-nine mine was operating, a pipe line 9,000 feet long was installed, but this has fallen into disuse. The water is clear and tasteless.

Mexican Spring lies in a deep ravine in the SW. ¼ sec. 30, T. 22 S., R. 57 E. It is a pit 3 feet in diameter and 4 feet deep in the wash and has been lined with stones. The wash is localized in the ravine for a distance of 200 feet near the place where thin limestones of the Bird Spring formation turn sharply from N. 70° W. to N. 40° W. No conspicuous faults or fractures were noted near by. A few hundred feet below the spring, where the water cascades over beds of limestone, the estimated discharge was 7½ gallons an hour (March, 1922).

Keystone Spring lies on the west side of a ravine in the S. ½ sec. 6, T. 24 S., R. 58 E. A cave 6 by 10 feet has been dug in the wash, and water accumulates on the bottom in a pool 5 feet in diameter and 1 foot deep.

In January, 1922, the discharge was estimated at 10 gallons an hour. The near-by rocks, which strike north and dip west, are shaly and sandy dolomite of the lower part of the Bird Spring formation. They are much broken, and a part of the Wilson thrust fault lies only a few feet east of the spring. The water is colorless and almost tasteless.

A review of the conditions under which these springs occur indicates that all except one are disposed around the border of the higher timber-covered part of the range, which doubtless receives the greatest rainfall in the region. No formation is particularly favored, but all the springs except one, Mexican Spring, lie close to conspicuous faults or fracture zones which lead toward the timber-covered areas.

Wells.—Water occurs in two areas elsewhere in the quadrangle where it may be obtained by sinking shallow wells. The larger of these areas is that on which the townsite of Goodsprings is located. The other area roughly coincides with Mesquite Valley, only a small part of which is included in this quadrangle. Mesquite Valley includes many square miles within which water of good quality may be obtained from 5 to 45 feet below the surface,[5] but only meager use has been made of it thus far.

As the water supply at Goodsprings is essential to the operation of the near-by mines, a special study was made of its occurrence. Figure 2 represents the results of a plane-table survey of the area, made by the writer in April, 1922, and shows all the wells then known. A list of the wells is given in the next column. The broken line in Figure 2 indicates the approximate limits of the area in which water may be obtained within 50 feet of the surface. According to Mr. S. E. Yount, who was one of the first settlers of Goodsprings, the original source of water was an open pool at the site of well 22 (fig. 2). As successive wells were dug farther west, the pool dried up. The water is clear, colorless, and nearly tasteless. No analyses are available, but it seems probable that the composition closely resembles that of Cottonwood Spring,[6] 15 miles north, which emerges from the same rocks under similar structural conditions. The composition of this water is indicated below:

Analysis of water of Cottonwood Spring

[Parts per million]

Silica	19	Carbonate (CO_3)	0
Iron	.4	Bicarbonate (HCO_3)	290
Calcium	102	Sulphate (SO_4)	146
Magnesium	43	Nitrate (NO_3)	.45
Sodium	36	Chlorine	11
Potassium	10		
		Total solids	563

[5] Waring, G. A., op. cit., pp. 68-71.

[6] Carpenter, Everett, Ground water in southeastern Nevada: U. S. Geol. Survey Water-Supply Paper 365, table opp. p. 30, 1915.

Wells in Goodsprings quadrangle, Nevada, and condition of water in April, 1922

No.	Altitude (feet)	Depth to rock (feet)	Depth to water (feet)	Total depth (feet)	Remarks
1	3,725	25	25	29	Goes dry when Yellow Pine well (No. 26) is pumped.
2	3,722.4	16	21.5	26	Lowers 4 feet when Yellow Pine well (No. 26) is pumped.
3	3,720.1	-------	19.5	(?)	No record.
4	3,717.9	4	15	24.5	Lowers 3 feet when Yellow Pine well is pumped.
5	3,724.7	20±	23	27.5	May be pumped dry.
6	3,719.8	7±	18	25.5	Thin limestone on dump.
7	3,714.5	5	12.5	19.5	Lowers 4 feet when Yellow Pine well is pumped.
8	3,721	-------	20.5	26	Water in thin limestone.
9	3,710.6	12±	20.5	29.5	Not affected by Yellow Pine well.
10	3,706.8	-------	16	36	Red shale and limestone.
11	3,704.8	-------	12	20.5	Water in thin limestone; no red shale.
12	3,702	-------	10.5	19.5	Do.
13	3,694.8	-------	7.3	16.2	Do.
14	3,694.6	-------	9.5	33.5	Water in red shale.
15	3,690.2	-------	-------	-------	Covered; abandoned.
16	3,718	(?)	-------	115	Dug to 85 feet; drilled to 115 feet; dry.
17	3,693.8	-------	12	28	Water in red shale.
18	3,699.7	-------	10	19	Never dry.
19	3,691	-------	5	9	
20	3,686	-------	-------	-------	Covered; abandoned.
21	3,683.8	-------	9	9	Water in red shale; covered.
22	3,693.5	-------	6	14.6	Site of original spring; water in red shale and limestone.
23	3,698.4	-------	9	16	Water in thin limestone.
24	3,710.7	-------	18	31	Red shale and thin limestone.
25	3,702.3	-------	10	19	Do.
26	3,718.9	-------	15	21	Yellow Pine well; best in town; water in green shale and limestone.
27	3,720	-------	19±	20+	Caving badly.
28	3,712.4	-------	11	11	Originally had water, none now.
29	3,718.9	3	18±	27.5	Water in thin limestone.
30	3,722.8	-------	20	27.5	Do.
31	3,735.4	10	33.5	35	Do.
32	3,742.5	-------	18	21	Do.
33	3,741.2	-------	14	18	Water in thin limestone; not affected by Yellow Pine well.
34	3,737.7	-------	32	50	Brown shale and limestone.
35	3,734.6	-------	33.5	37.5	Do.

The survey of these wells reveals several interesting conditions. From the altitude of the water table in each of the wells it is found that a line may be drawn from well 24 northwest to well 7, which will divide the area into two nearly equal parts. Southwest of this line the water table stands at an altitude that ranges from 3,700 to 3,703 feet, except in the two most remote western wells (Nos. 32 and 33), where it ranges from 3,724 to 3,727 feet. Northeast of this line the water table drops abruptly about 10 feet to a level that ranges from 3,690 to 3,692 feet. Further, the wells southwest of the line fluctuate in accordance with pumping at the Yellow Pine Mining Co.'s well, No. 26, which supplies the mill and is the most steadily pumped of all in the area. Wells northeast of the line show little if any response to the pumping at this well.

As the records of the wells show, the water occurs wholly in bedrock under a variable cover of wash or hardpan, and bears no close relation to the present surface. A review of the areal geology throws some light on the problem. There are enough outcrops to show that the water-bearing area coincides roughly with a syncline in the Kaibab limestone and Moenkopi formation, and that the water is wholly in the thin-bedded limestone near the base of the Moenkopi. This syncline extends westward at least a mile and probably farther until it passes under the Contact thrust near the Lavina mine. The relations indicate that the water is collected in this syncline and is delivered at the lower eastern lip of the syncline, doubtless confined by the underlying Kaibab limestone. If this interpretation is correct, the two levels of water may coincide with distinct impervious zones in Moenkopi limestones or may be separated by a fault. It seems clear that the water is drawn from a remote collecting area and is not local surface water.

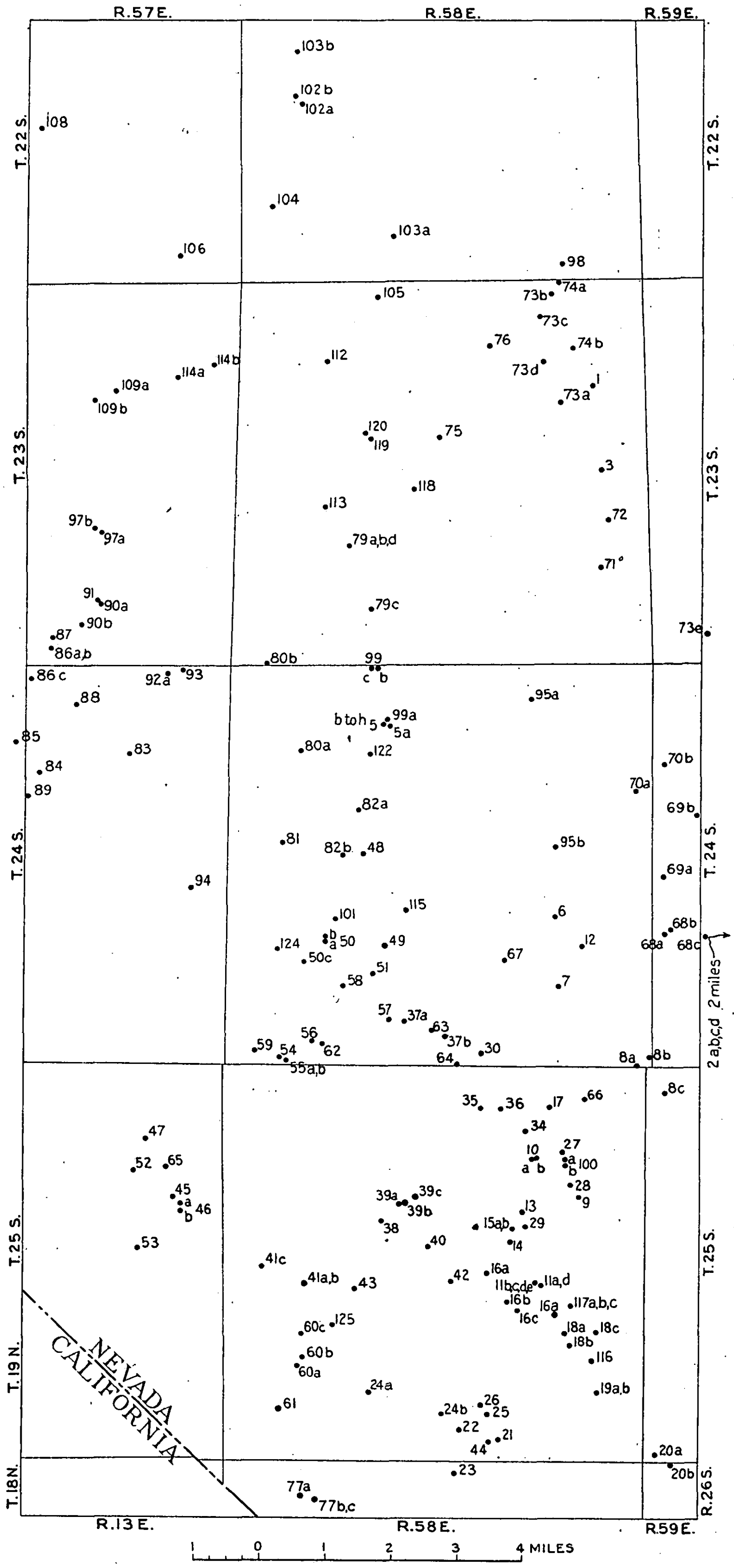


FIGURE 3.—Map showing location of fossil collections

As the Yellow Pine mill was idle when the water supply was examined, the productive capacity of the area is not known. Estimates by local residents range from 10,000 to 20,000 gallons a day. Well 26 is equipped with a stationary gasoline pump; the other wells are equipped with small gasoline pumps or hand pumps.

Water in mines.—In contrast with many other mines in the Western States, those of the Goodsprings district do not attain great depth, but even so they are uncommonly dry. Water stands here and there in the workings of five mines—the Potosi, Keystone, Alice, Lavina, and Valentine. In the Keystone mine pools of water stand on the 100-feet level south, 4,650 feet above sea level and roughly 200 feet vertically below the outcrop, but the lower levels, more than 400 feet vertically deeper, are dry. There are pools of water at the level of the lowest workings in the Potosi (6,125 feet), Alice (4,820 feet), and Valentine (4,030 feet), and water stands 125 feet below the surface in the Lavina mine (4,145 feet). On the other hand, the deepest workings of the Yellow Pine, about 585 feet vertically below the outcrop and 4,185 feet above sea level, as well as the workings of many smaller mines, such as the Bullion, Anchor, Milford, and Tam o' Shanter, are quite dry.

In some of the mines, such as the Keystone, Alice, and Lavina, the water is clearly due to the presence of dikes or sills of porphyry. This rock, which lacks bedding, is much less pervious to water than the limestones, and the water struck in the mines undoubtedly represents local pockets rather than the permanent water table. It is not possible to state with confidence the depth at which the permanent water table may be struck from place to place throughout the district. It would probably not be as deep as the water in the near-by alluvial valleys, Mesquite and Pahrump, at the lowest points of which it stands about 2,500 feet above sea level.[7] Probably most of the mines will encounter little water above an altitude of 3,500 feet, and some may not strike much above 3,000 feet. As the altitudes of the outcrops of most of the mines range from 3,500 to 4,500 feet above sea level, the higher ones may be nearly free of water for 1,000 feet vertically, and the lower ones should strike little for 500 feet.

[7] Waring, G. A., op. cit.

GEOLOGY

AGE AND CHARACTER OF THE ROCKS

The rocks exposed at the surface of this quadrangle include a wide variety of consolidated sediments, as well as intrusive igneous rocks and surface lavas. They range in age from Cambrian to Recent, but a few miles to the southeast the oldest rocks of this area are underlain by still earlier sediments, and these in turn rest upon crystalline granite and schist.

The section of stratified rocks has an aggregate thickness of about 13,000 feet, of which limestone and dolomite make up slightly more than 7,000 feet, largely confined to the lower half. The upper half is largely sandstone, shale, and conglomerate. Fossils are uncommon in the lower 3,000 feet of beds, but those found, with the aid of knowledge from near-by regions to the east, serve to determine the age of the beds. In the overlying 4,000 feet of limestone fossils are rather common, locally even abundant, and serve to determine the age of successive groups with confidence. In the upper 6,000 feet of the section fossils have been found only in the lower 1,200 feet, and correlation of the overlying beds is based on similarity of lithology. Only two unconformities have been recognized, that at the base of the Pennsylvanian Yellowpine formation and that at the base of the Triassic Moenkopi formation, but there may be others in the higher sandstones and conglomerates.

The igneous rocks fall readily into two groups—an early group of two varieties of coarsely crystalline intrusive rocks and a later group comprising several varieties of fine-grained surface flows and small intrusive masses. The early group is represented by several sills and dikes in the central part of the district that are probably related to large masses of similar intrusive rocks 25 miles or more farther south. They presumably did not reach the surface at the time of intrusion. The later group includes the products of several isolated volcanic vents and is confined to the southern half of the quadrangle.

The stratigraphic section is presented below.

Formations of the Goodsprings quadrangle, Nevada

Exposed in Goodsprings quadrangle

Age classification	Formation	Member	Character	Thickness (feet)
Recent.	Alluvium.		Unconsolidated mud, sand, coarse gravel, and boulders of local origin.	
Pleistocene.	Lower (later) gravel.		Cemented sand and gravel of local origin on the hills west of Goodsprings.	50–100
	Higher (earlier) gravel.		Unconsolidated sand, coarse gravel, and boulders, largely from remote source but partly local.	50–125
Tertiary (Miocene?).	Volcanic rocks.		Tuffs, breccia, and flows of latite, andesite, rhyolite, and basalt.	0–200
Jurassic (?).	Aztec sandstone.		Massive ledge of reddish or buff sandstone, minutely cross-bedded.	2, 100
Upper Triassic.	Chinle formation.		Reddish shaly sandstone and shale with several beds of chert and limestone conglomerate.	1, 000±
Upper (?) Triassic.	Shinarump conglomerate.		One or two beds of limestone and chert conglomerate separated by sandy shale.	10–30
Lower Triassic.	Moenkopi formation.		Thin-bedded buff limestone underlain by green and red shale and conglomerate and overlain by red sandy shale. Tuff and conglomerate of igneous pebbles overlie the limestone member 2 miles west of Goodsprings.	750–950
	—Unconformity—			
Permian.	Kaibab limestone.		Two massive ledges of gray limestone separated by 20 to 30 feet of buff to red shale and sandstone.	410–555+
	Supai formation.		Reddish sandstone separating red and greenish shaly sandstone below from red gypsum-bearing shaly sandstone above.	1, 000–1, 100
Pennsylvanian.	Bird Spring formation.		Gray limestone and dolomite in beds ranging in thickness from thinnest laminae to 60 feet, separated by shale and sandstone. From Goodsprings northward a conglomeratic sandstone at base.	2, 500±
	—Unconformity—			
Mississippian (middle and lower).	Monte Cristo limestone.	Yellowpine limestone.	Several beds of dark-gray limestone that locally weather as a massive ledge. In places completely altered to dolomite.	60–120
		Arrowhead limestone.	Thin-bedded blue and gray limestone alternating with gray shale; highly fossiliferous; no chert.	10–20

Formations of the Goodsprings quadrangle, Nevada—Continued

Exposed in Goodsprings quadrangle—Continued

Age classification	Formation	Member	Character	Thickness (feet)
Mississippian (middle and lower).	Monte Cristo limestone.	Bullion dolomite.	Massive light-gray limestone, now largely altered to cream-colored and white dolomite; chert uncommon.	185–300
		Anchor limestone.	Massive gray limestone with numerous thin chert layers; in places large belts are altered to dolomite; numerous fossils.	65–400
		Dawn limestone.	Thin-bedded dark-gray limestone; little chert; in large part of area altered to dolomite; numerous fossils.	60–400
Devonian.	Sultan limestone.	Crystal Pass limestone.	Very thin-bedded light-gray limestone; no fossils or chert.	150–260
		Valentine limestone.	Light-gray limestone and dolomite; numerous fossils.	75–380
		Ironside dolomite.	Dark-gray to black dolomite, in beds 2 to 5 feet thick; few fossils.	5–125
Devonian (?) to Upper Cambrian.	Goodsprings dolomite.		Thin-bedded light and dark gray mottled dolomite, with some magnesian limestone and locally near top 50 to 75 feet of dolomitic and sandy shale; very few fossils.	2, 450±

Not exposed in Goodsprings quadrangle

Age classification	Formation	Member	Character	Thickness (feet)
Middle Cambrian.	Bright Angel shale.		Green micaceous shale and brownish sandstone; contains trails but few fossils.	240±
	Tapeats sandstone.		Brownish sandstone, thin bedded.	130±
Algonkian.			Conglomerate, quartzite, and dolomite exposed in Kingston Mountains and possibly present beneath the Paleozoic rocks of the western part of the Goodsprings quadrangle.	
Archean.			Reddish granite gneiss.	

As the field work progressed and it was found that almost all the rocks of the Paleozoic and lower Mesozoic section are limestones and dolomites, it became desirable to distinguish between them constantly and to record their distribution carefully. With this end in view, hydrochloric acid was used in the field to distinguish between limestone, magnesian limestone, and dolomite. In the descriptions of the rocks the attempt has been made to use the terms with discrimination.

In describing the texture of the carbonate rocks, it will serve a purpose to assign definite limits to common descriptive terms. Most of the limestone of the region breaks with a conchoidal fracture, and the texture is that of porcelain. Except for a few crystalline crinoid stems, no individual grains can be seen with a hand lens. In a few limestones and most dolomites the entire groundmass is distinctly crystalline, and light is reflected from many cleavage facets. Where the average grain is less than 0.25 millimeter the rock is called finely crystalline; 0.25 to 1 millimeter, medium crystalline; above 1 millimeter, coarsely crystalline.

UNEXPOSED ROCKS

ARCHEAN SYSTEM

GRANITE GNEISS

The oldest rocks that crop out in the Goodsprings quadrangle are the thin-bedded dolomites near the base of the Goodsprings formation, exposed near the Potosi and Keystone mines. During the progress of the survey of the Ivanpah quadrangle in October, 1924, the base of the local Paleozoic section was found at the south end of Sheep Mountain, east of Jean, in sec. 32, T. 25 S., R. 60 E. Here hard dark-brown sandstone (Tapeats sandstone) rests on reddish granite gneiss, which crops out widely farther south in the McCullough Range and the parallel range farther west. The gneiss is a distinctive rock, about half its volume being composed of simple flat crystals of pale-reddish orthoclase, 1 to 2 inches long and as much as an inch wide. These crystals have persistent parallel orientation in a matrix that consists largely of dark biotite. Sufficient is known of the region to state with confidence that this is part of the Archean rocks that crop out widely in southeastern California and western Arizona.[8] Doubtless this gneiss, possibly overlain by Algonkian sediments in the western part of the quadrangle, underlies the Paleozoic section in the Goodsprings quadrangle.

ALGONKIAN SYSTEM

No rocks that belong to the Algonkian system crop out in the quadrangle, but it may be helpful in considering some stratigraphic and structural problems to record the discovery of 3,500 feet of conglomerate, quartzite, and dolomite, with intrusive sills, on the north slope of the Kingston Mountains, 25 miles west of the Spring Mountains, which doubtless belong to this system. Probably none of these rocks underlie the Spring Mountains, but they may be locally present beneath the Paleozoic rocks of the western part of the Goodsprings quadrangle.

CAMBRIAN SYSTEM

TAPEATS SANDSTONE AND BRIGHT ANGEL SHALE

The oldest rocks that crop out in the quadrangle are beds of dolomite near the base of the Goodsprings formation. It may aid the consideration of some structural problems to record here the beds that lie between that formation and the underlying granite gneiss outside the quadrangle, at the south end of Sheep Mountain, east of Jean, in sec. 32, T. 25 S., R. 60 E. Similar but thicker beds crop out in the ranges west of Mesquite Valley, and there can be little doubt that they underlie the Spring Mountains.

Section of Bright Angel shale and Tapeats sandstone at Sheep Mountain

	Feet
Goodsprings dolomite:	
Bright Angel shale:	
Covered (shale?)	5
Dolomite, gray with brown mottling	4
Shale, greenish	26
Sandstone, reddish brown, layers ½ to 1 inch thick	35
Dolomite, gray, weathers brown; thin layers in upper part	5
Shale, green, micaceous; splits in thin layers	14
Sandstone, brown, thin bedded	7
Shale, green, micaceous	4
Sandstone, brown, thin bedded	9
Sandstone, dark reddish brown, layers ½ to 2 inches thick	6
Sandstone, medium brown	3
Shale, brown	4
Sandstone, dark reddish-brown layers, most of them ½ to 1 inch thick; some of them 2 to 3 inches thick; ripple-marked; fossil collection 2d	55
Sandstone, medium brown, micaceous, beds ½ to 1 inch thick	8
Sandstone, pale brown, layers largely ¼ to ½ inch thick, shaly near base	25
Bright Angel shale—Continued.	
Shale, greenish, micaceous, thin sandy layers; fossil collection 2c	7
Sandstone, dark greenish, thin layers	5
Shale, dark gray, sandy, micaceous	16
Tapeats sandstone:	
Sandstone, gray and brown, layers 1 to 3 inches, thick, ripple-marked; fossil collection 2b from top layer	36
Sandstone, dark brown, layers ¼ to 2 inches; a layer of brown dolomite at base, 4 inches	90
Sandstone dark brown, layers ¼ to ½ inch thick; fossil collection 2a	3
	367

The fossil collections from this locality have been examined by Edwin Kirk, of the United States Geological Survey, who reports the following determinations:

Collection 2a, from basal sandstone: *Billingsella coloradoensis* (Shumard), trilobite fragments. Collection 2b: Annelid burrows and trails. Collection 2c: Fucoids. Collection 2d: Probably inorganic material. The basal lot is Upper Cambrian; I think you may assume that you are dealing with Bright Angel shale.

L. F. Noble, who has studied these formations in the Grand Canyon region,[9] was able to visit the Sheep Mountain locality and confirm the impression that, even though lacking the same species of fossils, the section presented above contains the same lithologic units as those that make up the formations in the Grand Canyon area, in a similar succession and of similar thickness. In both areas the beds were laid down on a surface of low relief, and the thickness of the lower sandstones differs from place to place in accordance with that relief. The overlying dolomites in the Sheep Mountain area present the mottled appearance characteristic of some of the beds of the Muav limestone, of Upper Cambrian age. Probably the beds that make up this stratigraphic unit in the Grand Canyon are the equivalent of beds in the lower part of the Goodsprings dolomite in southern Nevada.

EXPOSED ROCKS

UPPER CAMBRIAN TO DEVONIAN (?) ROCKS

GOODSPRINGS DOLOMITE

Areal distribution and thickness.—The formation to which the name Goodsprings dolomite is here applied is widely distributed throughout the quadrangle. The best and most extensive exposures form a belt from half a mile to 1½ miles wide that extends from the northern border of the quadrangle in a broad arc around the western part of the Spring Mountains to the southeast corner. In the northern and southern parts of the belt the formation is practically unbroken, but in the middle part, in T. 24 S., R. 57 E., it is much

[8] Lee, W. T., Geologic reconnaissance of a part of western Arizona: U. S. Geol. Survey Bull. 352, p. 14, 1908.

[9] Noble, L. F., The Shinumo quadrangle, Grand Canyon district, Arizona: U. S. Geol. Survey Bull. 549, pp. 61-65, 1914.

broken by faults and breccia zones. The maximum thickness of 2,450 feet was measured in the northern part of the belt, west of the Potosi mine. In the high ridge west of the Keystone mine (pl. 31, *A*) the upper 2,100 feet of beds is exposed in good detail. In the ridge west of the Lincoln mine the upper 1,050 feet of the formation is exposed, and in the ridge south of the mouth of Devil Canyon the upper 1,300 feet. An area of several square miles is underlain by these beds west of Little Devil Peak, but as they are much faulted no reliable measurement of thickness can be made; probably less than 1,000 feet is exposed.

A complete section of the formation is exposed on the southeast end of Sheep Mountain east of Jean, and the thickness of 2,500 feet was measured there. The name is that of the principal town of the region.

Lithology and sections.—The Goodsprings formation is largely made up of dolomite with some magnesian limestone and locally, on both sides of the ridge west of Kirby Wash, a layer of dolomitic and sandy shale 50 to 75 feet thick, 60 to 100 feet below the top of the formation. This layer of shale is well exposed south of the Mobile mine and in the workings of the Kirby mine. At a similar position in the formation west of the Lincoln mine there is a layer of sandstone 10 feet thick.

The color, texture, and magnesian content of the carbonate rock show considerable range throughout the quadrangle. In the region from the Lincoln mine southward the exposed portion is separable into three parts. The uppermost part, about 1,000 feet thick, is composed of uniformly light smoky-gray medium-crystalline dolomite. Under this is a layer of dolomite 50 to 100 feet thick, similar in texture but very dark smoky gray. This darker dolomite in turn is underlain by the lowest layer, which has the color, texture, and composition of the uppermost layer. When these beds are compared with the same part of the formation north of the Potosi mine, it is clear that in that region the color is generally distinctly blue-gray of several shades and the texture is finer.

In several areas, particularly north of Columbia Pass (pl. 5, *A*), many beds in the lower half of the formation have a peculiar mottled appearance. In general, outcrops show elongated, rounded light-gray areas in a dark-gray or nearly black matrix, but in several places the colors are reversed. Tests with acid show that the light-gray areas are made up of nearly pure dolomite whereas the dark-gray areas contain considerable calcite. Polished sections show that the borders between the two areas are not sharp but transitional. As the mottled beds are persistent in the midst of homogeneous beds, it appears that the distribution of lime and magnesia must have been accomplished during or shortly after the deposition of the beds.

At the base of the Sheep Mountain section southeast of Jean several beds 10 to 20 feet thick show brown markings in a dark-gray matrix. Similar beds crop out near the Ireland mine in the NE. ¼ sec. 24, T. 25 S., R. 58 E., but their relations are obscure. Both the brown and the gray materials effervesce when touched with acid, but the gray appears to be nearly pure calcite, and the brown contains 5 to 10 per cent of iron oxide. Possibly the iron content of the unweathered rock is present as ferrous carbonate. As uncommon sediments both these rocks would justify further careful study.

The beds in the large faulted area west of Wilson Pass, in secs. 10, 11, 14, and 15, T. 24 S., R. 57 E., resemble those south of the Lincoln mine, whereas those near the Keystone mine resemble in part those of the northern area and in part those of the southern area. In general the finely crystalline blue-gray rocks weather to smooth surfaces, with the same or slightly lighter color, whereas the smoky-gray, more crystalline rocks weather to irregularly pitted surfaces that are harsh to the touch because they are covered with minute crystals.

Only two analyses of rocks from the formation are available. Sample 14 (p. 62) is the light-weathering phase of a mottled bluish-gray, finely crystalline rock about 1,500 feet below the top of the formation, from the west center of sec. 30, T. 25 S., R. 58 E. The analysis shows that it is 65.87 per cent $CaCO_3$ and 28.32 per cent $MgCO_3$, or about 62 per cent dolomite molecule and 32 per cent calcite molecule. The analysis confirms the impression gained by testing with acid that the rocks of this type are magnesian limestones and that no pure limestones occur in the formation. Another sample, No. 15a, is a bluish to smoky gray medium-crystalline rock that weathers smoky gray and was collected about 300 feet below the top of the formation in the southwest corner of sec. 30, T. 25 S., R. 58 E. The analysis closely corresponds to that of pure dolomite. From field tests and these analyses, therefore, it appears that a large part of the beds of the Goodsprings formation were originally composed of dense magnesian limestone and that in most areas especially those where the rocks have been much disturbed, as near thrust faults or fractures, they have been altered to crystalline dolomite. In general, the alteration has been accompanied by bleaching and a slight change in color from bluish gray to smoky gray. During the change also the mottled layering common in beds 800 to 1,500 feet below the top was destroyed.

In general the magnesian limestones are more thinly bedded than the dolomites and tend to weather to flat slabs 2 to 10 inches thick, whereas the dolomites weather to more equidimensional angular blocks. Although the dolomites locally crop out in beds 5 to 15 feet thick, the magnesian limestone beds rarely exceed 5 feet.

Fossils and correlation.—Close search of the beds over a large area yielded only four collections of fossils, and most of the material is unsatisfactory for determining the age of the beds. The following collections have been examined by Edwin Kirk, of the United States Geological Survey:

Collection 83. Probably 1,500 to 2,000 feet below top of formation. Center of N. ½ sec. 11, T. 24 S., R. 57 E.: *Billingsella coloradoensis* (Shumard), Upper Cambrian.

Collection 88. About 1,000 to 1,200 feet below top of formation. Northwest corner of SE. ¼ sec. 3, T. 24 S., R. 57 E.: Gastropod; a very primitive type suggesting early Ordovician.

Collection 61. About 400 feet below top of formation. Center of NE. ¼ sec. 31, T. 25 S., R. 58 E.: Sponge, probably an undescribed genus. Silurian(?). No sponge like this has hitherto been collected either from the Devonian or Silurian of the West. A sponge of somewhat similar type is known from the Silurian of New Mexico, however. It is possible that this lot represents a Silurian horizon, though other fossils would be necessary to establish the fact.

Collection 60c. Sandy dolomite about 100 feet below top of formation. North central part of NW. ¼ sec. 29, T. 25 S., R. 58 E.: *Centronella?* sp., *Stropheodonta?* sp. This lot is probably Devonian; the imperfect preservation of the material makes specific determination impossible.

These identifications indicate that the Goodsprings dolomite contains beds that range in age from Upper Cambrian through Ordovician and Silurian and possibly into the Devonian.

The lack of distinctive fossils in the upper part of the formation and similarity of the beds that make it up justifies caution in making correlations with beds in near-by regions. In the Muddy Mountains, about 50 miles to the northeast, Longwell's Muddy Peak limestone,[10] largely Devonian, appears to contain beds equivalent to the upper 500 feet of the Goodsprings dolomite.

The magnesian limestone that makes up a large part of the formation 500 to 1,500 feet below the top, south of the Keystone mine and west of the Potosi mine, closely resembles the Upper Cambrian limestone 3,000 feet or more thick that makes up the Highland Range, near Pioche, Nev.,[11] but until more fossils are collected from the Goodsprings dolomite, no precise correlation can be made. The mottled brown and gray limestone at the base of the Sheep Mountain section closely resembles characteristic beds of the Muav limestone of the Grand Canyon, Ariz.,[12] 175 miles to the east, which conformably rest on Bright Angel shale and are limited upward by an unconformity. Doubtless beds near the base of the Goodsprings dolomite are equivalent to those of the Muav limestone, though the formation is not only thicker but also contains several hundred feet of beds probably of Ordovician and Silurian age, not present in the Grand Canyon area. In the Specter Range, 65 miles northwest of Goodsprings, Ball [13] observed 5,000 to 6,000 feet of dark fine-grained limestone, which he considered to represent the Eldorado ("Prospect Mountain") limestone of Eureka, Nev. Ball recognized similar beds elsewhere in western Nevada.

[10] Longwell, C. R., Geology of the Muddy Mountains, Nev.: Am. Jour. Sci., 5th ser., vol. 1, p. 45, 1921.

[11] Pack, F. J., Geology of Pioche, Nev., and vicinity: School of Mines Quart., vol. 27, pp. 292-296, 1906. Westgate, L. G., and Knopf, Adolph, Geology of Pioche, Nev., and vicinity: Am. Inst. Min. and Met. Eng. Trans., vol. 75, pp. 816-836, 1927.

[12] Noble, L. F., The Shinumo quadrangle: U. S. Geol. Survey Bull. 549, pp. 64-65, 1914.

[13] Ball, S. H., A geologic reconnaissance of southwestern Nevada and eastern California: U. S. Geol. Survey Bull. 308, pp. 148-149, 1907.

DEVONIAN SYSTEM

SULTAN LIMESTONE

AREAL DISTRIBUTION

The rocks here named Sultan limestone are widely distributed throughout the Goodsprings quadrangle, but as they are much thinner than the underlying Goodsprings dolomite the area of the outcrops is much smaller. The best exposed and most persistent belt extends from the northern border around the west side of the Spring Mountains to the vicinity of the Boss mine, where it is interrupted by faulting. East of the faulted area it extends eastward across the range and southward along the east front, although it is repeatedly interrupted by faults. There are also extensive exposures north and west of Potosi Mountain, northwest and southwest of Little Devil Peak, and in a small area west of the Lavina mine. The name is derived from the Sultan mine, in the neighborhood of which the exposures are very good.

For purposes of lithologic description the formation has been divided into three members—the Ironside dolomite at the base, the Valentine limestone in the middle, and the Crystal Pass limestone at the top. In the southern part of the quadrangle the three members have distinctive features and are readily separable. In the northern part some of the distinctive features disappear. The following table presents a summary of the thickness of the members throughout the quadrangle:

Approximate thickness, in feet, of members of the Sultan limestone

	Ridge north of Anchor camp, SE. ¼ sec. 23, T. 25 S., R. 58 E. Dip 20° W.	Ridge southwest of Crystal Pass, E. ½ sec. 11, T. 25 S., R. 58 E. Dip 10° W.	West end of Bonanza Hill, SW. ¼ sec. 14, T. 25 S., R. 57 E. Dip 40° E.	Ridge west of Kirby Wash, NW. ¼ sec. 31, T. 24 S., R. 58 E. Dip 85° N.	Mobile Ridge, NE. ¼ sec. 35, T. 24 S., R. 57 E. Dip 20° NW.	W. ½ sec. 15, T. 24 N., R. 57 E. Dip 45° W.	SW. ¼ sec. 10, T. 24 N., R. 57 E. Dip 25° W.	West edge of sec. 3, T. 24 S., R. 57 E. Dip 45° W.	West central part of sec. 34, T. 24 S., R. 57 E. Dip 70° N.	Northwest corner of sec. 35, T. 24 S., R. 57 E. Dip 40° NW.	Southeast corner of sec. 22, T. 23 S., R. 57 E. Dip 35° W.	Ridge west of Potosi mine, W. ½ sec. 11, T. 23 S., R. 57 E. Dip 45° W.	W. ½ sec. 36, T. 23 S., R. 57 E. Dip vertical
Crystal Pass limestone	(?)	260	150	150	200	200	210	150	300	200	(?)	250	200
Valentine limestone	[a] 282	280	(?)	75	250	(?)	240	125		200	[a] 380	300	(?)
Ironside dolomite	50	100	(?)	80	125	(?)	(?)	60	70	(?)	(?)	(?)	(?)
	------	640	------	315	575	------	------	335	370	------	------	------	------

[a] Detailed section recorded below.

IRONSIDE DOLOMITE MEMBER

Lithology.—The beds here designated Ironside dolomite member of the Sultan limestone consist of nearly black limestone that has been altered to dolomite throughout the quadrangle, except in several small areas, notably in the W. ½ sec. 29, T. 25 S., R. 58 E. The name is derived from the Ironside mine, a mile north of the Boss mine, on the west side of the range, near which it is well exposed. Although the individual beds range from 2 to 5 feet in thickness, they are commonly inconspicuous and in the south half of the quadrangle form a rather massive unit 50 to 125 feet thick, sharply separated from the overlying and underlying beds. This unit is conspicuous from Columbia Pass westward 5 miles to the Boss mine. In this portion of the area a large part of the member is dark-gray dolomite of porcelainlike texture, locally uniformly mottled by lighter, more coarsely crystalline areas 1 to 2 inches in diameter. In the north half of the quadrangle the limiting surfaces are locally indistinct and mottling is uncommon, but there is a dark zone of dolomite that contains distinctive fossils. It is noteworthy that dolomitization has produced little change in color or texture.

Fossils.—Although the dolomite contains but few fossils (see p. 16), they can be found with close search at most exposures. The Stromatopora are dark masses of chert that somewhat resemble heads of cauliflower 2 to 4 inches in diameter and in some localities are abundant. In the zones where they occur other masses of chert are present, but with this exception chert is rather uncommon in the unit.

VALENTINE LIMESTONE MEMBER

Lithology.—The middle part of the Sultan limestone, here named Valentine limestone member, is made up of several types of beds that are distinctive by contrast with the Ironside dolomite below and the Crystal Pass limestone above. The name is derived from the Valentine mine, in sec. 23, T. 25 S., R. 58 E., east of which the limestone is well exposed. As originally deposited, most of the beds were pure limestone; at present many of the beds are largely altered to dolomite. Thin layers of shale are undoubtedly present, but they are obscure. The only coarse sediment in the Sultan limestone is a lens of brownish sandstone or quartzite 5 feet thick near the middle of the Valentine member, which crops out for a distance of several miles near the Mountain Springs, in secs. 18 and 19, T. 22 S., R. 58 E., and east of the Ingomar mine, in the NW. ¼ sec. 4, T. 25 S., R. 58 E. At the latter locality, in the midst of characteristic beds of limestone, there is a lens of cross-bedded sandstone 3 feet thick and 25 feet long. The coarsest grains of quartz range from 0.5 to 1 millimeter in diameter and are well rounded.

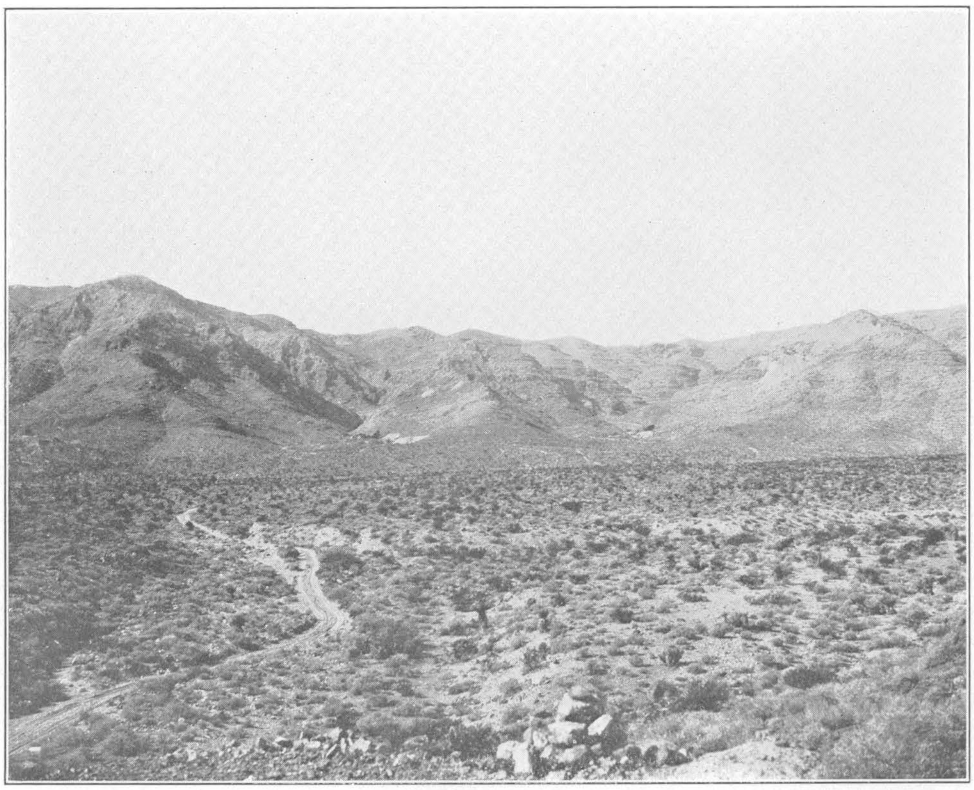
Section of Valentine limestone member in SE. ¼ sec. 23, T. 25 S., R. 58 E.

	Feet
Limestone, bluish gray, massive; numerous vertical chert tubes	8
Limestone, light bluish gray, platy	40
Dolomite, light buff, platy; sporadic chert	30
Limestone, bluish gray, massive	30
Limestone, bluish gray, massive; few brachiopods and gastropods; fossil collection 117b	5
Limestone, light bluish gray, platy	4
Limestone, bluish gray, three beds	7
Limestone, bluish gray, three beds altered here and there to light-gray dolomite	12
Limestone, bluish gray, massive, containing corals; fossil collection 117c	5
Limestone, bluish gray, made up of alternating massive beds 2 to 3 feet thick and platy beds 1 foot thick; the unit is capped by 1 to 2 feet of buff crystalline dolomite	30
Limestone, bluish gray, platy, showing sporadic dolomitization in zones 1 to 2 feet thick	12
Dolomite, light bluish gray, massive; chert zone 1 foot thick near middle; fossil collection 117a from top	7
Dolomite, smoky gray, thin bedded	80
Ironside dolomite.	
	282

The distinctive features of this member are the alternating beds of massive limestone 5 to 30 feet thick, which rather persistently bear a few fossils, and the

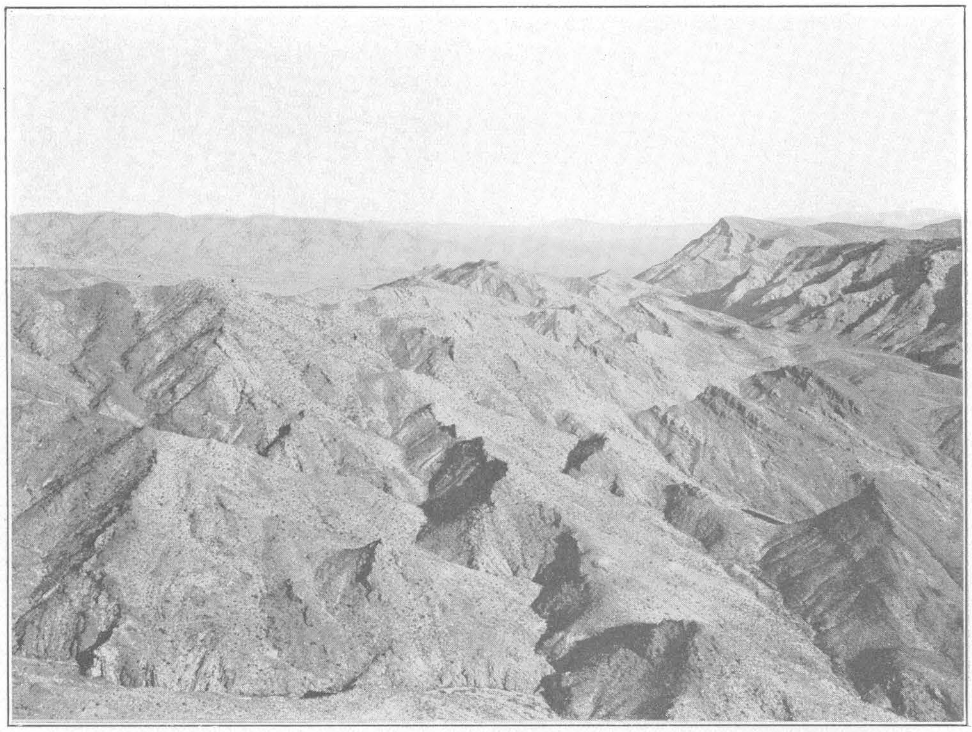
A. GOODSPRINGS, TOWN AND VALLEY

Spring Mountains and Potosi Mountain on the left; Bird Spring Range on the right.



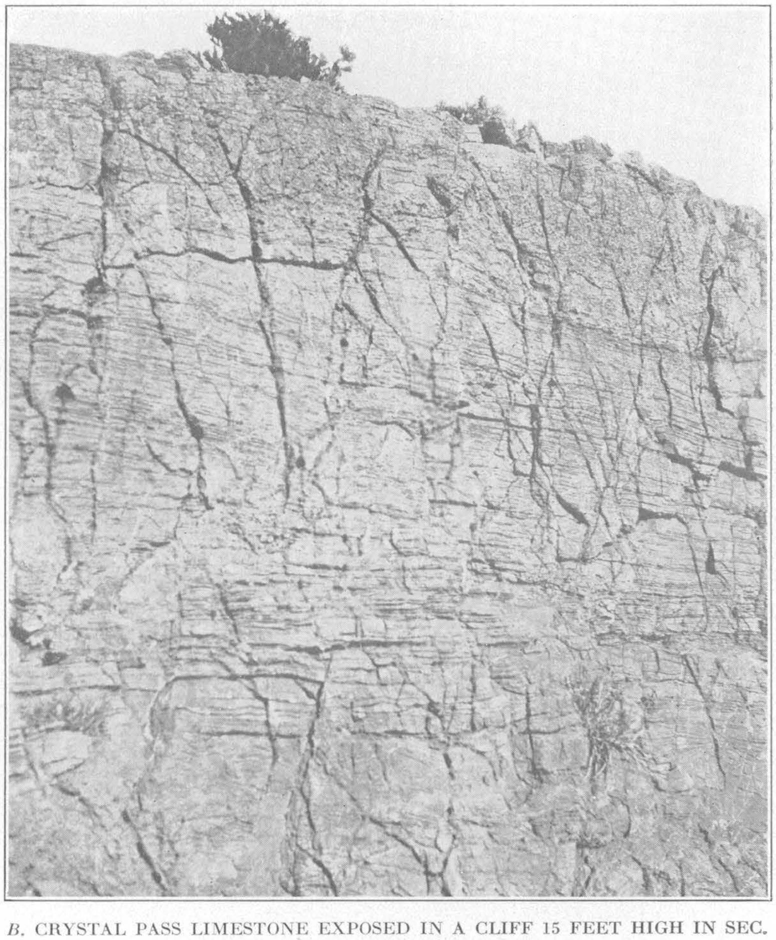
B. SPRING MOUNTAINS AT THE MOUTH OF PORTER WASH

The Anchor mill and waste dumps are shown in the left center; the mine is in the shadow on the left. The Bullion mill is in the right center; the mine lies higher on the right. The Valentine mine is at the extreme left.



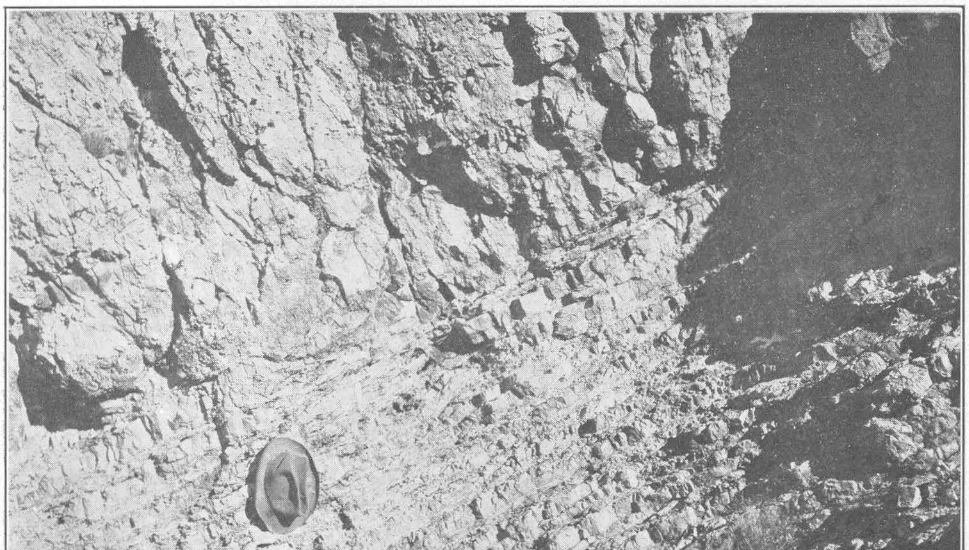
A. THIN-BEDDED DOLOMITES OF THE UPPER PART OF THE GOODSPRINGS FORMATION IN SECS. 28, 29, AND 30, T. 24 S., R. 58 E.

View due east from the hill (altitude 5,214 feet) west of Kirby Wash toward Columbia Pass and Goodsprings. The town is hidden by the hill in the middle distance.



B. CRYSTAL PASS LIMESTONE EXPOSED IN A CLIFF 15 FEET HIGH IN SEC. 30, T. 26 S., R. 59 E., SOUTH END OF SPRING MOUNTAINS

A. DETAILS OF ANCHOR LIMESTONE, SHOWING CHERT NODULES, IN OUTCROP 1,000 FEET WEST OF MILFORD MINE, IN SEC. 6, T. 26 S., R. 58 E.



B. ARROWHEAD LIMESTONE SOUTHEAST OF THE YELLOW PINE MINE IN CENTER OF SEC. 20, T. 24 S., R. 58 E.

beds of platy limestone, which show no trace of fossils. Of the two the massive beds are altered to cream-colored or buff crystalline dolomite over large as well as small areas, but only rarely are the beds of platy limestone so altered. (See pl. 5, *B.*) In the region south of Wilson Pass sporadic dolomitization is common; from Kirby Wash eastward beyond Columbia Pass the entire section is completely altered to dolomite. Partial dolomitization is very well shown in the hills west of the Boss mine camp and near Crystal Pass. In the northwest quarter of the quadrangle massive beds of limestone make up a smaller part of the member and the layers of platy limestone are more common and thicker. The following section was measured across a small hill (altitude, 4,782 feet) in this area.

Section of the Valentine member in the SE. ¼ sec. 22, T. 23 S., R. 57 E.

	Feet
Dolomite, very dark, finely crystalline, massive; weathers to flat slabs, 1 to 5 feet thick; fossil collection 97b	100
Dolomite, light bluish gray, finely crystalline, thin bedded, alternating with thin layers of platy limestone	140
Dolomite, very dark, finely crystalline, massive; weathers to thick slabs; fossil collection 97a	40
Dolomite, light gray, finely crystalline, thin bedded	100
	380

From the region where this section was measured northward to the border of the quadrangle platy limestone is progressively more abundant, and near the Mountain Springs it makes up a large part of the member.

There is little chert in this member, but in some places, generally in the upper half, there are one or locally two beds of dolomitized massive limestone 5 to 15 feet thick that contain abundant small cherty masses. These masses are a quarter of an inch to 1½ inches in diameter, irregularly rounded, much resembling small cauliflower heads, and uniformly distributed throughout the thickness of the bed. At first the chert masses appeared to be organic remains, but after observation over a large area this interpretation was abandoned. Such beds do not appear to be parts of one continuous bed but local lenses at different horizons. One bed crops out below the workings of the Columbia mine and can be traced westward as far as Kirby Wash. Others crop out high on the ridge west of the Potosi mine and along the tramroad from the Potosi mine and the head of the aerial tramway.

CRYSTAL PASS LIMESTONE MEMBER

Lithology.—Between the massive limestones that contain Devonian fossils and somewhat similar higher beds that yield the lowest Mississippian fossils there is a zone of limestone 150 to 260 feet thick that is uncommonly homogeneous throughout the region and lacks any traces of fossils or chert. This limestone forms the top member of the Sultan limestone and is here named Crystal Pass limestone member, from Crystal Pass, in sec. 2, T. 25 S., R. 58 E. It is made up of light bluish gray limestone of porcelainlike texture. Weathered surfaces yield many flat plates, commonly half an inch to 2 inches thick, and fresh fractures show similar lamination. (See pl. 5, *B.*) The limestone is identical in appearance with the thinner beds that occur in the underlying Valentine limestone member. Here and there massive beds appear, but they are uncommon. On flat slopes the outcrops are broadly rounded and yield considerable angular débris, but on steep slopes and cliffs, as along the northeast face of Potosi Mountain, where it is protected by higher massive beds, it forms a single massive bed, homogeneous in color, texture, and lamination throughout. Considered as a unit it is the most persistent in the entire region and therefore forms a valuable stratigraphic horizon.

In contrast with the other limestone masses in the Devonian and Mississippian formations, the Crystal Pass limestone is less susceptible to alteration to dolomite than any other. In several localities, as near Crystal Pass, where the overlying and underlying beds are completely altered to dolomite, it shows only sporadic patches. (See pl. 17, *C.*) In the region from Kirby Wash eastward to the front of the range, however, where the underlying and overlying beds are completely converted to dolomite, the Crystal Pass limestone is also completely altered.

No analyses have been made of specimens of limestone collected from the Sultan formation. Field tests indicate that all the material was originally very pure limestone. A lens of Crystal Pass limestone exposed in the hill at Sloan, 15 miles northeast of Goodspring, has survived the process of dolomitization, which has affected the near-by beds, and is mined by the Nevada Lime & Rock Co. as a source of limestone. Large quantities are mined annually that range from 97.5 to 98.5 per cent calcium carbonate. The lime is used in sugar refining.

AGE AND CORRELATION OF SULTAN LIMESTONE

On the basis of his identifications of the fossils from the Sultan limestone Edwin Kirk writes:

> The fauna is correlative with that of a horizon in the upper part of the Nevada limestone of the Eureka district and with the Martin limestone of Arizona. This statement certainly holds as regards the faunas above the Ironside dolomite. The fauna collected from the Ironside dolomite is too meager definitely to establish its exact equivalence.
>
> Some uncertainty exists as to the exact age assignment of this fauna. Williams[14] considered the fauna to be of Middle Devonian age. Apparently equivalent beds in Iowa have variously been assigned to the Upper and Middle Devonian. Until such time as a definite age assignment of the fauna is made in the well-known Iowa section, it seems inadvisable definitely to place the fauna in the West, where neither its relation to

[14] Williams, H. S., in Ransome, F. L., Geology and ore deposits of the Bisbee quadrangle, Ariz.: U. S. Geol. Survey Prof. Paper 21, pp. 35–42, 1904.

underlying and overlying faunas nor its biologic character is well known. The fauna then had best be defined as late Middle Devonian or early Upper Devonian.

Kirk[15] has described 1,500 feet of beds in the Inyo Range that contain Devonian fossils. In part these beds resemble the Crystal Pass limestone, but Ball did not recognize any Devonian beds in a large region north of the Amargosa Desert and east of the Inyo Range. The Temple Butte limestone, of Devonian age, of the Grand Canyon region, Arizona, which is limited at both top and bottom by unconformities,[16] is regarded as probably Upper Devonian.

[15] Kirk, Edwin, in Knopf, Adolph, A geologic reconnaissance of the Inyo Range: U. S. Geol. Survey Prof. Paper 110, pp. 36-37, 1918.

[16] Walcott, C. D., Pre-Carboniferous strata in the Grand Canyon of the Colorado: Am. Jour. Sci., 3d ser., vol. 26, p. 438, 1883. Noble, L. F., A section of the Paleozoic formations of the Grand Canyon at the Bass trail: U. S. Geol. Survey Prof. Paper 131, pp. 51-53, 1923.

Stratigraphic distribution of fossil collections from the Sultan limestone

[Identifications by Edwin Kirk, U. S. Geological Survey]

Author's field No. (see fig. 3)	Ironside dolomite member					100-foot zone overlying Ironside dolomite member										
	41a	56	18c	86a	86b	9	[a]28	41b	[a]43	57b	59	60a	60b	62	86c	90a
CORALS																
Alveolites sp	×			×							×					
Cladopora sp		×	×					×				×				×
Cyathophyllum sp	×			×	×	×	×	×					×	×		×
Diphyphyllum sp								×				×				
Pachyphyllum woodmani White						×										
Stromatopora sp	×	×	×	×	×		×	×					×	×		×
Striatopora sp													×			
Syringopora sp								×								
Aulopora sp								×								
BRACHIOPODS																
Atrypa missouriensis Miller					×	×		×	×	×		×	×	×		
Atrypa reticularis Linné							×									
Cyrtia cyrtiniformis Hall and Whitfield								×				×			×	
Spirifer argentarius Meek																×
GASTROPODS																
Platyschisma mccoya Walcott						×		×					×			

Author's field No. (see fig. 3)	100-foot zone overlying Ironside dolomite member									Zone 100 to 300 feet above Ironside dolomite member						
	90b	91	94	97a	100a	100b	116	117a	104	97b	102a	106	109a	114a	117b	117c
CORALS																
Cladopora sp									×							
Cyathophyllum sp					×						×					
Diphyphyllum sp				×												×
Heliophyllum sp				×												
Stromatopora sp	×															
Syringopora sp				×	×								×			
BRACHIOPODS																
Atrypa missouriensis Miller	×		×	×		×		×		×				×		
Atrypa reticularis Linné					×		×				×	×	×		×	
Cyrtia cyrtiniformis Hall and Whitfield				×			×			×	×		×	×		
Schuchertella sp									×				×			
Spirifer hungerfordi Hall										×						
Spirifer whitneyi Hall				×						×		×				
GASTROPODS																
Platyschisma mccoyi Walcott		×		×	×		×				×	×	×	×	×	

[a] Precise position of collection uncertain.

CARBONIFEROUS SYSTEM

MONTE CRISTO LIMESTONE

AREAL DISTRIBUTION

The general areal distribution of the Monte Cristo limestone, which is here made to include all the Mississippian rocks in the Goodsprings quadrangle, coincides closely with that of the underlying Sultan limestone. In addition to the belt that extends from the northern edge of the quadrangle southward around the western slope of the Spring Mountains, however, there are large areas in the vicinity of Potosi Mountain, along Shenandoah Gulch, and along the southern part of the range.

SUBDIVISIONS

Lithologically the formation can be divided into five members, on the basis of distinct features of bedding as well as chert and fossil content. Beginning with the lowest and oldest they are here named Dawn limestone member, Anchor limestone member, Bullion dolomite member, Arrowhead limestone member, and Yellowpine limestone member. Originally each of these members was nearly pure calcium carbonate with thin shale partings, but now each member is either sporadically or entirely altered to dolomite. No sand or sandy layers have been found in any part of the formation.

Approximate thickness, in feet, of members of the Monte Cristo limestone

	Milford Ridge, N. ½ sec. 5, T. 26 S., R. 58 E. Dip 35° SW.	Bonanza Hill, SE. ¼ sec. 14, T. 25 S., R. 57 E. Dip 40° E.	Crystal Pass, secs. 11, 12, T. 25 S., R. 58 E. Dip 10° W.	Mobile Ridge, NE. ¼ sec. 35, T. 24 S., R. 57 E. Dip 20° NW.	Lavina Ridge, W. ½ sec. 21, T. 24 S., R. 58 E. Dip 45° W.	Ridge northwest of Blue Jay, W. ½ sec. 9, T. 24 S., R. 58 E. Dip 25° W.	Potosi Mountain, sec. 8, T. 23 S., R. 58 E. Dip 25° SW.	Potosi mine, SW. ¼ sec. 12, T. 23 S., R. 57 E. Dip 80° E.	Nigger Tent, W. ½ sec. 36, T. 23 S., R. 57 E. Dip vertical	Ridge west of Potosi mine, E. ½ sec. 10, T. 23 S., R. 57 E. Dip 35° W.	West of Potosi mine, SW. ¼ sec. 10, T. 23 S., R. 57 E.
Yellowpine limestone member	Present.	Present.	Present.	Eroded.	Present.	100	120	120	Present.	Present.	Present.
Arrowhead limestone member	12	Absent.	Absent.	Eroded.	Present.	10	15	20	Present.	Absent.	Absent.
Bullion dolomite member	Present.	600	185	Eroded.	300	300	Present.	300	300	Present.	Present.
Anchor limestone member	Present.		65	300+	400	Covered.	Present.	200±	100	400	Present.
Dawn limestone member	Absent.	90	125	400	(?)	(?)	Present.	60	150	Present.	Present.

DAWN LIMESTONE MEMBER

Lithology.—The basal member of the Monte Cristo formation, here named Dawn limestone member, is made up of massive limestone beds that are commonly from 2 to 10 feet thick. The color ranges from light bluish gray to dark smoky gray, and the texture is porcelainlike or finely crystalline, except where the material is altered to dolomite. In general stratigraphic features this limestone closely resembles the Valentine member of the Sultan limestone, from which it is separated by the Crystal Pass limestone. It lacks the one or two beds of chert-bearing limestone characteristic of the Valentine, and in addition it contains distinctive fossils.

The Dawn limestone derives its name from the Dawn mine, in the SW. ¼ sec. 15, T. 23 S., R. 58 E., west of which it is well exposed. It is distinct and recognizable throughout a large part of the quadrangle, but there can be little doubt that it is absent in some places, such as along the ridge in the W. ½ sec. 24, T. 23 S., R. 57 E. Estimates of thickness are given above.

Although all the beds consist of limestone along the southern edge of the quadrangle, they are largely dolomite in most of the area and undoubtedly have been altered during the deformation of the region, as described on pages 57–61. By this process the texture has become coarser and the color slightly lighter. The general features of the limestone are shown in Plate 38, *A*.

Fossils.—This limestone has yielded several large collections of fossils, but they are not abundant. Some species are common to this and the overlying Anchor limestone.

ANCHOR LIMESTONE MEMBER

Lithology.—The Anchor limestone member is characterized by thick, massive beds of porcelain texture and light bluish-gray color. The beds commonly range from 20 to 50 feet in thickness and form broadly rounded outcrops, although adjacent to deep ravines the entire unit may form steep cliffs. In addition to its texture and absence of lamination, numerous layers of chert nodules are a persistent characteristic. These nodules range from rudely spherical to irregularly rounded elongated masses 2 to 3 inches thick and 5 to 10 inches long. Such nodules are distributed in persistent parallel layers 3 to 10 inches apart. (See pl. 6, *A*.) In the region of the Bullion and Anchor mines and elsewhere these layers of nodules are well developed and are uniformly distributed across the outcrops of beds 50 feet or more thick. Most of the fossils collected from this limestone were found in these nodules. Other forms of chert are conspicuously lacking. The general features of the beds are shown in Plates 6, *A*, and 38, *A*, *B*. The name is derived from the Anchor mine, in sec. 23, T. 25 S., R. 58 E.

The Anchor limestone resists dolomitization almost as widely as the Crystal Pass limestone, but there are large belts within which it is completely altered to dolomite. Such a belt extends from the region of Kirby Wash southeastward 4 or 5 miles. Where the member is overturned under the Keystone fault on the west side of the range it is largely converted to dolomite. Many of the ore deposits of the region occur in the Anchor limestone (see p. 95), and near by the limestone is completely altered to dolomite, as in the Anchor, Monte Cristo, Whale, and other mines.

The upper limit of the Anchor limestone is a sinuous surface that separates it from the overlying Bullion dolomite member. This surface is locally nearly parallel to the bedding, but in a broad way they do not coincide. On the other hand, the upper surface of the Bullion dolomite is nearly parallel to the lower surface of the Anchor limestone—that is, where the Bullion dolomite is thin the Anchor limestone is thick. If these relations are considered with the characteristic features of the Bullion dolomite, it is clear that the Bullion is the altered upper part of a group of limestone beds of which the Anchor limestone is the unaltered lower part. Analyses recorded in the tables on pages 61–62 show that where the Anchor is unaffected by recent dolomitization it is a very pure limestone.

BULLION DOLOMITE MEMBER

Lithology.—The features of the beds here named Bullion dolomite member of the Monte Cristo limestone are uncommonly uniform throughout the region. In the southern part of the quadrangle the beds generally consist of cream-colored and coarsely crystalline material; weathered surfaces are darker and harsh to the touch, owing to the presence of many minute crystals of dolomite. North of Wilson Pass the beds are light gray to nearly white and more coarsely crystalline. Traces of bedding are present here and there, but the presence of numerous vertical joints where the beds dip at low angles permits erosion to form very rough and locally pinnacled surfaces. In some places the beds are much crushed, and the fragments are recemented by white dolomite veins. Throughout most of its areal extent this dolomite contains small irregular cavities, commonly lined with crystals of dolomite. Where the cavities are present, they are rather uniformly distributed through the rock. As explained on page 66 they were formed during the process of dolomitization, and calcite was deposited in them, but this is generally dissolved from surface outcrops.

In secs. 2 and 3, T. 26 S., R. 58 E., south of the Christmas mine, the Bullion dolomite is represented by limestone similar to that which makes up the underlying Anchor limestone. In the region farther north the dolomite does not contain any remnants of the original limestone.

Chert is uncommon in the dolomite. In several parts of the region the lower limit of the member is the uppermost zone of chert nodules in the underlying Anchor limestone. The relations suggest that the solutions which produced the dolomitization were hindered in their movement by the zones of chert nodules.

The name of this member is derived from the Bullion mine, in sec. 23, T. 25 S., R. 58 E.

Fossils.—Only a few fossils have been found in the Bullion dolomite, but one of these, a brachiopod, *Rhipidomella thiemi*, appears to be restricted to this member, and it can generally be found.

ARROWHEAD LIMESTONE MEMBER

Although the Arrowhead member, named from a prospect in sec. 9, T. 24 S., R. 58 E., is only 10 to 20 feet thick it is widespread and possesses characteristics that permit its ready recognition throughout a large area. It is made up of alternating layers of blue and gray limestone 2 to 4 inches thick and thinner layers of gray shale. (See pl. 6, *B*.) The limestone layers do not have uniform thickness, and the limiting surfaces are wavelike rather than plane. No chert is present. As shown in the list of fossils (p. 20), this limestone contains an abundant and rather distinctive fauna, only a part of which is present in the underlying beds.

The limestone appears to be persistent throughout the range north of Columbia Pass but was not recognized west of the Keystone thrust. South of Columbia Pass it has been recognized only near the Ingomar mine and assuredly is absent near the Bill Nye mine and the mines on Porter Wash. In several places it, as well as the overlying massive limestone, was probably removed by erosion before the basal sandstone of the Bird Spring formation was deposited. In many localities this limestone marks the upper limit of dolomitization.

YELLOWPINE LIMESTONE MEMBER

Throughout the range north of Columbia Pass the Arrowhead limestone is overlain by a massive ledge of dark-gray limestone, 60 to 120 feet thick (pl. 33, *B*), here named Yellowpine limestone member, from the principal mine of the region, in sec. 20, T. 24 S., R. 58 E. This limestone contains the productive ore bodies of the Yellow Pine, Potosi, Ingomar, and several other mines; but it is completely altered to dolomite near by. A distinctive feature is the persistent presence of great numbers of corals of the *Zaphrentis* group, 3 to 6 inches long, which lie prostrate and weather in relief; here and there they are accompanied by poorly preserved large gastropods. A similar bed overlies the Arrowhead limestone near the Milford and Ingomar mines and is present near the Accident and Christmas mines where that limestone could not be found.

AGE AND CORRELATION OF MONTE CRISTO LIMESTONE

On the basis of the fossil collections, the identifications of which are presented on page 19, G. H. Girty, of the Geological Survey, concludes that all the beds included in the Dawn and Anchor limestones and

Bullion dolomite are lower Mississippian, and that the fossils from the Arrowhead limestone are of middle Mississippian age; the few fossils from the Yellowpine limestone do not serve to establish its age, but it probably is middle Mississippian also.

The fossil content of the Monte Cristo limestone warrants its correlation in a broad way with that group of limestones of lower and middle Mississippian age that are widespread over the Western States. On the other hand, there has been little detailed work in the region within 100 miles of Goodsprings, on the basis of which precise correlations might be made. The characteristic fossils of the Rogers Spring limestone of the Muddy Mountains [17] are present in the Monte Cristo limestone, and the two formations are probably approximately equivalent. At more remote localities, such as the Grand Canyon, Ariz., the basal part of the Redwall limestone may represent a part of the Monte Cristo limestone. Some of the faunal elements of the Escabrosa limestone in the Bisbee district, Arizona,[18] 450 miles to the southeast, closely resemble those included here. Beds of lower Mississippian age are not definitely recognized in northern and western Nevada; the fauna of the White Pine shale, which is extensive in eastern Nevada, indicates that it probably is all upper Mississippian,[19] although lower Mississippian may possibly be represented in it.

[17] Longwell, C. R., Geology of the Muddy Mountains, Nev.: Am. Jour. Sci., 5th ser., vol. 1, p. 46, 1921.

[18] Ransome, F. L., Geology and ore deposits of the Bisbee district, Arizona: U. S. Geol. Survey Prof. Paper 21, pp. 42-50, 1904.

[19] Girty, G. H., in Knopf, Adolph, op. cit., pp. 38, 39.

Fossils collected in the Monte Cristo limestone

[Identifications by G. H. Girty, U. S. Geological Survey]

	Dawn limestone member										Anchor limestone member					
U. S. Geological Survey collection No.	4279	4281	4289	4290	4291	4292	4293	4295	4299	4196	4218g	4220	4229	4276	4277	4284
Author's field No. (see fig. 3)	27	34	66	75	84	87	92	103b	112	115	5a	11a	21	24	25	44
CORALS																
Cladochonus sp.						×										
Cyathophyllum? sp.											×	×	×			
Cyathaxonia aff. C. minor						×										
Lithostrotion? sp.											×		×			
Lithostrotion? aff. L. harmodites?											×	×				
Michelinia aff. M. meekana							×									
Syringopora sp.											×					
Syringopora aff. S. surcularia		×					×					×				
Triplophyllum sp.				×			×				×					
Triplophyllum aff. T. excavatum						×										
BRYOZOANS																
Fenestella sp.															×	
BRACHIOPODS																
Avonia sp.			×													
Brachythyris sp.															×	
Camarotoechia sp.								×								
Camarotoechia metallica																×
Chonetes logani					×											
Cliothyridina? sp.							×									
Cliothyridina? aff. C. incrassata			×	×											×	
Productus gallatinensis	×			×	×											×
Productus keokuk								×								
Productus aff. P. burlingtonensis			×					×							×	
Productus ovatus				×				×								
Productus semireticulatus														×	×	
Productus setiger								×								
Productella aff. P. hirsutiformis															×	
Pseudosyrinx sp.								×								
Pustula sp.															×	
Pustula aff. P. pustulosa				×												
Rhipidomella aff. R. burlingtonensis						×										
Rhipidomella pulchella				×				×								
Reticularia cooperensis				×												
Schuchertella chemungensis	×			×					×						×	
Schizophoria sp.					×											
Schizophoria aff. S. swallowi				×											×	
Spirifer centronatus	×		×	×	×	×	×	×						×	×	
Spirifer aff. S. grimesi				×				×	×					×	×	×
Spirifer aff. S. keokuk				×												
Spiriferina sp.				×												
Spiriferina solidirostris						×									×	
Syringothyris sp.															×	

Fossils collected in the Monte Cristo limestone—Continued

	Dawn limestone member										Anchor limestone member					
U. S. Geological Survey collection No.	4279	4281	4289	4290	4291	4292	4293	4295	4299	4196	4218g	4220	4229	4276	4277	4284
Author's field No. (see fig. 3)	27	34	66	75	84	87	92	103	112	115	5	11	21	24	25	44
PELECYPODS																
Pernipecten shumardianus?				×												
GASTROPODS																
Loxonema? sp				×												
Holopea sp										×						
Platyceras sp				×												
CEPHALOPODS																
Orthoceras sp				×												

	Anchor limestone member								Bullion dolomite member						Arrowhead limestone member	
U. S. Geological Survey collection No.	4285	4286	4288	4294	4296	4297	4274	4280	4220-2	4224-c	4278	4282	4283	4287	4298	4272
Author's field No. (see fig. 3)	45	53	63	102b	105	109b	120	30	11d	16d	26	38	41c	54	114b	118
CORALS																
Cyathophyllum? aff. C. subcaespitosum										×				×	×	
Lithostrotion? sp											×					
Syringopora aff. S. surcularia											×					
Triplophyllum sp	×										×	×	×		×	×
Triplophyllum aff. T. excavatum									×							
Zaphrentis sp			×													
ECHINODERMS																
Echinocrinus sp															×	×
Dichocrinus sp															×	
Rhodocrinus sp															×	
Schizoblastus lotoblastus								×				×	×			
BRYOZOANS																
Cystodictya sp																×
Fenestella sp								×	×						×	×
Fenestella aff. F. tenax															×	×
Polypora sp															×	
Ptilopora sp						×										
Stenopora sp															×	
BRACHIOPODS																
Brachythyris sp							×									
Camarotoechia sp															×	
Camarotoechia metallica						×										
Camarotoechia aff. C. purduei															×	×
Chonetes loganensis var	×														×	×
Cliothyridina? monticola						×										
Cliothyridina? aff. C. incrassata		×		×									×			
Composita aff. C. immatura	×															×
Composita aff. C. madisonensis var. pusilla															×	
Composita aff. C. humilis	×															
Dielasma sp						×										
Dielasma aff. D. burlingtonense	×															
Leptaena analoga				×												
Orthotetes? sp															×	
Orthotetes? kaskaskiensis	×															×
Productus gallatinensis						×										
Productus aff. P. burlingtonensis				×												
Productus ovatus						×									×	×
Productus sp													×			
Pustula sp		×	×			×							×		×	
Pustula aff. P. curtirostris						×										
Rhipidomella nevadensis?															×	×
Rhipidomella pulchella																
Rhipidomella thiemei										×	×	×				
Reticularia cooperensis				×												
Schuchertella sp			×		×											

Fossils collected in the Monte Cristo limestone—Continued

	Anchor limestone member								Bullion dolomite member						Arrowhead limestone member	
U. S. Geological Survey collection No.	4285	4286	4288	4294	4296	4297	4274	4280	4220-2	4224-c	4278	4282	4283	4287	4298	4272
Author's field No. (see fig. 3)	45	53	63	102b	105	109b	120	30	11d	16d	26	38	41c	54	114b	118
BRACHIOPODS—continued																
Spirifer n. sp.															×	×
Spirifer centronatus	×	×	×		×	×			×			×	×			
Spirifer aff. S. grimesi				×												
Spirifer aff. S. montgomeryensis			×													
Spiriferina n. sp.															×	×
PELECYPODS																
Conocardium sp.																×
Cypricardinia aff. C. scitula				×												
Edmondia sp.																×
Leptodesma aff. L. spergenense																×
Schizodus sp.						×										
GASTROPODS																
Euomphalus utahensis			×													
Naticopsis? sp.																×
Pleurotomaria sp.																×
Straparollus spergenensis	×														×	
CRUSTACEA																
Paraparchites aff. P. carbonarius																×
Phillipsia? sp.															×	

BIRD SPRING FORMATION

Areal distribution and thickness.—The rocks herein named Bird Spring formation are exposed over a larger area in the quadrangle than any other formation. The central mass of the Spring Mountains is largely underlain by them, and an interrupted belt extends around the west side of the range from the northern to the southern edge. They also underlie a large area in the Bird Spring Range, from which the name of the formation is derived. The maximum thickness of 2,500 feet was measured in secs. 5 and 6, T. 24 S., R. 58 E.

Lithology.—The formation consists essentially of limestone, shale, and sandstone, but many beds, and even large thicknesses over considerable areas, that were originally limestone have been altered to dolomite. The estimated maximum thickness of 2,500 feet includes many thin beds in the upper 1,000 feet that were doubtless originally dolomite, but it appears probable that the remaining lower part was made up wholly of limestone, shale, and sandstone. Sand is present as distinct beds, and grains of sand are uniformly distributed through many of the beds of limestone.

The beds of limestone range from the thinnest laminae to massive layers 60 feet thick. Several of the thickest beds occur near the base, but others lie about 1,000 feet above it. There are numerous good exposures of sections 200 to 400 feet thick in which most of the beds range from 2 to 15 feet thick, whereas here and there 50-foot sections contain no beds more than a foot thick. Thus, it stands in striking contrast to the underlying massive formations. (See pl. 7, *A*.) The beds of limestone also display a wider range in color than exists in the lower formations. Most of the beds are bluish gray, but they range from nearly black to white. Some of the higher beds in the Spring Mountains and the Bird Spring Range weather reddish brown, thereby indicating an appreciable content of iron. In general the light colors indicate the presence of dolomite, but here and there, as in sec. 32, T. 23 S., R. 58 E., alteration to dolomite has not produced any change in color.

The limestones of the formation are uniformly fine grained or porcelainlike in texture. A few show sporadic crystalline areas that represent fragments of crinoid stems. The dolomitized beds are more coarsely crystalline. From the few thin sections that have been studied it appears that the fine texture of the limestone is due to the small size of the organisms or fragments that make them up. The dark colors are due to finely disseminated carbon and hydrocarbons, and these yield a fetid odor when the rock is broken. During the process of dolomitization the hydrocarbons were largely eliminated.

Small quantities of chert are present persistently throughout the formation, although it is most abundant near the base. The chert takes the form of elongate nodules arranged in layers roughly parallel to the bedding, as in the Anchor limestone member of the underlying Monte Cristo limestone, or of layers or persistent lenses from several inches to 6 feet thick. The layers of nodules are conspicuous in several beds near the base of the formation, but they occur sporadically throughout. Doubtless the silica now found as nodules was disseminated in the limestones when they were deposited, but the process of segregation took place after the burial and before recent weathering. Commonly nodules partly envelop and replace fossils, and some very large ones are found about 600 feet above the base of the formation on the crest of the Bird Spring Range, replacing corals of the genus *Chaetetes*.

Only a few beds of clean sandstone are recorded, but many beds of apparently fine limestone contain 5 to 50 per cent of sand grains (analyses 10 and 11, p. 61). Weathered surfaces of such beds show cross-bedding. In the several specimens that have been examined the range in size is 0.02 to 0.10 millimeter, but in single specimens the range is much less. About 90 per cent of the grains are clear quartz, but feldspar (microperthite and plagioclase) are also present, and zircon is an accessory. The grains are largely subangular, but a few of the largest are well rounded.

The thickest and most persistent sandstone in the formation is that which lies at the base. (See p. 46.) Although the outcrop of this sandstone is nowhere conspicuous, it extends throughout the region north of Columbia Pass. Where exposed in the workings of the Yellow Pine mine it is 23 to 28 feet thick, pale yellowish brown, fine grained, and without distinct bedding. On the surface from the Contact mine northwest to the Ninety-nine mine and around Potosi Mountain to the Potosi mine it is thin bedded and distinguished by round brown markings, probably due to oxidized pyrite. For a distance of 1,200 feet near the Snowstorm mine, the sandstone zone is largely occupied by a bed of conglomerate whose maximum thickness is 10 feet. Here the conglomerate bed is made of two or three lenses of closely packed, well-rounded chert pebbles, whose maximum diameter is 4 inches. The conglomerate is overlain and underlain by 3 feet of sandstone. Both north and south from the area of maximum thickness the thickness decreases and the bed becomes a sandy limestone with sporadic pebbles as much as half an inch in diameter. Near the Snowstorm mine the bed is highly indurated, owing to the presence under it of a sill of porphyry. Recent work at the Prairie Flower mine shows that a zone of conglomerate occupies the position of the sandstone. (See p. 128.)

This bed of sandstone and conglomerate is not noticeably unconformable on the underlying beds, but other features indicate that it marks a persistent unconformity in the stratigraphic section. Probably there is not an appreciable unconformity in the range north of Columbia Pass, as all the members of the Monte Cristo limestone are present under the sandstone. South of Columbia Pass, however, both the Arrowhead limestone member of the Monte Cristo and the massive overlying bed are sporadic, and limestones with fossils characteristic of the Bird Spring formation rest on the Bullion dolomite member of the Monte Cristo, as, for example, near the Bill Nye mine. Also the Bird Spring formation consists of thin-bedded limestones with considerable clastic material, whereas the underlying massive limestones are almost free of clastic material.

Fossils are common in the lower part of the formation and are abundant in some beds 100 to 300 feet above the base. A few beds may be recognized with assurance rather widely, not only on account of the fossil species present but by their abundance.

Several partial sections of the formation are given below.

Section of the Bird Spring formation under the Potosi thrust in sec. 5, T. 24 S., R. 58 E.

	Feet
Limestone, bluish gray, in beds 3 to 5 feet thick but appearing massive; no chert	45
Dolomite, light gray	10
Limestone, bluish gray, in massive beds 3 feet thick, alternating with 6-inch beds of white dolomite; traces of *Fusulina*	70
Limestone, bluish gray, in massive beds 10 feet thick with round chert concretions; few spines and corals	35
Limestone, bluish gray, sandy, locally cross-bedded	18
Limestone, bluish gray, in massive sandy beds 10 feet thick with several beds of white dolomite 1 foot thick; few spines	41
Limestone, bluish gray, in massive beds 10 feet thick alternating with beds of white dolomite 1 to 2 feet thick	81
Limestone, bluish gray, sandy, in massive beds 6 feet thick	31
Limestone, bluish gray, in 3-foot beds, locally dolomite in upper part, cherty in lower part	52
Limestone, bluish gray, with layers of chert	5
Limestone, bluish gray, massive; no chert	10
Dolomite, light gray; many fractures	6
Limestone, bluish gray, in massive 3-foot beds; no chert	21
Limestone, bluish gray, in 3-foot beds with layers of chert 4 inches thick	4
Limestone, bluish gray, massive; no chert	58
Dolomite, cream-colored layers of chert 1 to 6 inches thick	1
Limestone, bluish gray; chert layers	3
Limestone, bluish gray, massive; no chert	31
Limestone, bluish gray, massive, sandy; local layers of chert	28
Limestone, bluish gray, massive, with 1-foot layer of chert near middle	31
Limestone, bluish gray; few round chert concretions	10
Limestone, bluish gray, with half-inch layer of chert	12
Limestone, bluish gray, massive	15
Dolomite, light gray, locally sandy, with few lenses of chert 3 inches thick and 3 feet long. Several patches of residual limestone	102
Dolomite, light gray, with few layers of chert; a 5-foot bed of limestone near top; fossil collection 4268 (99a)	92
Dolomite, light gray, with few layers and nodules of chert; few lenses of unaltered limestone	61
	873

Partial section of the Bird Spring formation above the Potosi thrust, in sec. 5, T. 24 S., R. 58 E.

	Feet
Limestone, bluish gray, in thin beds but weathers as a massive unit	35
Limestone, bluish gray, in beds 3 to 8 feet thick; contains *Fusulina*	26
Limestone, bluish gray, in beds 3 to 8 feet thick, alternating with beds of cream-colored dolomite 1 to 2 feet thick	46
Dolomite, white	3
Limestone, bluish gray	5
Limestone, bluish gray, cherty; contains spines	2
Limestone, bluish gray; contains *Fusulina*	5
Limestone, bluish gray, thick bedded	21
Dolomite, white	5
Limestone, bluish gray, in beds 3 to 5 feet thick	25
Limestone, bluish gray, with lenses of chert	20
Dolomite, pale reddish, sandy	26
Limestone, gray, very sandy; sand in thin layers	15
Limestone, bluish gray, massive	5
Dolomite, white, massive	16
Limestone, blue-gray; thin layers of sand	20
Limestone, bluish gray, massive; very little chert	21
Limestone, bluish gray, massive; round chert concretions as much as 1 foot in diameter	60
Potosi thrust.	
	356

Partial section of the Bird Spring formation in Bird Spring Range, sec. 33, T. 24 S., R. 59 E.

	Feet
Limestone, gray, sandy, massive	6
Limestone, gray, sandy, thin bedded	7
Limestone, gray, sandy, massive; fossil collection 4217e (2c)	24
Limestone, gray, sandy, thin bedded	4
Limestone, gray, sandy, massive; *Chaetetes*	13
Limestone, gray, sandy, massive	6
Limestone, gray, thin bedded	8
Limestone, gray, sandy, massive	30
Limestone, gray, thin bedded	23
Limestone, gray, sandy, massive	20
Limestone, gray and reddish, sandy, thin bedded	85
Limestone, gray, dense	8
Limestone and dolomite in thin beds	34
Sandstone, buff, calcareous	8
Dolomite, cream-colored	7
Sandstone, buff, cross-bedded	34
Shale, sandy, light gray	20
Limestone, alternating thin and massive beds; many layers of chert 4 to 10 inches thick	46
Limestone, gray, sandy; thin-bedded layers of chert (fossil collection 4217d) (2d)	55
Chert, white, nonpersistent	6
Limestone, reddish gray, thin bedded	11
Limestone, gray, massive; fossil collection 4217c (2c)	13
Chert, white, nonpersistent	4
Limestone, reddish gray, thin bedded	12
Limestone, reddish, nonpersistent	3
Limestone, reddish gray; layers of chert; fossil fragments	5
Limestone and dolomite, alternating layers, with lenses of chert in the limestone	60
Limestone, gray, in beds 1 to 5 feet thick; chert in center	30
Limestone, gray, thin bedded, local chert	12
Limestone, alternating gray and buff, beds 1 to 10 feet thick; few fossils	72
Limestone, gray, massive	12
Dolomite, cream-colored, massive	17
Limestone, light gray, thin bedded; fossil collection 4217 (2a)	5
Dolomite, cream-colored, massive	21
	721

Section of lower part of Bird Spring formation, measured up the ridge southwest of the Porter mine, in the NE. ¼ sec. 22, T. 25 S., R. 58 E.

	Feet
Minor fault, exposed on ridge.	
Limestone, alternating beds, medium gray, as much as 5 feet thick	30
Dolomite, light cream-colored, crystalline; shows shrinkage cavities	60
Limestone, alternating beds, medium and light gray, as much as 15 feet thick	300
Dolomite, light gray	2
Limestone, alternating beds of medium and light gray, dense texture	145
Fault; strike N. 20° W., dip 80° SW.	
Limestone, medium gray, dense texture, beds 1 to 2 feet thick; contains considerable chert	25
Limestone, same as above, but without chert	12
Limestone, medium gray, dense texture; some chert	20
Limestone, light gray, dense; weathers white; persistent chert layer 4 to 8 inches thick	3
Limestone, medium gray, dense texture; forms bench	4
Limestone, light gray; weathers white	3
Limestone, medium gray, dense texture; forms bench	10
Limestone, medium gray, dense texture, in beds 2 to 4 feet thick	20
Limestone, medium gray, dense texture; contains few brachiopods and corals; forms massive ledge	25
Limestone, medium gray, dense texture, some chert, much broken up	45
Limestone, medium gray, dense texture, considerable iron-stained chert; forms a bench	10
Limestone, successive bed, medium gray, dense texture, little chert, several benches, uppermost contains a coral reef	125
Total below fault	302

Age and correlation.—According to G. H. Girty, of the United States Geological Survey, who has identified all the fossils recorded in the following tables, the fauna from the Bird Spring formation is Pennsylvanian.

Fossils of Pennsylvanian age collected from the Bird Spring formation

[Identifications by G. H. Girty, U. S. Geological Survey]

	0–450 feet above the base																				
U. S. Geological Survey collection No.	4218	4219	4221	4264	4219	4220a	4220b	4225	4226	4226a	4241	4242	4243	4248	4249	4250	4257	4258	4259	4259a	4260
Author's field No. (see fig. 3)	5b	10a	13	85	10b	11b	11c	17	18a	18b	46a	46b	47	52	55a	57	73e	76a	77a	77b	79a
CORALS																					
Campophyllum n. sp.						×															
Cyathophyllum subcaespitosum	×	×				×			×												
Lithostrotion? sp.			×	×																	
Lonsdaleia? sp.				×																	
Michelinia aff. M. meekana															×						
Syringopora n. sp.	×																				
Syringopora aff. S. surcularia									×												
Triplophyllum sp.					×															×	
BRYOZOANS																					
Batostomella sp.								×		×			×				×				
Rhombopora sp.						×	×														
Stenopora sp.								×			×	×					×		×		
BRACHIOPODS																					
Avonia aff. A. arkansana						×			×				×	×	×			×			×
Avonia aff. A. arkansana var. multilirata										×											×
Chonetes sp.												×									
Chonetes aff. C. laevis						×							×		×						
Cliothyridina aff. C. sublamellosa					×	×	×				×	×				×			×		
Composita sp.										×											
Composita aff. C. subquadrata					×	×		×			×		×	×				×	×	×	×
Crania sp.																	×				
Dielasma sp.												×									
Dielasma aff. D. arkansanum						×															×
Hustedia n. sp.											×		×								
Hustedia aff. H. multicostata					×										×				×		
Orbiculoidea sp.																					×
Orthotetes sp.								×									×				
Orthotetes kaskaskiensis						×							×		×						
Productus aff. P. adairensis						×									×				×	×	
Productus aff. P. inflatus						×	×											×			×
Productus ovatus						×			×	×	×	×	×		×			×		×	×
Productus ovatus var. minor						×	×			×	×		×	×							×
Productus semireticulatus						×															×
Pustula aff. P. wallaciana						×	×														
Reticularia? sp.															×						
Rhipidomella sp.															×						
Rhipidomella n. sp.							×														
Rhynchopora aff. R. beecheri											×				×						
Spirifer sp.					×																
Spirifer aff. S. arkansanus					×																
Spirifer aff. S. increbescens						×	×	×	×	×	×	×	×	×	×	×	×	×	×		×
Spiriferina sp.																					×
Spiriferina aff. S. spinosa					×						×	×	×		×		×		×		

PELECYPODS																					
Aviculipecten sp														X							
Deltopecten sp																	X				
Deltopecten aff. D. occidentalis						X															X
Myalina? aff. M. subquadrata								X													
Myalina? aff. M. swallowi								X													
Solenomya sp																	X				
GASTROPODS																					
Bellerophon sp						X											X				
Euomphalus n. sp																	X				

	0–450 feet above the base																				
U. S. Geological Survey collection No.	4260a	4260c	4266	4268	4270	4270	4244	4223	4230	4232a	4233	4235	4236	4236a	4239	4249a	4253	4259b	4265	4271	4220
Author's field No. (see fig. 3)	79b	79d	93	99a	103a	119	48	15a	22	24b	29	36	37a	37b	40a	55b	65	77c	89	113	11f
CORALS																					
Campophyllum n. sp								X													
Cladochonus (Syringopora?) n. sp								X											X		
Lithostrotion? sp								X													
Michelinia aff. M. eugeneae	X																				
Michelinia aff. M. meekana			X																		
ECHINODERMS																					
Echinocrinus sp			X																		
ANNELIDS																					
Enchostoma sp	X																				
BRYOZOANS																					
Batostomella sp				X													X	X			
Dichotrypa sp										X											
Fenestella sp						X															
Fistulipora sp										X											
Rhombopora sp										X											
Stenopora sp						X			X									X			
BRACHIOPODS																					
Avonia aff. A. arkansana				X	X						X		X		X			X		X	
Avonia aff. A. arkansana var. multilirata							X														
Chonetes aff. C. laevis	X		X				X		X									X	X		
Cliothyridina aff. C. sublamellosa									X	X			X					X	X		
Composita sp	X	X	X													X					
Composita aff. C. subquadrata					X				X	X								X			
Dielasma sp																		X			
Hustedia sp									X												
Hustedia n. sp	X									X								X			
Liorhynchus carboniferum?	X																				
Orbiculoidea sp																		X		X	
Orthotetes sp		X					X										X				
Orthotetes kaskaskiensis																		X			
Productus aff. P. adairensis	X	X	X						X		X								X		
Productus aff. P. inflatus						X												X		X	X
Productus aff. P. longispina															X						

Fossils of Pennsylvanian age collected from the Bird Spring formation—Continued

	0–450 feet above the base																				
U. S. Geological Survey collection No.	4260a	4260c	4266	4268	4270	4270	4244	4223	4230	4232a	4233	4235	4236	4236a	4239	4249a	4253	4259b	4265	4271	4220c
Author's field No. (see fig. 3)	79b	79d	93	99a	103a	119	48	15a	22	24b	29	36	37a	37b	40a	55b	65	77c	89	113	11f
BRACHIOPODS—continued																					
Productus ovatus	×			×		×			×		×				×			×	×	×	
Productus ovatus var. minor													×					×			
Productus semireticulatus									×												
Pustula n. sp					×													×			
Pustula aff. P. alternata									×												
Rhynchopora sp	×																				
Rhynchopora aff. R. beecheri							×														
Spirifer sp																					×
Spirifer aff. S. increbescens						×					×		×	×	×		×	×		×	
Spirifer aff. S. rostellatus					×																
Spiriferina aff. S. spinosa							×			×							×	×			
PELECYPODS																					
Aviculipecten sp					×						×			×							
Conocardium sp												×									
Deltopecten aff. D. occidentalis											×										
Myalina? sp		×																			
Solenomya sp		×																			
Sphenotus? sp											×										
Schizodus sp		×																			
GASTROPODS																					
Bellerophon sp												×									
Euomphalus n. sp												×									
Euomphalus (Schizostoma?) sp																		×			
Euphemus? sp												×									
Pleurotomaria sp											×										
CRUSTACEANS																					
Griffithides sp											×							×			

Fossils of Pennsylvanian age collected from the Bird Spring formation—Continued

	0–450 feet above the base																				
U. S. Geological Survey collection No.	4223a	4210	4224b	4224a	4275	4228	4228a	4254	4254a	4254b	4255	4255a	4256a	4231	4246	4246a	4246b	4251	4269	4268a	4252
Author's field No. (see fig. 3)	15b	42	16c	16b	122	20a	20b	68a	68b	68c	69a	69b	70b	23	50a	50b	50c	58	101	99b	64
CORALS																					
Acervularia? sp								×													
Campophyllum n. sp																×					
ECHINODERMS																					
Echinocrinus sp				×					×		×										×
ANNELIDS																					
Enchostoma sp															×						
BRYOZOANS																					
Fenestella sp							×														
Fistulipora sp							×														
Stenopora sp						×											×	×			×
BRACHIOPODS																					
Avonia aff. A. arkansana	×			×		×						×		×		×	×				
Chonetes sp				×																	
Chonetes aff. C. laevis			×				×														
Cliothyridina aff. C. sublamellosa							×														
Composita sp						×															
Composita aff. C. subquadrata			×	×			×		×	×	×	×	×	×	×	×	×	×			
Dielasma sp																				×	
Dielasma aff. D. arkansanum														×							
Eumetria verneuilana?																			×		
Eumetria? aff. E. vera							×														
Hustedia n. sp																				×	
Hustedia aff. H. multicostata														×							
Orthotetes sp			×															×			
Orthotetes kaskaskiensis										×											
Productus aff. P. adairensis	×		×											×							
Productus aff. P. inflatus					×									×							
Productus ovatus		×		×			×			×				×		×					
Pugnax n. sp																				×	
Pustula aff. P. indianensis																				×	
Rhipidomella aff. R. burlingtonensis														×							
Rhynchopora aff. R. beecheri																	×			×	
Spirifer aff. S. increbescens			×	×		×	×		×	×	×	×	×	×	×		×	×	×		×
Spiriferina aff. S. spinosa							×												×		×
PELECYPODS																					
Aviculipecten sp																	×				
Deltopecten sp						×															
Deltopecten aff. D. occidentalis					×																
Myalina? sp					×																
CRUSTACEANS																					
Phillipsia sp																	×				

Fossils of Pennsylvanian age collected from the Bird Spring formation—Continued

	450–750 feet above the base															
U. S. Geological Survey collection No.	4218a	4218b	4227	4227a	4263	4263a	4217	4217a	4224	4245	4247	4220e	4262	6091	4260b	4222
Author's field No. (see fig. 3)	5c	5d	19a	19b	82a	82b	2a	2b	16a	49	51	11e	81	124	79c	14
PROTOZOA																
Fusulina secalica			×	×			×				×					
CORALS																
Campophyllum sp			×				×						×			
Chaetetes radians	×	×						×				×				
Chaetetes milleporaceus (radians?)																×
Clisiophyllum? sp							×									
Lithostrotion? (Lonsdaleia?) sp										×						
Syringopora sp									×	×						
Syringopora n. sp		×														
Triplophyllum? sp	×						×			×						
Michelinia? sp													×			
Zaphrentis excentrica															×	
ECHINODERMS																
Echinocrinus sp			×				×									
BRYOZOA																
Rhombopora sp						×										
Rhombopora lepidodendroides	×													×		
Stenopora sp					×	×										
Chainodictyon? sp														×		
Cystodictya aff. C. carbonaria														×		
Cystodictya aff. C. morrowensis														×		
Fenestella sp														×		
Pinnatopora aff. P. nerideis														×		
BRACHIOPODS																
Chonetes sp						×										
Chonetes granulifer	×			×												
Cliothyridina orbicularis	×															
Composita aff. C. subquadrata					×	×										
Composita subtilita	×						×	×						×		×
Derbya sp						×						×				
Derbya crassa																×
Dielasma sp														×		
Dielasma n. sp						×										
Hustedia n. sp					×	×										
Hustedia mormoni	×													×		
Marginifera muricata var														×		
Marginifera splendens	×															
Productus coloradoensis														×		
Productus cora var	×													×		
Productus semireticulatus	×															
Pugnoides n. sp					×	×										
Pustula semipunctata				×												
Pustula aff. P. symmetrica														×		
Rhipidomella carbonaria	×															
Spirifer rockymontanus																×
Spirifer triplicatus	×															
Spiriferina aff. S. spinosa					×	×										
Tegulifera sp				×												
PELECYPODS																
Cypricardella n. sp					×	×										
GASTROPODS																
Aclisina sp						×										
Euphemus sp						×										
Holopea sp																×
Meekospira sp						×										
Murchisonia sp						×										
Orthonema sp						×										
Pleurotomaria sp					×											
Pleurotomaria sp. a						×										
Pleurotomaria sp. b						×										
Schizostoma catilloides?										×						
Trachydomia n. sp						×										
Zyglopleura sp						×										

Fossils of Pennsylvanian age collected from the Bird Spring formation—Continued

	750–1,000 feet above the base						1,000 + feet above the base							
U. S. Geological Survey collection No.	4217d	4234	4256	4161a	4218e	4218c	4968b	4261	4218d	4218f	4217e	4238	4238a	4238b
Author's field No. (see fig. 3)	2c	35	70a	80b	5g	5e	99c	80a	5f	5h	2d	39a	39b	39c
PROTOZOA														
Fusulina secalica					×	×		×						
CORALS														
Amplexus sp						×								
Campophyllum sp					×	×								
Chaetetes radians	×										×			
Cladochonus? sp						×								
Syringopora sp					×	×								
ECHINODERMS														
Echinocrinus sp			×	×										×
BRYOZOA														
Polypora sp					×									
Rhombopora lepidodendroides					×									
Stenopora sp												×		×
BRACHIOPODS														
Chonetes sp						×							×	
Chonetes granulifer			×							×				
Chonetes mesolobus												×		
Chonetes mesolobus var														×
Composita subtilita			×	×	×		×		×					×
Crania sp														×
Derbya crassa			×									×	×	
Enteletes hemiplicatus					×									
Hustedia mormoni								×						
Marginifera splendens			×					×						
Meekella straticostata?				×										
Productus cora var														×
Productus semireticulatus								×						
Pugnoides utah								×		×				
Pustula semipunctata			×		×									
Spirifer sp						×								
Spirifer cameratus		×												×
Spirifer rockymontanus	×											×		×
Spirifer triplicatus			×									×		
Spirifer aff. S. increbescens													×	
Squamularia perplexa			×				×			×				
PELECYPODS														
Myalina sp			×											

According to Schuchert[20] and Noble,[21] there is probably an unconformity between the base of the Supai formation in the Grand Canyon and the underlying Redwall limestone (Mississippian). Darton[22] has expressed the opinion that this unconformity is widespread in Arizona.

The Bird Spring formation of the Goodsprings quadrangle seems to be equivalent to the Callville limestone (Pennsylvanian) of the Muddy Mountains.[23] It is too early to make confident correlation with the beds of the Ely and other districts in northern Nevada.

SUPAI FORMATION

Areal distribution.—Beds corresponding in stratigraphic position and lithology to the Supai formation[24] crop out in the valley east of Cottonwood Pass (pl. 8, *A*) and east of Mule Spring Mountain. They are not known in the southern part of the quadrangle.

Lithology.—Where the formation is exposed in sec. 13, T. 23 S., R. 58 E., the following section was measured:

Section of Supai formation in sec. 13, T. 23 S., R. 58 E.

	Feet
Kaibab limestone.	
Supai formation:	
Sandstone, buff, massive	5
Shale, gray to buff	6
Sandstone, reddish and buff	4
Shale, red, sandy	70
Gypsum	6
Shale, red, sandy	50
Gypsum	5
Shale, red, sandy	20
Gypsum	4
Shale, red, sandy	25
Gypsum	4
Shale, red, sandy	20
Gypsum	4
Shale, red, sandy	20
Limestone, gray	1
Sandstone, pale reddish, cross-bedded	460
Sandstone, pale reddish, calcareous, sandy	12
Shale, red, sandy; weathers to thin plates	55
Sandstone, red, massive	12
Shale, red, sandy; weathers to thin plates	55
Sandstone, red, massive	12
Shale, red, sandy, weathers to thin plates	25
Sandstone, olive-green, calcareous	5
Shale, red, sandy	75
Limestone, pale greenish, sandy; beds largely about 5 inches thick, separated by shale	45
Covered	150
Bird Spring formation.	
	1, 150

The massive sandstone at the middle of the formation is uncommonly homogeneous in color and size of constituent grains. In the single specimen examined closely the grains were largely quartz and ranged from 0.2 to 0.5 millimeter in diameter. The sandstone is made up of beds that largely range from 2 to 20 feet in thickness, although one is 40 feet thick. In detail, each bed is made up of lenses, each of which in turn is made up of thin laminae that dip more steeply than the true bedding. The same kind of cross-bedding is present in the Aztec sandstone. (See p. 35.) The color seems to be due to red clay washed down from the overlying shale. Where this sandstone has been traced northward from this area, it becomes thin and inconspicuous. East of Mule Spring Mountain it was not recognized, but the middle part of the formation contains considerable thin-bedded red sandstone.

The gypsum beds of the upper part of the formation have been explored by prospects in the region north and east of the Goodsprings quadrangle. No fossils were found in any part of the formation in this region.

Age and correlation.—The correlation of the Supai formation in this region is based on the lithology and fossil content of the overlying Kaibab limestone and underlying Pennsylvanian limestones.

The massive sandstone at the middle of the formation bears a close resemblance to the Coconino sandstone of western Arizona, and a correlation with that formation was at first considered possible. The recent work of Reeside and Bassler,[25] however, shows clearly that the Coconino sandstone thins steadily westward from the Grand Canyon region and that in the Muddy Mountains its identity is lost.[26] The exposures in the Goodsprings region are not good enough to permit the recognition of an unconformity in the beds mapped as Supai formation, such as that found by Noble[27] in the Grand Canyon and considered to mark the base of the overlying Hermit shale. All the Permian beds beneath the Kaibab limestone in the Goodsprings quadrangle are therefore assigned to the Supai formation.

KAIBAB LIMESTONE

Areal distribution.—Exceptionally complete and good exposures of the Kaibab limestone are shown along the north end of the Bird Spring Range, east of Cottonwood Pass, and in Mule Spring Mountain. Several isolated hills southward from Cottonwood Pass along the east front of the range display parts of the formation. The exposures of Mule Spring Mountain are the most western thus far known of this formation, which is so widely distributed in the southwestern part of the United States.[28]

[20] Schuchert, Charles, The Cambrian of the Grand Canyon of Arizona: Am. Jour. Sci., 4th ser., vol. 45, p. 358, 1918.

[21] Noble, L. F., A section of the Paleozoic formations of the Grand Canyon at the Bass trail: U. S. Geol. Survey Prof. Paper 131, pp. 57–59, 1923.

[22] Darton, N. H., A résumé of Arizona geology: Arizona Univ. Bull. 119, p. 80, 1925.

[23] Longwell, C. R., Geology of the Muddy Mountains, Nev.: Am. Jour. Sci., 5th ser., vol. 1, pp. 46–47, 1921.

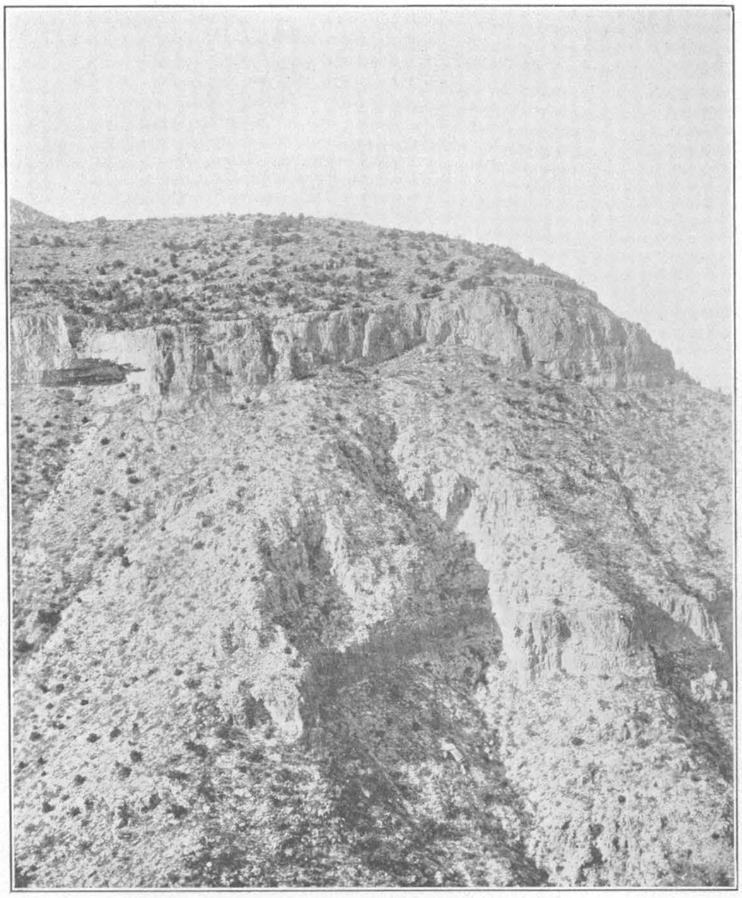
[24] Darton, N. H., A reconnaissance of northwestern New Mexico and northern Arizona: U. S. Geol. Survey Bull. 435, p. 25, 1900.

[25] Reeside, J. B., jr., and Bassler, Harvey, Stratigraphic sections in southwestern Utah and northwestern Arizona: U. S. Geol. Survey Prof. Paper 129, pp. 53–77, 1922.

[26] Longwell, C. R., op. cit., p. 48.

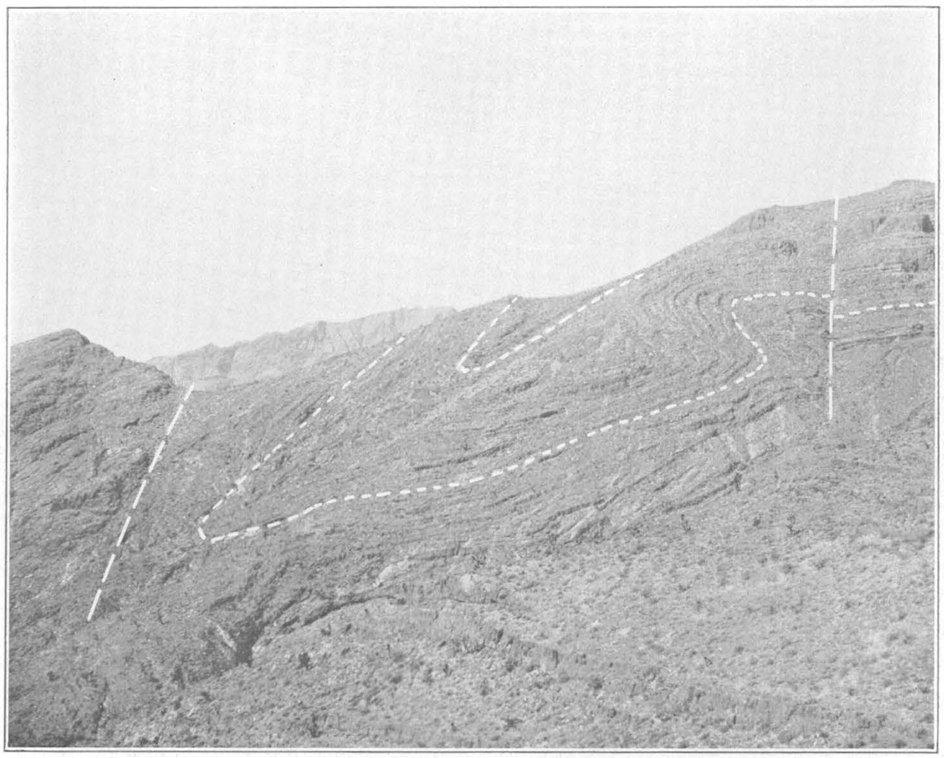
[27] Noble, L. F., A section of the Paleozoic formations of the Grand Canyon at the Bass trail: U. S. Geol. Survey Prof. Paper 131, p. 63, 1922.

[28] Gregory, H. E., and Noble, L. F., Notes on a geological traverse from Mohave, Calif., to the mouth of San Juan River, Utah: Am. Jour. Sci., 5th ser., vol. 5, pp. 229–238, 1923.



A. VIEW NORTHWEST TOWARD RIDGE IN S. ½ SEC. 4, T. 23 S., R. 58 E.

The spur is capped by the sandstone at the base of the Bird Spring formation. The prominent cliff is the Yellowpine limestone, the top member of the Monte Cristo limestone, underlain successively by the Arrowhead limestone, Bullion dolomite, and Anchor limestone members.

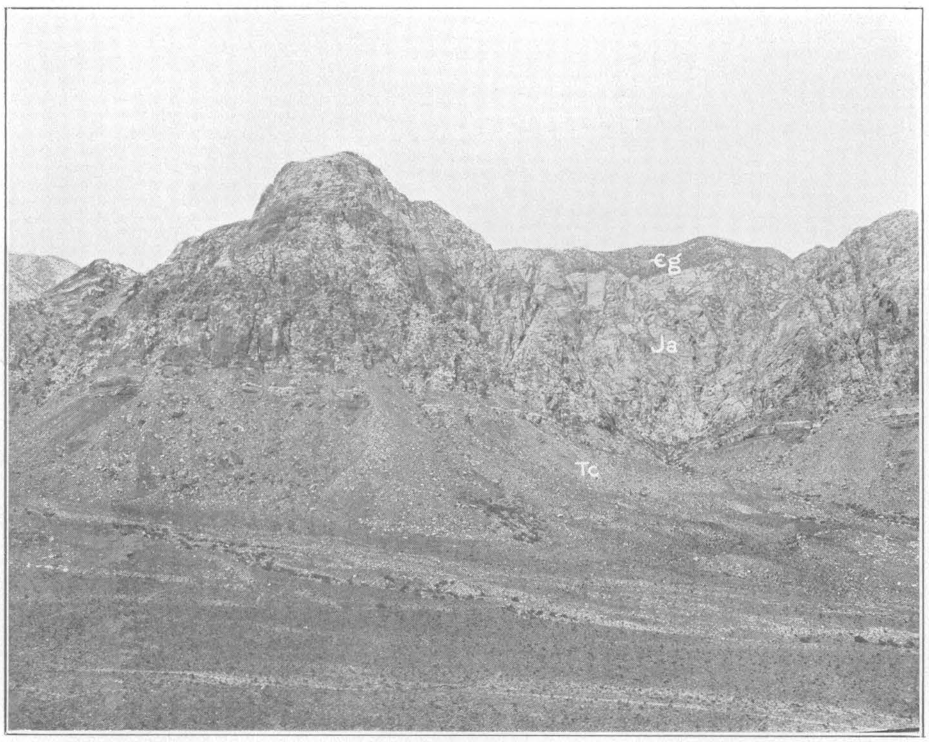


B. LIMESTONES OF THE LOWER PART OF THE BIRD SPRING FORMATION IN SEC. 16, T. 25 S., R. 58 E.

These closely folded limestones are adjacent to the Puelz thrust fault, which crosses the low saddle on the left. The Bullion dolomite forms the hill on the extreme left.

A. SUPAI FORMATION OVERLAIN BY THE KAIBAB LIMESTONE EAST OF COTTONWOOD PASS, IN SEC. 13, T. 23 S., R. 58 E.

The conspicuous sandstone, 460 feet thick, forms the middle part of the Supai formation. It is overlain successively by gypsum-bearing sandy shale at the top of that formation and the two massive beds of limestone of the Kaibab limestone. Potosi Mountain in the distance.



B. AZTEC SANDSTONE (Ja) OVERLYING CHINLE FORMATION (Tc) IN SEC. 22, T. 22 S., R. 58 E.

The Aztec sandstone is overlain by thin-bedded dolomite of the Goodsprings formation (€g), from which it is separated by the Keystone thrust fault. (Compare with pl. 14, *A*.)

Lithology and thickness.—In this region a group of beds correlated with the Kaibab limestone of northern Arizona is separable into three members. Each member appears to have the same general character and approximate thickness throughout the quadrangle. From the base upward these members consist of massive limestone with some sandstone, 200 to 230 feet thick; sandstone with some shale, 20 to 30 feet thick; and massive limestone, 200 to 210 feet thick.

The following section of the basal part of the formation was measured in the escarpment east of Cottonwood Pass. (See pl. 8, *A*.)

Section of basal part of Kaibab limestone in the N. ½ sec. 24, T. 23 S., R. 58 E.

	Feet
Limestone, gray, massive bed, highly fossiliferous	30
Limestone, gray; traces of bedding	60
Dolomite, light gray; few chert concretions	25
Limestone, gray, in beds 10 to 25 feet thick, with several beds of lighter dolomite	80
Sandstone, buff; some iron concretions	8
Limestone, gray, sandy, massive	30
	233

Most of the species recorded in the fossil list below were collected from the uppermost bed of this part of the Kaibab limestone. Almost every species recorded is present at the same horizon in the low hill in sec. 6, T. 25 S., R. 59 E. This part of the limestone makes the conspicuous ledge shown in Plate 8, *A*.

The middle part of the Kaibab limestone is largely pale yellowish-brown sandstone, although locally the color is red, and thin zones of sandy shale are present. In the S. ½ sec. 14, T. 24 S., R. 58 E., where two prospect pits have been sunk in search of carnotite,[20] this zone is 20 feet thick and is made up of 5 feet of yellowish sandstone below and 15 feet of dark-red shaly sand stoneabove. In the N. ½ sec. 31, T. 22 S., R. 59 E., the sandstone beds are 30 feet thick.

The uppermost part of the Kaibab limestone is a rather massive bed of gray limestone from 200 to 210 feet thick. It is interrupted only by inconspicuous bedding planes. By contrast with the lower limestone member it contains considerable chert, especially near the top. As this bed resists erosion and is overlain by soft shale, it commonly underlies dip slopes that are thickly strewn with angular fragments of reddish chert. Such surfaces are present on the west flank of the Bird Spring Range east of Cottonwood Pass, southwest of Goodsprings, and in sec. 6, T. 25 S., R. 59 E.

In this bed the chert forms a few thin but persistent layers parallel to the bedding, as well as zones of small nodules. These yield numerous fossils but not the range of species found near the top of the middle member.

[20] Hewett, D. F., Carnotite in southern Nevada: Eng. and Min. Jour. Press, vol. 115, pp. 232-235, 1923.

Section in the SE. ¼ sec. 21, T. 22 S., R. 57 E., Mule Spring Mountain

	Feet
Kaibab limestone:	
Limestone, gray, massive; many chert lenses 3 to 6 inches thick	200
Limestone, yellowish, sandy	15
Dolomite, gray	60
Limestone, gray, massive	160
Dolomite, light gray	8
Limestone, gray, massive	50
Limestone, gray, cherty	3
Sandstone, yellowish, calcareous	4
Limestone, reddish, sandy	5
Sandstone, yellowish, calcareous	20
Sandstone, red, shaly	5
Limestone, gray	1
Sandstone, red, shaly	20
Limestone, gray	4
Supai formation: Shale, red, sandy; base concealed.	
	555

Section of Kaibab limestone in the NW. ¼ sec. 31, T. 22 S., R. 59 E.

	Feet
Limestone, gray to faint reddish, weathering brownish, cherty, locally brecciated; many fossils	210
Limestone, gray, heavily iron stained, without chert; few thin layers of brick-red sandstone	30
Dolomite, white, without chert	10
Limestone, gray to bluish gray; sparse layers of chert; in massive beds about 5 feet thick	160
	410

Fossils.—The fossils listed below were collected from the limestone beds of the Kaibab limestone. Most of the species came from the upper portion of the lower limestone member.

Fossils collected from the Kaibab limestone

[Identifications by G. H. Girty, U. S. Geological Survey]

	Goodsprings quadrangle	Darton, Grand Canyon[a]	Longwell, Muddy Mountains[b]	Reeside, southwestern Utah and northern Arizona[c]
Sponge	×			
BRYOZOANS				
Amplexus sp	×			
Fistulipora sp	×		×	
Stenopora sp	×			
Leioclema sp	×			×
Fenestella, several sp	×			×
Polypora sp	×			×
Septopora sp	×			×
Phyllopora n. sp	×		×	
BRACHIOPODS				
Derbya? sp	×		×	×
Meekella pyramidalis	×	×		×
Chonetes sp	×			
Productus ivesi	×	×	×	×
Productus occidentalis	×	×	×	×
Productus mexicanus?	×			

[a] Darton, N. H., A reconnaissance of parts of northwestern New Mexico and northern Arizona: U. S. Geol. Survey Bull. 435, p. 30, 1910.
[b] Longwell, C. R., op. cit., p. 48.
[c] Reeside, J. B., and Bassler, Harvey, Stratigraphic sections in southwestern Utah and northwestern Arizona: U. S. Geol. Survey Prof. Paper 129, pp. 66-67, 1922.

Fossils collected from the Kaibab limestone—Continued

	Goodsprings quadrangle	Darton, Grand Canyon	Longwell, Muddy Mountains	Reeside, southwestern Utah and northern Arizona
BRACHIOPODS—continued				
Productus sp	×	×	------	------
Pustula aff. P. horrida	×	------	------	×
Pustula subhorrida	×	------	×	×
Pustula subhorrida var. rugatula	×	------	------	------
Pustula aff. P. humboldti	×	------	------	------
Aulosteges? sp	×	------	------	------
Rhynchopora? sp	×	------	------	------
Camarophoria sp	×	------	------	------
Squamularia	×	------	×	×
Spiriferina campestris	×	×	------	------
Composita subtilita	×	------	×	×
PELECYPODS				
Deltopecten coreyanus	×	------	------	------
Deltopecten sp	×	------	------	------
Deltopecten aff. D. mccoyi	×	------	------	------
Acanthopecten coloradoensis	×	------	×	×
Pseudomonotis sp	×	------	------	×

Age and correlation.—The fauna and lithologic features of the Kaibab limestone are so distinctive that no uncertainty is attached to correlation with characteristic exposures in northwestern Arizona and southwestern Utah.

The number of members and the general character of each bear a close resemblance to those recorded by Reeside in southwestern Utah[30] except that the uppermost Harrisburg gypsiferous member of that region is absent in Nevada. Nearly the same divisions were observed also by Longwell[31] in the Muddy Mountains.

TRIASSIC SYSTEM

MOENKOPI FORMATION

Areal distribution.—In this region the Moenkopi formation consists of three distinct members—at the base a member composed of conglomerate and associated red shale approximately 150 feet thick; a middle member of thin-bedded buff sandy limestone and dolomite, which attains a maximum thickness of 600 feet; and an uppermost member of red sandy shale, of undetermined thickness but probably not exceeding 200 feet, which 2 miles west of Goodsprings is represented by tuff and conglomerate containing igneous pebbles. The best exposures of the beds occur in the belt that extends from Cottonwood Pass northeastward to the corner of the quadrangle. They also crop out for several miles west of Goodsprings, and 466 feet of beds crop out between the top of the Kaibab limestone and the Keystone fault in the NW. ¼ sec. 6, T. 25 S., R. 59 E. The formation is not known on the west side of this part of the Spring Mountains.

[30] Reeside, J. B., jr., and Bassler, Harvey, op. cit., pp. 58–59.

[31] Longwell, C. R., op. cit., p. 48.

Only small parts of the uppermost shale member are exposed, but in several localities, as on the north border of the quadrangle and in the valley south of the Lavina mine, the uppermost limestone of the Moenkopi formation is overlain by red shale. Above this lie two beds of coarse conglomerate which are correlated with the Shinarump conglomerate of western Utah and Arizona. In the areas where this conglomerate was observed the rocks are so much folded that no close measurements of the thickness of the underlying red shale could be made.

According to Longwell,[32] there is an unconformity at the base of the Moenkopi formation on the north slope of the Spring Mountains. Conclusive evidence of an unconformity has not been found in the Goodsprings area, but the sporadic conglomerate at the base is highly suggestive that one is present.

Lithology.—The conglomerate at the base of the Moenkopi formation is present a mile northeast of Cottonwood Pass and 1,000 feet east of Goodsprings, but it is absent in the hills southeast of Cottonwood Pass and 2 miles southeast of Goodsprings.

Section of basal conglomeratic beds of the Moenkopi formation 1,000 feet east of Goodsprings, Nev.

	Feet
Limestone, buff, thin bedded, and sandy shale, red, sandy	40
Limestone, buff; weathers to plates 1 and 2 inches thick; sparse pebble zones	20
Limestone, buff, sandy, cross-bedded; sporadic chert pebbles, largest 1 inch in diameter	3
Limestone, buff to pale reddish, in beds 6 to 12 inches thick; sporadic pebble zones	8
Sandstone, cross-bedded	4
Covered (shaly sandstone?)	2
Conglomerate, cross-bedded; chert pebbles one-half to 1 inch in diameter	3
Sandstone, lime matrix, cross-bedded	2
Conglomerate, more chert than lime; pebbles range in size from one-half to 1½ inches, subangular; sandy lime matrix; persistent	3
Sandstone, cross-bedded, lime matrix	2
Sandstone, conglomeratic; about one-third is composed of lenses of angular chert and lime pebbles one-fourth to 1 inch	3
Conglomerate, massive bed, with few layers of sand; largely rounded lime pebbles one-half to 2 inches	15
Kaibab limestone.	
	105

Southeast of Cottonwood Pass the lowest member of the Moenkopi is made up of a zone of red shale about 75 feet thick, which rests upon the upper limestone bed of the Kaibab limestone. It is overlain by a less persistent zone of greenish-gray shale, also about 75 feet thick. Both zones are well exposed in the SW. ¼ sec. 24, T. 23 S., R. 58 E., east of bench mark 4649. The lower red shale crops out southwest of Goodsprings, and it is present in many wells in the

[32] Longwell, C. R., Pre-Triassic unconformity in Nevada: Am. Jour. Sci., 5th ser., vol. 10, p. 93, 1925.

town. Other wells in the town show the green shale, but it is thinner here than farther north.

The middle member of the Moenkopi is made up of buff sandy limestone and dolomite that largely range from 1 to 5 feet in thickness but locally attain 10 feet. These limestone beds are separated by thin beds of gray and greenish shale. Here and there, especially near the top, the limestones are highly fossiliferous, the star-like plates of *Pentacrinus* being sufficiently widespread to permit the identification of isolated outcrops.

By contrast with most of the Paleozoic limestones, those of the Moenkopi formation are uniformly sandy and sufficiently rich in iron to yield buff to light-brown material by weathering. The content of sand is shown on outcrops by persistent lamination of even the massive layers. One specimen collected in the upper part of the limestone member, in the SE. ¼ sec. 13, T. 22 S., R. 58 E., yielded by solution in hydrochloric acid about 25 per cent of sand. Nearly all the sand grains were quartz, were subangular in form, and ranged from 0.01 to 0.03 millimeter in diameter. Traces of chlorite were present, but feldspars were conspicuously absent. Chert nodules are very uncommon in the formation.

About a mile south of the Lavina shaft, north of the center of sec. 28, T. 24 S., R. 58 E., there are two small exposures of tuffaceous rock and conglomerate of igneous pebbles whose relations are obscure but which are tentatively placed in the Moenkopi formation. Both areas are narrow belts that lie along the north sides of shallow ravines, and each is entirely surrounded by wash. It can only be said with assurance that the beds overlie the limestone member of the Moenkopi and underlie the Shinarump conglomerate. The most abundant material is highly indurated greenish-gray tuff, which shows small white grains of feldspar. Thin sections of the material show that it is made up of angular grains that largely range from 0.05 to 0.25 millimeter in diameter. About one-fourth of the grains are brownish glass, and the remainder are oligoclase, orthoclase, and to a less degree biotite. The prevailing strike of the largest exposure is S. 60° W., and the dip 70° S. The dip accords with that of near-by outcrops of Moenkopi limestone, but the strike is different. There can be no doubt that these beds have participated in the folding that deformed the rest of the Moenkopi formation.

South of the belt of tuffs, and therefore overlying them, are exposed several lenses of conglomerate in which the well-rounded cobbles largely range from 3 to 6 inches, although a few exceed 10 inches in diameter. Most of the cobbles are composed of reddish trachyte flow, but a few are indurated breccia. Many pebbles show sporadic alteration to epidote and are therefore green. This alteration clearly took place before the cobbles were rounded by erosion.

Considerable interest is attached to the presence of volcanic material in the early Mesozoic rocks of this region, and it is unfortunate that the exposures are isolated instead of exposed in a continuous section. So far as the writer is aware, the only persistent beds of igneous rocks are the volcanic clays that overlie the Shinarump conglomerate in southern Utah. These clays have attracted attention because they contain small quantities of gold.[33] Microscopic examination of the material by the writer indicates that it is a variety of bentonite and probably a decomposed tuff.

In contrast with these rocks, the Tertiary tuffs of this region have a different composition, show a different type of alteration, and have lower angles of dip. There seems to be but slight chance that these rocks are of Tertiary age. (See p. 40.)

According to H. G. Ferguson,[34] there is near Candelaria, Nev., a great thickness of andesitic tuffs which probably overlie slate and sandstone of Lower Triassic age. There is a fair possibility that these tuffs were deposited contemporaneously with the tuffs and conglomerates of the Moenkopi formation of the Goodsprings quadrangle.

Fossils.—Fossils are common in the limestones of the formation, but the number of species is not large.

Fossils collected from the Moenkopi formation in the Goodsprings district and neighboring areas

[Identifications by G. H. Girty, U. S. Geological Survey]

	Goodsprings quadrangle	Longwell, Muddy Mountains [a]	Reeside, southwestern Utah [b]
Pentacrinus asteriscus	×		
Solenomya? sp	×		
Aviculipecten utahensis?	×	×	
Aviculipecten utahensis? (in part)	×		
Aviculipecten aff. A. parvulus	×		
Myalina n. sp	×	×	×
Pseudomonotis? sp	×	×	×
Bakewellia? n. sp	×		×
Myophoria ambilineata	×		
Myophoria n. sp	×	×	
Pleurophorus? sp	×	×	×
Sphaera whitneyi?	×		
Laevidentalium? sp	×		
Naticopsis? sp	×		×
Macrocheilina angulifera	×		

[a] Longwell, C. R., Geology of the Muddy Mountains, Nev.: Am. Jour. Sci., 5th ser., vol. 1, p. 50, 1921. See also U. S. Geol. Survey Bull. 798, p. 45, 1928.
[b] Reeside, J. B., jr., and Bassler, Harvey, op. cit., p. 67.

Correlation.—The Moenkopi formation (originally spelled Moencopie) was named by Ward,[35] who applied the name to a group of red and brown shales and sandstones in northern central Arizona, overlying the "Upper Aubrey" (Kaibab) limestones and underlying the Shinarump conglomerate. More recent work by

[33] Lawson, A. C., The gold of the Shinarump at Paria, Utah: Econ. Geology, vol. 8, pp. 434–448, 1913.

[34] Personal communication.

[35] Ward, L. F., Geology of the Little Colorado Valley: Am. Jour. Sci., 4th ser., vol. 12, p. 403, 1901.

Reeside and Bassler, Noble, and Shimer has resulted in tracing the formation 200 miles westward into northwestern Arizona and southwestern Utah. All these geologists are agreed that the proportion of limestone steadily increases westward and that the shale and sandstone decrease. The character and thickness of the beds here referred to the Moenkopi formation indicate that this tendency continues at least 50 miles westward into southern Nevada. Similarly, the conglomeratic material at the base of the Moenkopi formation east of Goodsprings is in harmony with sporadic conglomerates at the base farther east and is consistent with the interpretation that there is a widespread unconformity at the base.

The three members of the Moenkopi formation in the Goodsprings region appear to correspond with the lowest three of the five members recognized by Reeside and Bassler in southwestern Utah,[36] the Virgin limestone member of Utah probably corresponding with the middle member of the Goodsprings region.

The Moenkopi formation is everywhere classified as of Lower Triassic age.

SHINARUMP CONGLOMERATE

In the neighborhood of the Lavina mine there are several outcrops of limestone and chert conglomerate which, though isolated, are sufficiently similar to justify the assumption that they are essentially the same bed or group of beds. In one locality 3,000 feet northeast of the Lavina shaft there are assuredly two beds, a lower 4 feet thick and an upper 5 to 8 feet thick, separated by 20 feet of sandy shale. Both are traceable 500 feet on the surface, although the adjacent rocks are largely concealed by wash. The beds strike N. 40° W. and dip 35° SW. Similarly, 1,500 feet northwest of the Lavina shaft, two beds that strike N. 10° W. and dip 35° W. locally project through the wash. On the other hand, there are several outcrops southwest of the Lavina shaft, one of which may be traced almost without interruption a distance of 2,500 feet, and at each locality there appears to be but one bed 10 to 15 feet thick.

The conglomerate contains lenses of coarse pebbles 3 to 4 feet thick in which 60 to 75 per cent of the mass consists of well-rounded pebbles 1 to 3 inches in diameter. The largest pebble observed was 5 inches in diameter. The Paleozoic limestones and dolomites are most abundantly represented, but there are also pebbles of black chert and red sandstone. The matrix is dark-brown sand. No igneous material was found in the conglomeratic beds.

There is considerable uncertainty concerning the correlation of this conglomerate with beds in the near-by regions that have been studied. The relations to overlying and underlying beds, however, indicate that it occupies the position of the Shinarump conglomerate in southwestern Utah described by Reeside and Bassler.[37] On the other hand, the rocks represented in the pebbles differ greatly in the two regions. These differences are reconcilable, however, if the pebbles have a local origin, as they appear to have near Goodsprings. The conglomerate beds indicate simultaneous local warping in the general region. On the whole there seems to be little doubt that these beds correspond to the Shinarump conglomerate, and they are therefore designated by that name. There is some doubt as to whether the Shinarump conglomerate is of Upper or Middle Triassic age, and it is at present classified by the United States Geological Survey as Upper (?) Triassic.

CHINLE FORMATION

In this region the Chinle formation, of Upper Triassic age, consists largely of red shaly sandstone and yellowish-brown sandstone with several beds of chert and limestone conglomerate. Except for the small section locally exposed above the Shinarump conglomerate south of the Lavina mine, the basal part of the formation does not crop out here. Where there is apparently conformable succession from the Moenkopi formation to the Aztec sandstone north of Rose Tank, the upper part is well exposed. (See pl. 8, *B*.)

Section of Chinle formation from the E. ½ sec. 15 to the W. ½ sec. 14, T. 22 N., R. 58 E.

	Feet
Aztec sandstone.	
Chinle formation:	
Sandstone, red, shaly	20
Sandstone, white, persistent	15
Sandstone, red, shaly, thin-bedded	450
Shale, chocolate-brown	5
Sandstone, yellowish brown, with sporadic chert pebbles; persistent; makes ledge	35
Shale, brown	10
Conglomerate, brownish, made up of chert pebbles ranging from one-eighth to 2½ inches in maximum diameter	10
Shales, red and olive-green	60
Conglomerate, chert, mostly of grains less than one-fourth inch in diameter	3
Shale, red	15
Conglomerate, made up of rounded limestone grains that are largely less than one-fourth inch in diameter	4
Shale, reddish and olive-green	100
Shale, red, sandy	100+
	827+

The olive-green shale near the base of the section closely resembles a variety of impure bentonite that is common in the Cretaceous of western Wyoming. Consequently, a specimen was disintegrated in water and examined under a microscope. The grains largely range from 0.02 to 0.06 millimeter, but a few are 0.1 millimeter in diameter. Subangular chert grains are

[36] Reeside, J. B., jr., and Bassler, Harvey, op. cit., p. 59.

[37] Reside, J. B., jr., and Bassler, Harvey, op. cit., p. 62.

most abundant; calcite is next; then quartz, but there are only traces of feldspar, and microcline is the most common variety. It is thus clear that the material is largely the waste from a limestone region, probably eroded under arid conditions, and not a decomposed volcanic ash, like bentonite. Fragments of fossil wood from 5 to 10 inches long are not uncommon in the zone above the chert conglomerate.

There can be little doubt that the base of the overlying Aztec sandstone in the region north of the Arden road (see pl. 8, *B*) is the same as that exposed near the base of the two ridges east of the Contact mine, as the underlying 50 feet of beds are nearly identical.

JURASSIC (?) SYSTEM

AZTEC SANDSTONE

Areal distribution.—The beds here named Aztec sandstone crop out in two areas, forming the impressive bluffs northwest of Rose Tank and the two parallel ridges east of the Contact mine. The name is derived from Aztec Tank, a natural depression in the sandstone several hundred feet east of the Contact mine, in which water accumulates at times of heavy rain.

Lithology.—This sandstone is an uncommon rock unit because, throughout its thickness, 2,100 feet at the northern border of the quadrangle, it is almost uniform in texture and lacks the parallel bedding planes characteristic of such sediments; trustworthy observations on dip are very hard to find. This great thickness is made up of many lenses, mostly from 10 to 25 feet thick. Each lens in turn is made up of smaller laminae one-half to 2 inches thick. In the horizontal cross section of a group of lenses the strikes of the laminae of adjacent lenses commonly diverge as much as 40°. By contrast, the dips are nearly constant, although slightly steeper than the average dip of the larger units. In cross section these laminae end abruptly against the next higher lens. The outcrops closely resemble that of the Jurassic sandstone 12 miles north of St. George, as shown by Reeside and Bassler.[38]

The color is uncommonly uniform throughout the thickness. It ranges through several shades of buff to pale reddish. A mile north of the quadrangle there is a lens of brilliant red sandstone, 250 to 300 feet thick and 2,500 feet long, in the midst of the mass of rock of average color. Such features may be observed on a much smaller scale here and there and lead to the conclusion that the average color was originally much redder, but that the ferric oxide which caused it has been largely dissolved and leached out, probably before the beds were exposed at the surface.

The Aztec sandstone rests on the shaly sandstone of the Chinle formation. In both areas where it is exposed in the quadrangle the upper limit is a thrust fault—the Contact fault south of Cottonwood Pass and the Keystone fault north of Cottonwood Pass. A careful examination indicates that the Keystone thrust cuts across the bedding of the Aztec sandstone at a low angle, both in strike and in dip. This relation suggests that the upper limit of the sandstone is a surface of erosion, across which the overlying Cambrian dolomites were thrust. It is difficult to imagine that a fault could cut across so massive a sandstone so near to a bedding surface and yet not coincide with that surface.

Age and correlation.—In the absence of any fossils in the sandstone it is necessary to depend upon stratigraphic correlation in order to reach a tentative conclusion concerning the age of the formation. There seems to be little doubt that this sandstone is the same as that observed by Longwell[39] in the Muddy Mountains, 45 miles northeast of Goodsprings, and by Reeside and Bassler[40] near St. George, Utah, 100 miles farther northeast. In the latter region this sandstone is regarded as Jurassic, but its correlation with a similar formation in regions still farther east is uncertain.

REGIONAL RELATIONS OF THE GOODSPRINGS SECTION

In the preceding descriptions of the Paleozoic and Mesozoic formations that crop out in the Goodsprings quadrangle, tentative correlations of each with similar formations in the Southwest have been suggested. These correlations indicate that the formations of the upper Paleozoic and Mesozoic in southern Nevada bear close resemblance to those in northern Arizona and southern Utah. The same resemblance of the basal beds of the Goodsprings section (Tapeats sandstone and Bright Angel shale) may be found for beds at the base of the Paleozoic in northern Arizona. The intervening beds have similar lithology in the two regions but are appreciably thicker in the Nevada section. If the effects of erosion at unconformities are ignored, the Paleozoic beds of the Grand Canyon area are about 4,000 feet thick, whereas those at Goodsprings are about 8,500 feet thick.

The nearest region westward from Goodsprings within which stratigraphic sections have been carefully measured is that of the Inyo Range, Calif.[41] As little areal geologic work has been done in the intervening area, 165 miles wide, it is too early to hazard more than tentative correlations of systems, which are shown on Figure 4. This diagram shows in an impressive way that the tendency of the Paleozoic formations toward thickening westward continues northwest of Goodsprings. The systems of the

[38] Reeside, J. B., jr., and Bassler, Harvey, Stratigraphic sections of southwestern Utah and northwestern Arizona: U. S. Geol. Survey Prof. Paper 129, pl. 11, *B*, 1922.

[39] Longwell, C. R., Geology of the Muddy Mountains, Nev.: Am. Jour. Sci., 5th ser., vol. 1, p. 51, 1921.

[40] Reeside, J. B., jr., and Bassler, Harvey, op. cit., pp. 63-64.

[41] Knopf, Adolph, A geologic reconnaissance of the Inyo Range and the eastern slope of the Sierra Nevada, Calif.: U. S. Geol. Survey Prof. Paper 110, 1918.

Paleozoic that are represented by 8,500 feet at Goodsprings are represented by more than 17,000 feet of beds in the Inyo Range, and lower Paleozoic formations not represented at Goodsprings are 1,000 feet thick in the Inyo Range. This difference tends to confirm the conclusion of Schuchert[42] that in Paleozoic time there was in east-central Nevada a trough trending northeast, the Cordilleran geosyncline, which received much more sediment than the region to the southeast.

POST-JURASSIC ROCKS

The rocks of this region that are younger than the Aztec sandstone fall readily into three groups, but as they contain no fossils definite age assignments can not be given to them. From what is known of the geology of several areas as much as 200 miles distant, however, it seems possible to estimate their ages approximately. These units include (1) intrusive igneous rocks of two varieties; (2) bedded tuffs, breccias, dikes, and flows of volcanic rock; (3) consolidated and unconsolidated gravel and boulders. The tuffs, breccias, and flows are considered to be related to near-by volcanic necks to which a middle Tertiary age is assigned, probably upper Miocene, and they are therefore herein classified as Miocene (?). (See p. 40.) The gravel and boulders are distinctly younger and are considered so be of Pleistocene age.

IGNEOUS ROCKS

GENERAL FEATURES

Although igneous rocks are widespread in Nevada and locally cover enormous areas, they are not a conspicuous feature of the Spring Mountains. They are wholly lacking in the high part of the range for many miles north of the Goodsprings quadrangle but are found sporadically in the quadrangle and farther south.

In general, igneous rocks may be considered and described from several points of view, such as petrographic character, texture, and geologic age. In a region where economic studies are being made, however, they are best considered according to their relative age, especially whether they appeared in or on the crust before or after the ore deposits. In some places the evidence of their relation to the near-by ore deposits is good, but elsewhere it is obscure. Hence it is necessary to assume that rocks having similar mineralogic make-up, texture, and alteration probably belong to the same epoch.

From the standpoint of the mineralogist the igneous rocks of the Goodsprings quadrangle present many varieties, but in an economic report there is little to be gained by distinguishing these exhaustively. They are therefore separated here into two groups—an early group, which is wholly crystalline and largely coarse grained, and a later group, which contains some crystals in a glassy matrix and is rather fine grained. The geologic relations, especially those bearing on the place of the groups in the structural and erosional history, indicate that the rocks of the early group were intruded before the ore deposits were formed and that those of the latter group, consisting largely of surface lavas and breccias, were extruded long after the ore deposits were formed and after a long period of erosion had intervened.

The rocks of the early group are separable into two varieties. One of these varieties, here classified as granite porphyry, is a light-colored, rather coarse grained rock that forms a number of dikes and sills in the central part of the quadrangle. The total area underlain by these rocks is limited to several hundred acres. The other variety was noted as small dikes in three mines only, the Singer, Puelz, and Star. It is a dark rock of finer grain than the light-colored rock, and although it shows slight variations in texture and mineral content it is classed as lamprophyre.

The later group of fine-grained igneous rocks includes several varieties that take the form of volcanic necks, dikes, and surface flows. Bedded tuffs are associated with the flows. These rocks range from latite through several varieties of andesite to basalt. They underlie a larger area than the coarse-grained intrusive rocks, but it scarcely exceeds 3 square miles. The area lies in the southern part of the quadrangle and is therefore adjacent to but does not overlap that in which the coarse-grained intrusive rocks occur. The fine-grained intrusive and extrusive rocks are distinctly younger than the coarse rocks and appeared at the surface long after the ore deposits were formed.

EARLY COARSE-GRAINED IGNEOUS ROCKS

Granite porphyry.—Dikes and sills of granite porphyry are common in an area 3 miles wide and 8 miles long that extends from the Boss Extension mine on the northwest nearly to the Lincoln mine on the southeast. None are known in the northern half of the quadrangle nor southwest of Table Mountain. The largest outcrop is that of the Yellow Pine sill, which is about 780 feet thick south of the Yellow Pine mine and was probably once continuous for 3 miles (p. 47). Next in size are the irregular dikes at the Keystone and Lavina mines (pp. 104, 107). The upper surface of the Lavina dike is the Contact thrust, but the Keystone dike cuts across the measures and adjoins the Keystone thrust on the north. The other bodies are simple small dikes, rarely more than 50 feet wide, that are found in a belt of the Goodsprings dolomite which extends from the Keystone mine on the northwest to Crystal Pass on the southeast. This belt lies but a few hundred feet above the Keystone thrust. These dikes uniformly cut across the strike and dip of the inclosing dolomites. The only other

[42] Schuchert, Charles, Sites and nature of the North American geosynclines: Geol. Soc. America Bull., vol. 34, pp. 184-187, 1923.

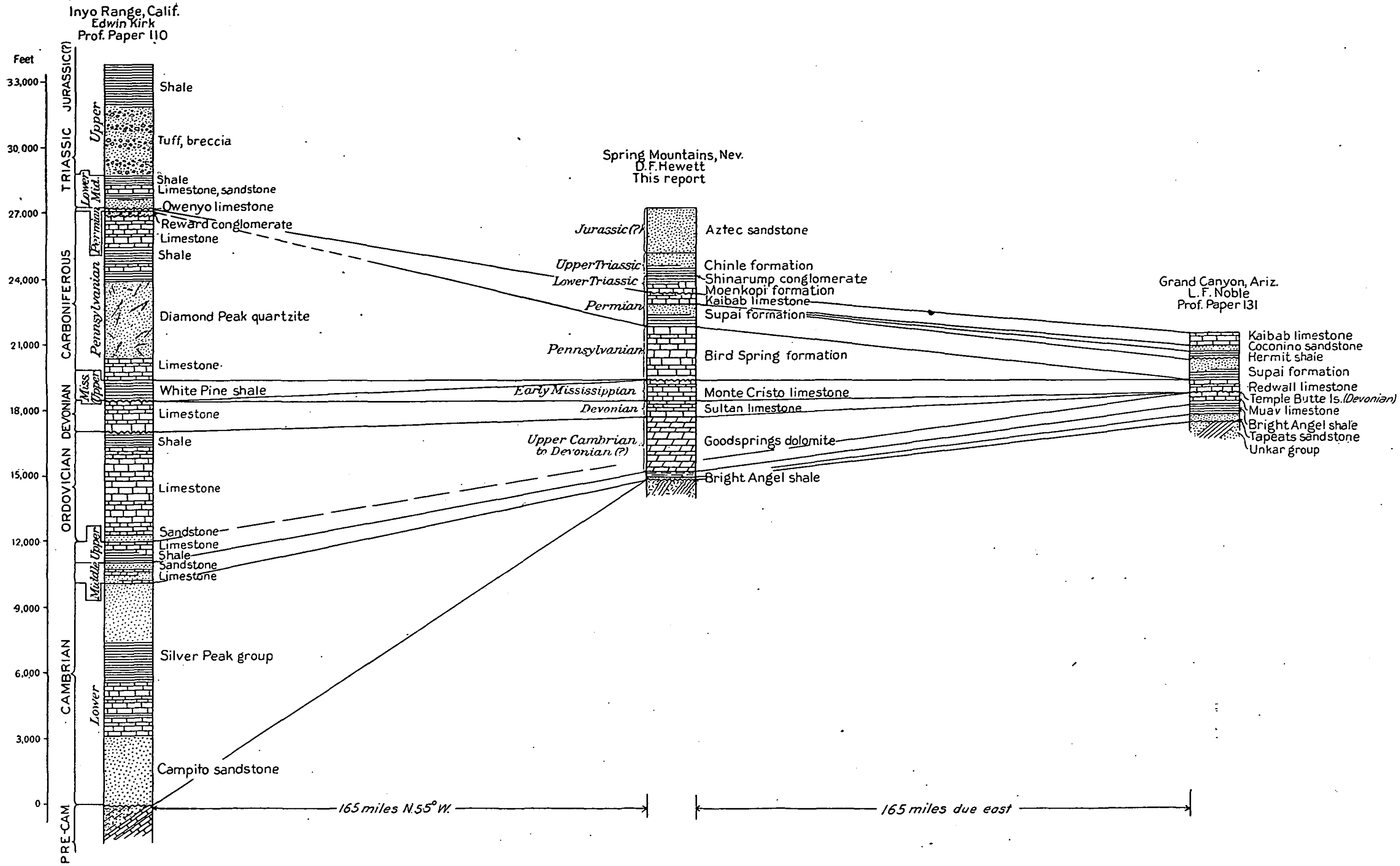


FIGURE 4.—Comparison of thickness of Paleozoic and Mesozoic formations in Inyo Range, Calif., Spring Mountains, Nev., and Grand Canyon, Ariz.

dikes of this variety of rock recognized are those in which the Red Cloud mine lies (p. 103), the dike that extends northeastward from the Alice mine (p. 137), and the one explored in the Boss Extension mine tunnel. One of the drifts near the bottom of the east shaft of the Columbia mine explores a dike of similar rock.

This rock presents only slight variations from the average in composition, texture, and color; the variations in color seem to be due largely to alteration since its intrusion. The only exposures of fresh rock were found in several dikes southeast of Crystal Pass. (See pl. 9, *A*.) Here the rock contains many crystals of orthoclase, as much as 1 centimeter long, in a groundmass of microgranular orthoclase through which iron oxide is dusted. Some of the crystals show zonal growth, and others contain nuclei of aggregates of orthoclase. There are a few rounded aggregates of dark-green biotite, slightly altered to chlorite; these appear in hand specimens. The groundmass contains accessory zircon and apatite. No quartz appears either in hand specimens or in thin sections.

From this dike northwestward all exposures of the rock, surface and underground, are considerably altered; probably the most thoroughly altered is the Yellow Pine sill. The coarsest texture is found in a dike just south of Crystal Pass, which may be traced 750 feet and which attains a maximum width of 30 feet. In the middle part of the dike crystals of reddish-brown orthoclase from 0.5 to 2 inches long make up about one-third of the volume. The crystals separate freely from the matrix, are uncommonly perfect, and present several of the common types of twins, Carlsbad, Baveno, and others. The border zones, 3 to 8 inches thick, are fine grained. There are no dark minerals or quartz in this dike. About 1,500 feet south of this dike is another, 40 feet thick, along which the dolomitized Crystal Pass limestone is altered to serpentine (p. 56).

The dikes of granite porphyry in the belt of Goodsprings dolomite from the Columbia to the Keystone mine crop out in local depressions, and many have been explored by prospects because the record of the Keystone and Red Cloud mines indicated that the rock might be gold-bearing. Underground the rock breaks in angular blocks, but on the dumps these soon disintegrate. This rock is uniformly light colored, either slightly greenish or yellowish, but the texture is obscure.

The Keystone dike is an extremely irregular body that generally cuts across the bedding of the inclosing dolomite but locally conforms with it. In the central part of the body the feldspars are completely altered to a reddish clay, and the matrix is a pale-greenish material. The borders are highly sheared and have lost all trace of texture (p. 106). A tunnel in the dike 1,500 feet south of the Keystone mine reveals angular blocks of dolomite as much as 2 feet in diameter in the porphyry, but they show no alteration. Sparse crystals of quartz were noticed in the Keystone dike.

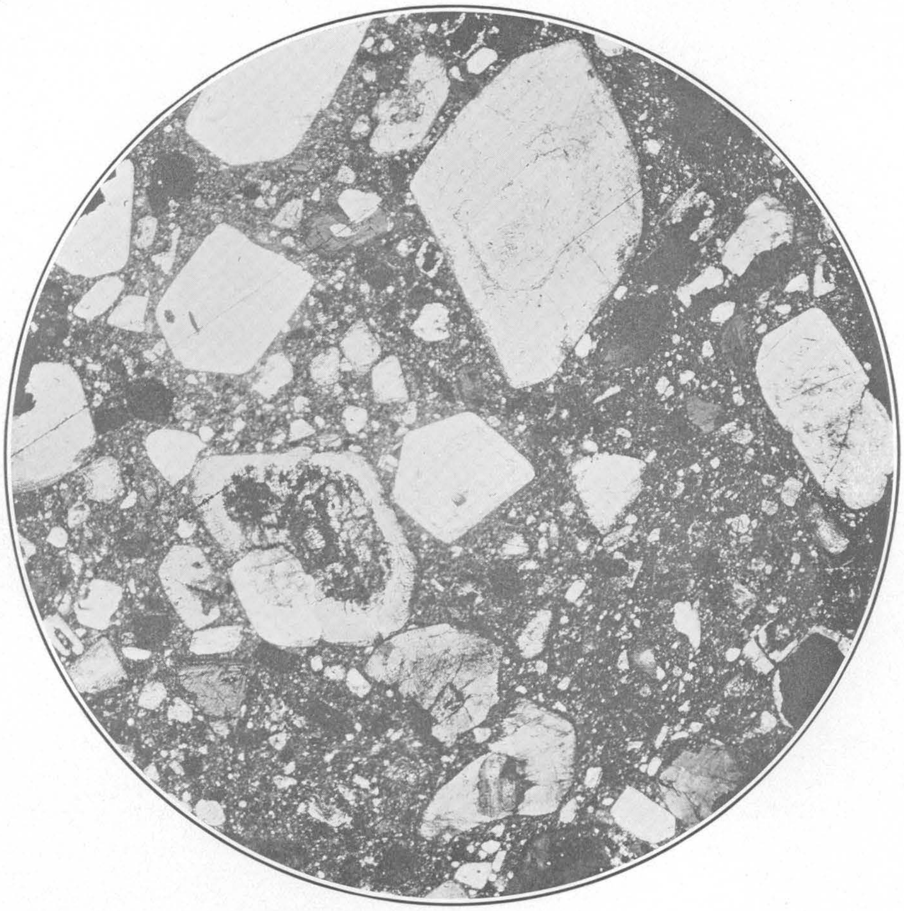
The Yellow Pine sill underlies about 100 acres near the mine and weathers to smooth, rounded forms of low relief. Even though it is considerably altered the texture is still preserved, both on the surface and underground. The orthoclase crystals are largely untwinned and range from 0.25 to 0.5 inch in length. Generally they are distinctly reddish and darker than the groundmass. There are sporadic areas within which quartz is common as slightly rounded grains 0.125 to 0.5 inch long. Neither mica nor hornblende is conspicuous, but these may have been destroyed by alteration, as the rock from the deeper mine workings contains disseminated pyrite. Tests indicate that the feldspar crystals as well as the matrix are now largely sericite. The north end of the Yellow Pine sill on the Snowstorm claims is the most northern outcrop of the porphyry observed in the district.

The evidence that these porphyry intrusions preceded the deposition of the ore minerals is fairly conclusive. At the Red Cloud mine large quantities of the dike rock have been treated for the gold content (p. 103). At the Keystone and Lavina mines the ore-bearing fractures cut through the dikes (pp. 106, 108), and in the Yellow Pine mine there are mineral-bearing fractures which displace the thick sill that overlies the ore bodies (p. 136). In the Keystone and Yellow Pine mines the fractures that break the dike and sill are probably related to the later part of the epoch of thrust faults (p. 47).

The best evidence of the age of these intrusive rocks is based upon their place in the succession of structural events in the region. In the chapter on structure (p. 54) the conclusion is reached that they were intruded in either late Cretaceous or early Tertiary time, probably the latter.

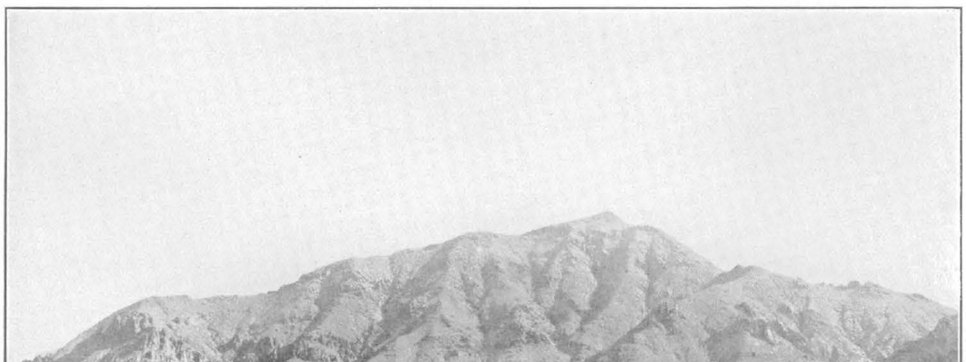
Lamprophyre dikes.—At three localities in the quadrangle—the Singer, Puelz, and Star mines—fairly crystalline basic dikes are exposed. In the upper workings of the Singer mine a dike of dark rock 3 to 5 feet wide trends northeast and stands vertically. At one place it is divided into three parallel dikes 1 to 3 feet wide. There is no noticeable contact effect on the adjacent dolomite. Biotite and hornblende are conspicuous in the hand specimen, but a thin section shows green augite, brown hornblende, and brown biotite, named in decreasing order of abundance. The matrix is composed of small crystals of labradorite with apatite and magnetite.

The dike at the Puelz mine crops out in an open cut. It is 1 to 5 feet wide and is slightly flatter than the local bedding. The dolomite under the dike is heavily stained with limonite, and it may have been slightly altered to siderite before weathering. The dike has a finer texture than that at the Singer mine, but the



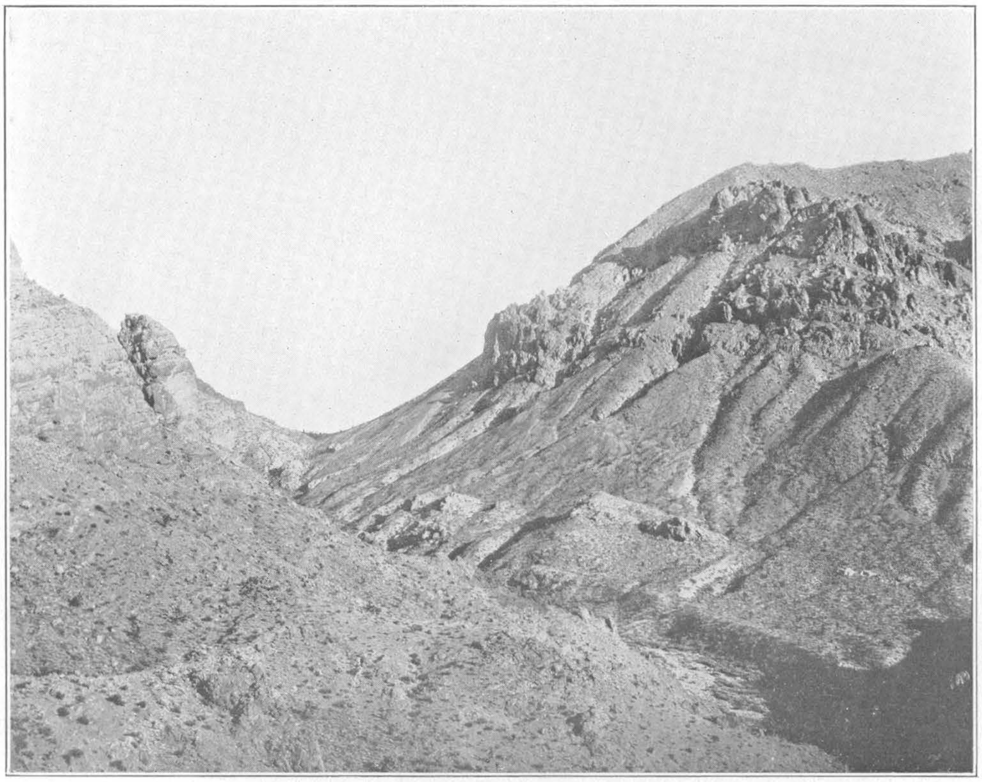
A. THIN SECTION OF GRANITE PORPHYRY FROM NE. ¼ SEC. 12, T. 25 S., R. 58 E.

All the crystals are orthoclase, but there are a few aggregates of biotite, and the groundmass is microgranular orthoclase. The texture of this specimen is not typically granitic. The thin section is reproduced because it indicates the character of the rock in the least altered exposure seen. Enlarged 6.4 diameters.



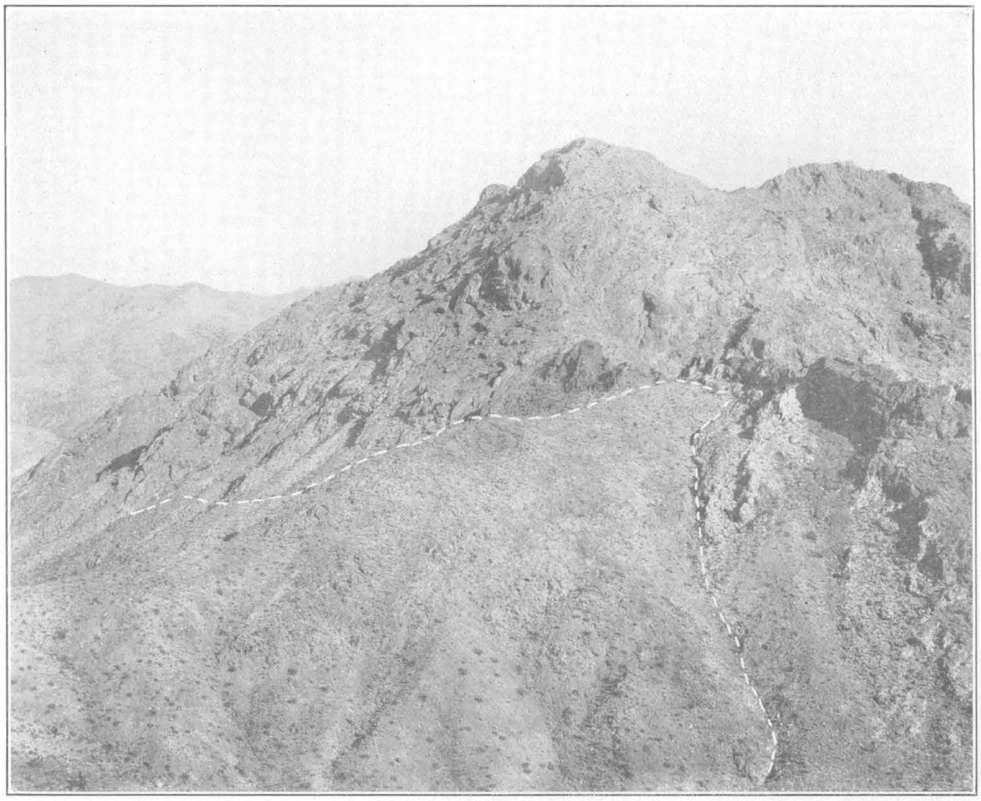
B. DIABLO GRANDE PEAK FROM THE NORTHWEST, IN SEC. 10, T. 26 S., R. 58 E.

The mountain is a plug of rhyolite about a mile in diameter intrusive into Paleozoic limestones and dolomite that are but slightly deformed. The foothills in the foreground are made up of dolomite of the Goodsprings formation.



A. CONTACT OF INTRUSIVE ROCK OF DIABLO GRANDE PEAK AND LIMESTONE OF THE SPRING MOUNTAINS

The rhyolite is on the right and the limestones of the Monte Cristo formation on the left. The limestones are bleached and altered to dolomite in a zone 100 to 200 feet wide along the contact.



B. NECK OF LATITE INTRUSIVE INTO DEVONIAN LIMESTONES IN THE NORTHEAST CORNER OF SEC. 19, T. 25 S., R. 58 E.

The limestone resists erosion and forms a persistent ridge, whereas the igneous rock is readily disintegrated and worn away.

essential minerals appear to be the same. It is broken by three small faults that trend east and dip north and are probably premineral. The dike in the workings of the Star mine is a greenish-gray rock in which only biotite has resisted decomposition.

All these dikes are classified as lamprophyres. Their mineral composition and texture indicate that they are complementary to the granite porphyry, and their occurrence either in mineral-bearing faults or near ore deposits suggests that they were intruded in the epoch preceding ore deposition.

FINE-GRAINED IGNEOUS ROCKS

The fine-grained igneous rocks are localized in six areas—Big Devil, Sultan, Table Mountain, and three smaller areas.

Big Devil area.—Although only the northern edge of the Big Devil intrusive mass lies within the quadrangle, it is an uncommon rock and justifies brief description. Diablo Grande (Big Devil) Peak (5,865 feet) forms a conspicuous cone along the axis of the Spring Mountains south of the Goodsprings quadrangle. (See pl. 9, *B*.) It is a simple intrusive mass about 8,000 feet in diameter, which cuts through the nearly horizontal Paleozoic section, so that on the surface the intrusive rock is in contact with beds that range from the Goodsprings dolomite to the upper part of the Bird Spring formation. There are small patches of related tuffs, breccias, and flows on the northeast, east, south, and west borders. The lack of locally disturbed beds around the borders indicates that the intrusive displaced a block of the limestones by pushing it out. The surface on which the tuffs and breccias rest has low relief and is smoother than most of the near-by surface.

As exposed at the surface the rock is light gray and very fine grained, without visible coarse crystals. Many blocks show parallel lenticular cavities, which indicate that the rock moved appreciably while still viscous. The northern part has a persistent system of vertical joints that trend north and under weathering yield rugged pinnacles. The rock is weathered several shades of brown. A thin section shows a groundmass of microgranular texture without any crystals much larger than the average and without glass. The grains range from 0.02 to 0.06 millimeter in diameter. The principal mineral is orthoclase, but there are traces of sodic plagioclase and quartz. Minute crystals of biotite, 0.02 to 0.5 millimeter in diameter, to the extent of several per cent, are uniformly distributed through the mass. According to a partial analysis by J. G. Fairchild, of the Geological Survey, the rock contains silica, 73.58 per cent; lime, 0.05 per cent; soda, 2.99 per cent; and potash, 5.52 per cent. It is classified as rhyolite, even though it contains less than the common amount of quartz.

The only breccia near this intrusive rock included in the quadrangle occupies an area 75 by 400 feet in the S. ½ sec. 2, T. 26 S., R. 58 E. It is made up of angular blocks of dense gray rhyolite as much as 12 by 15 by 20 inches, embedded in a similar fine-grained matrix.

The alteration of the Paleozoic limestone in contact with the rhyolite is discussed on pages 67–68. (See pl. 10, *A*.)

Sultan area.—North of the Sultan mine there is an area of about a square mile underlain by tuffs and flows, and three smaller areas of similar material extend as far as the Tiffin mine. The source of most of this material is probably a volcanic neck in the NE. ¼ sec. 19, T. 25 S., R. 58 E., but a part may be derived from a smaller neck a mile south, in the NE. ¼ sec. 30, T. 25 S., R. 58 E.

The outcrop of the larger neck is lenticular, about 600 by 1,200 feet, and it occupies a low saddle in a ridge, thus showing that under the prevailing dry climate the igneous rock is less resistant to disintegration than the near-by limestones of the Sultan formation. (See pl. 10, *B*.) The limestones are fractured but otherwise are not much disturbed around the border. The dolomite of the Monte Cristo limestone on the northern border is bleached and altered as described on pages 67–68.

The intrusive rock is pale reddish, and the only visible crystals in the dense groundmass are flakes of brown biotite. It weathers into angular blocks. It has not been examined in thin section but seems to be a latite similar to the flow a mile east and that in the other neck a mile south.

The smaller neck measures about 300 by 1,500 feet and lies along the north slope of a ravine. The northern limit is a vertical wall of dolomite, but the southern limit is obscure. The central and largest part of the neck is a pale-reddish, layered rock that shows a few crystals of orthoclase and biotite in a dense glassy groundmass. The thin section does not reveal other minerals but shows typical trachytic fabric. At several places along the border there are lenses of a black vitreous variety that show a vertical layering and here and there contain angular fragments of the pale-reddish variety. Curiously the dark rock contains no orthoclase but a little sodic plagioclase in a groundmass of glass. It contains a few augite crystals but no biotite. Probably these slight differences in mineral constitution do not deserve much consideration, and the two rocks may be regarded as varieties of latite.

A partial section of the tuffs and flows northeast of the Sultan mine is presented below. The total thickness of tuff differs from place to place according to the form of the irregular surface of the limestones on which it rests; probably it does not exceed 400 feet. The tuffs strike N. 30° W. and dip 30° E.

Partial section of tuffs and flows in the S. ½ sec. 17, T. 25 S., R. 58 E.

	Feet
Latite flow, pale reddish, stratified	150
Latite flow, pale reddish	60
Latite breccia; many black glassy fragments in pale-brownish tuff	10
Latite breccia; few fragments of black glass 1 to 8 inches in diameter	10
Latite tuff, pale reddish; sparse fragments of black glass	20
Latite tuff, pale brown, well stratified; no fragments larger than 1 inch	100+
	350+

A thin section of the flow at the top of the section shows sparse crystals of oligoclase and orthoclase in a glassy groundmass. There are a few accessory flakes of brown biotite but no quartz. The rock is a typical latite.

Table Mountain area.—The flat part of the main range, known as Table Mountain, coincides with a flow of andesite that overlies tuffs and breccias of variable thickness. Although the mountain is now dissected by four ravines, tributary to Deadmans Canyon, the flow was probably once continuous over the entire area. Most of the border of the mountain is a cliff whose height is the thickness of the flow, but under this cliff on the east, north, and west sides tuffs several hundred feet thick crop out. Where the underlying surface of the Paleozoic limestones is well exposed on the north and east end of the mountain, it is smooth and locally slopes inward toward the mountain. The overlying tuffs also dip inward. In sec. 10, T. 25 S., R. 58 E., ravines have cut down into the flow and show a confused mass of breccia. From these data the conclusion is reached that the source of the entire local body of volcanic rocks was a local vent not far from the SW. ¼ sec. 10. The tuffs and breccias first extruded probably filled the near-by ravines, and then the flow evened up the surface. The evidence is clear south of the Mountain Top mine that the flow was later than the Fredrickson fault and covered it. On the other hand, the flow is broken by a few small faults northwest of the Houghton mine. The main body of the flow has not been perceptibly tilted since it was poured out.

The commonest variety of the flow that forms the top of the mountain is dark gray and finely vesicular but with only sparse crystals visible to the eye. Most of these crystals are feldspar, but a few are hornblende. A thin section shows that the feldspar is oligoclase and the groundmass is glass in which there are minute blades of feldspar. There are a few sparse grains of augite but no biotite or quartz. A few thin dark flows of only local extent in Deadmans Canyon show needles of hornblende as much as an inch long. The breccias show a wide range of color and texture.

Other areas.—There remain to be mentioned two areas of tuffs whose source is obscure. North of bench mark 4385, in the N. ½ sec. 2, T. 24 S., R. 57 E., about 15 feet of bedded gray volcanic ash underlies 15 feet of wash. The ash contains fragments of pumice and plates of biotite. The bedding trends north and dips 10° W., toward Mesquite Valley, but it seems doubtful that the inclined bedding indicates later tilting.

South of Little Devil Peak, in the SW. ¼ sec. 33, T. 25 S., R. 58 E., in the small park at the head of Devil Canyon, bedded gray tuffs that dip east are exposed over several acres. The material closely resembles that near the Sultan mine and may have had the same source.

Basalt dikes.—An unusual dike of basalt lies in the SW. ¼ sec. 30, T. 24 S., R. 58 E. It is interesting because it has caused an unusual alteration of the surrounding dolomites of the Goodsprings formation. The dike attains a maximum thickness of 50 feet at the south end and is traced northward 1,000 feet, to a point where it splits into several thinner dikes. Outcrops of similar rock 2,500 feet north indicate that it extends thus far. It appears to fill a fracture parallel to the mineralized faults at the Kirby and Rose mines, 2,500 feet east. At the south end it connects with a sill-like body 300 feet long.

The rock is dark gray and dense throughout, but at the north end it contains round grains of olivine as much as 0.5 inch in diameter. The middle shows a platy cleavage parallel to the walls, but the border is massive and vesicular. The sill has a slightly coarser texture than the dike and shows columnar structure. A thin section shows a few coarse crystals of olivine and augite in a holocrystalline fine groundmass of plagioclase and augite. No hornblende or biotite is present.

The dike is surrounded by a zone of altered dolomite about 20 feet thick (p. 68). Although the normal color of the dolomite is gray, the zone is light brown. In the process of alteration small percentages of iron, probably in the form of carbonate, and water have been added. (For analyses, see p. 62.)

The Rosella tunnel, on the Azurite group of claims, encountered a dike of similar material 3 to 8 inches wide, but the adjacent dolomite is unaltered.

ALLUVIUM

On the basis of its lithology and distribution and the position of the surface on which it rests the alluvium is separable into three groups—the early alluvium, the later alluvium, and recent alluvium or wash. Each of these groups is distinguished by a separate symbol on Plate 1.

Early alluvium.—Within the early alluvium are included patches of unconsolidated coarse rounded gravel and boulders of diverse lithology that in large part lie on the tops of low hills or ridges. By contrast, the later alluvium is made up of angular blocks that are largely limestone cemented by calcite.

As shown on Plate 1 several patches of the later alluvium lie at a higher altitude than the patches of early alluvium. The most northern area lies near Cottonwood Pass, but five others lie along Goodsprings Valley. There is an isolated area near the Red Cloud mine and another west of Wilson Pass, in the SW. ¼ sec. 34, T. 23 S., R. 57 E. In the center of sec. 24, T. 23 S., R. 58 E., east of Cottonwood Pass, an area of several acres is strewn with similar boulders, but they have moved locally by the erosion and slumping of the underlying material.

The material that caps the hill in the west center of sec. 30, T. 23 S., R. 59 E., is typical of the early alluvium and will be described in detail. The deposit is about 100 feet thick, and it rests on a surface that slopes gently southeast. The largest boulder is Kaibab limestone, 5 by 5 by 7 feet, but most of the boulders are light-brown quartzite, uncommonly well rounded. The largest quartzite boulder is 2½ by 3 by 4 feet. Some of the boulders show traces of facets, and all are covered with percussion marks. No glacial striae could be found. It is an interesting feature of the cherty limestone boulders that the layers of chert stand in relief, from one-half to 1½ inches above the adjacent limestone, which shows evidence of solution. The matrix of the large boulders is a mixture of small uncemented boulders, gravel, and sand. It is clear that the material has been subjected to weathering for a long time, doubtless longer than the later alluvium, which forms remnants in the northeast corner of the quadrangle.

The limestone and dolomite boulders might be derived from several parts of the near-by range, but the source of the quartzite boulders must be sought farther away, because no beds of quartzite are known in the range southeast of Charleston Peak. The work of T. B. Nolan,[43] who was associated with C. R. Longwell in the examination of the Spring Mountains in 1923, shows that there are extensive areas of quartzite beds of Cambrian age along the range 15 miles northwest of Charleston Peak. Plate 12, *A*, which is a view taken from the crest of the Bird Spring Range, shows an old valley that extends N. 35° W. from the hill in sec. 30, T. 23 S., R. 59 E., through the pass in the range toward Charleston Peak, 35 miles distant. The gradient of the 8 miles of the channel in this quadrangle is about 100 feet to the mile, and in 40 miles northwest the channel would attain an altitude of about 8,700 feet. As the hills of Cambrian quartzite in that neighborhood now range from 8,200 to 8,500 feet, they could have been the source of the boulders. Speculation concerning the source of the boulders is not worth while here, but it should be noted that this channel is now broken into three parts by recent capture. The northwestern part drains west to Pahrump Valley, the middle part as far southeast as Cottonwood Pass drains northeast to Las Vegas Valley, and the southeastern part drains south to Ivanpah Valley. It seems clear that in early Pleistocene or even late Tertiary time a vigorous stream flowed southeastward from the region of the Amargosa Desert past Charleston Peak toward Ivanpah Valley, possibly even to the Colorado River. It is noteworthy that the gradient does not seem to be disturbed by recent uplift or by faulting.

This channel offers a reasonable explanation of the source of the boulder deposits at the north end of Goodsprings Valley but does not explain the deposit near the Red Cloud mine, which is also largely made up of quartzite boulders. Probably this deposit was also brought across the range by another stream flowing southeast from the hills north of Pahrump Valley to Ivanpah Valley. Such a stream might also have carried the boulders found in sec. 34, T. 23 S., R. 57 E.

The existence of such stream channels has a direct bearing on the general pattern of early Pleistocene or late Tertiary drainage in this region and the manner by which it changed from a region of extensive drainage lines, possibly leading to the Colorado River, to a region containing several closed basins, which receive only local drainage. This will be considered further in connection with the survey of the Ivanpah quadrangle now in progress.

Later alluvium.—Patches of later alluvium are found in five areas in the quadrangle—in the northeast corner north of Cottonwood Valley, along the west slope of the Spring Mountains north of Mountain Springs, on the tops of several hills 3 miles west of Wilson Pass, at the mouth of Keystone Wash, and along the ridge several miles northwest of Goodsprings. Unlike the early alluvium, which was largely derived from sources northwest of the Spring Mountains, the later alluvium may be wholly derived from local sources.

The northeastern area includes four remnants of what was probably once a more widespread, continuous layer. The greatest thickness of these remnants is about 300 feet, which is found in the most northern one, in sec. 13, T. 22 S., R. 58 E. The gravel shows a great range in size, from the fine material that forms the matrix to huge blocks 6 by 6 by 8 feet. One block 40 by 15 feet was noted in the NE. ¼ sec. 18, T. 22 S., R. 59 E. These blocks include all the varieties of limestone and dolomite of the Paleozoic section, but the upper part of the deposit locally contains a few blocks of sandstone (Aztec sandstone?). All the blocks are characteristically angular in outline and cemented by calcite. The remnants rest upon a surface that slopes uniformly northeast at a gradient of about 250 feet to the mile and therefore slightly steeper than the recent wash near by. The underlying rocks are thin limestones of the Moenkopi formation. Viewed broadly, the mate-

[43] Nolan, T. B., Note on the stratigraphy and structure of the northwest portion of Spring Mountain, Nevada: Am. Jour. Sci., 5th ser., vol. 17, pp. 461-472, 1929.

rial is rudely stratified, but there is meager evidence of sorting.

The material seems to be part of an alluvial fan, which probably once continued southwest and west into the range, where it was derived from the block of Paleozoic sediments thrust across on the Aztec sandstone. Even though the alluvium was probably deposited during a period of arid climate, it seems difficult to understand why more sand and sandstone from the bluffs that terminate the range were not laid down with the limestone.

North of Mountain Springs the ridges that extend west from the main range are covered with cemented alluvium. Most of the material consists of subangular blocks of limestone and dolomite 1 to 4 inches in diameter, but some blocks are 2 feet in diameter and one is 5 by 5 by 6 feet. There are faint traces of stratification, and the bedding trends north and dips 15°–20° W. Doubtless little if any of this inclination is due to tilting after deposition.

The four areas of alluvium in sec. 2, T. 24 S., R. 57 E., northwest of Wilson Pass, and that which forms the hill north of the mouth of Keystone Wash, in sec. 24, T. 24 S., R. 57 E., have many features in common. The material consists of coarse angular fragments of upper Paleozoic limestone and dolomite wholly cemented by calcium carbonate. Fossils, largely those characteristic of the Monte Cristo limestone, are rather common in the fragments. There are only faint traces of stratification, and the surfaces on which the masses rest dip gently west. Examined casually, they might readily be taken for thrust-fault breccias, but they lack the evidence of alteration to dolomite and are more completely cemented than most fault breccias. Further, in their present position, it is difficult to relate them to thrust faults, as they closely resemble the material of Cottonwood Valley. The conclusion is reached that they are alluvium from the higher parts of the mountains.

The gravel northwest of Goodsprings (pl. 12, *B*) covers the crests of two low ridges which extend nearly to the Yellow Pine mine 4 miles distant. The deposits include all the local varieties of Paleozoic limestone and dolomite. A wide range of sizes is present, but the maximum is 4 by 4 by 5 feet. The material is highly angular, but in rough blocks rather than tabular masses. Compared to the gravel north of Cottonwood Pass, there is more evidence of stratification and sandstone is common. The gravel is cemented by finely crystalline calcite.

These gravel deposits rest on a smooth surface that has the form of a broad trough whose axis trends southeast toward Ivanpah Valley. The maximum thickness is about 100 feet. Doubtless, like the gravel deposits north of Cottonwood Pass, they are only a part of a once extensive sheet in Goodsprings Valley. Unlike those farther north, however, they have been dissected by intermittent streams that flow into a closed basin. To accomplish the amount of dissection shown, it seems that either the mountain mass must have risen relative to the basin or that the basin must have sunk since the gravel was laid down.

The recent wash is briefly described on page 4.

STRUCTURE

GENERAL PRINCIPLES

The structure of a region is studied for the purpose of determining the distribution and attitude of the different rock units, the positions of fractures and the movements along them, both in direction and extent, the chronologic order of the events, and the relation of any igneous rocks to these events. If a region contains ore deposits the structure is also studied for the purpose of determining with which group or groups of fractures the ores are associated and at which stage they were deposited. It is rarely possible, however, to obtain all the desired data or to interpret them with confidence throughout the district. In areas where there is little soil and vegetation, such as that surrounding Goodsprings, it may be possible to recognize the surface exposures of most of the beds and fractures and record them on the map, but such a map gives little more than the two horizontal dimensions. Where good observations of the dips of the beds are recorded, the extent of the folds in the near-by crust may be inferred with confidence, but only here and there, even where the surface exposure and dip of a fracture are known, can the direction and extent of the relative movement be inferred. In order to determine these elements, grooves or good striae on the fractures and the detailed structure of each block adjoining the fault must be known. In a few places reliable data have been obtained in mine workings, such as those of the Yellow Pine mine.

Figure 5 has been reproduced with slight modifications to illustrate the use of several terms necessary in describing faults.[44] The figure shows a rectangular block separated into two parts, *A* and *B*, along an inclined fracture, by moving block *B* downward to the right. A bed is shown intersecting the block *A* at *bf* and block *B* at *ag*, thus indicating that the points *a* and *g* once coincided with *b* and *f*, respectively. The significance of the terms slip, dip slip, strike slip, perpendicular slip, trace slip, throw, and heave is indicated. In dealing with actual surface exposures it is rare that slip and strike slip can be determined, but commonly the dip slip and perpendicular slip can be estimated.

In the following description two classes of faults will be recognized—normal and thrust or reverse. These terms, of course, are descriptive and do not

[44] Reid, H. F., Davis, W. M., Lawson, A. C., and Ransome, F. L., Report of the committee on the nomenclature of faults: Geol. Soc. America Bull., vol. 24, pp. 163-186, fig. 2, 1912.

necessarily indicate the circumstances of origin. Normal faults are those in which the hanging-wall block has been depressed relatively to the footwall.[45] In a few places, however, where the horizontal shift or strike slip has been large, the effect may be apparent rather than real. A thrust or reverse fault is one in which the hanging-wall block has been raised relatively to the footwall.

BROAD FEATURES OF THE REGION

Until 1919, when Longwell undertook a detailed study of the Muddy Mountains,[46] little was known of the structure of the ranges of southern Nevada. The visits of Gilbert[47] and Spurr[48] served only to indicate the most apparent structural features. The outstanding structural feature discovered by Longwell was the presence of immense sheets of old sediments (Devonian limestone) resting on top of much younger sediments (Jurassic sandstone), which indicates that there were enormous overthrusts in the region. Work in the Goodsprings quadrangle by the writer during 1921 and 1922 showed that similar overthrusts are present in the Spring Mountains, and it is now known that overthrusts are a characteristic feature of many ranges in southern Nevada.

For structural study the quadrangle may be divided into four areas, the lines of separation on the surface being extensive overthrust faults which, if projected downward, mark the lower limits of great composite masses of rock that have been thrust upon other underlying masses. (See pl. 11.) The eastern and lowest mass almost coincides with the Bird Spring Range and will be called the Bird Spring block. Although it is broken by a few faults, it is otherwise a fairly simple block of sediments that range in age from Upper Cambrian to Jurassic(?), overthrust along the east face of the range upon beds of Permian and Triassic age. The overthrust crops out east of the Goodsprings quadrangle.

The second structural area includes the central higher part of the Spring Mountains, from the pass east of Mountain Springs on the north nearly to Columbia Pass, 12 miles south. This mass is separated from the underlying mass by the Contact overthrust fault, well exposed for several miles near the Contact mine but only from place to place farther south. This block is bounded on the west by the Keystone overthrust, which may be traced from the north edge of the quadrangle southward around the west side of the range to Keystone Wash, thence eastward across the range north of Columbia Pass, and thence southeastward to the edge of the quadrangle. This central block coincides with the highest part of the range from Potosi Mountain to Shenandoah Peak. It is rather complex structurally. Along the Contact overthrust fault beds as old as Upper Cambrian are thrust eastward on those as young as the Shinarump conglomerate (Upper (?) Triassic). The mass will be referred to as the Contact block.

The third structural area is limited on the east by the Keystone overthrust fault, on the west by the wash of Mesquite Valley, and in the southwestern part of the range by the Sultan overthrust. In the north half of the quadrangle this mass is rather simple, almost a homocline, but in the south half it is much folded and broken by many faults. Along the Keystone overthrust beds of the Goodsprings dolomite are thrust upon those as high in the stratigraphic section as the

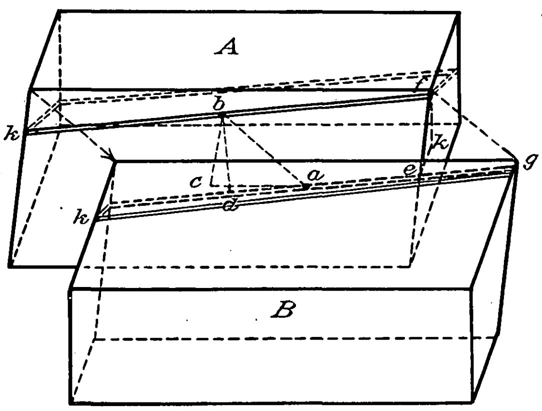


FIGURE 5.—Diagram illustrating terms used in describing faults. *ab*, Slip or net slip; *bc*, dip slip; *ca*, strike slip; *bd*, perpendicular slip; *da*, trace slip; *fk*, throw; *ek*, heave. (See text.)

Moenkopi formation (Lower Triassic). This mass will be referred to as the Keystone block.

The fourth structural area lies in the southwest corner of the quadrangle. It is limited on the east by the Sultan overthrust and is rather complex in detail. Along the Sultan overthrust beds of the Goodsprings dolomite are thrust upon those of the Bird Spring formation. This area will be referred to as the Sultan block.

The general relations of these four areas are shown in Plate 11.

In the description of the stratigraphy it is stated that the relations of the beds indicate that although there are two major and possibly several minor unconformities present, which indicate slight local oscillations in the earth's crust, there were no great dislocations here between the early Cambrian and the Jurassic. At a later time, either in the late Cretaceous or early Tertiary, there were great disturbances, recorded now as complicated folds and both thrust and normal faults, and during two epochs bodies of igneous rock were

[45] Reid, H. F., and others, op. cit., p. 177.

[46] Longwell, C. R., Geology of the Muddy Mountains, Nev.: Am. Jour. Sci., 5th ser., vol. 1, pp. 39–62, 1921; U. S. Geol. Survey Bull. 798, 1928.

[47] Gilbert, G. N., U. S. Geog. and Geol. Surveys W. 100th Mer. Rept., vol. 3, pp. 21–42, 1875.

[48] Spurr, J. E., Descriptive geology of Nevada south of the fortieth parallel and adjacent portions of California: U. S. Geol. Survey Bull. 208, pp. 164–180, 1903.

intruded. These disturbances continued throughout the Tertiary period and perhaps until rather recent time.

The local record indicates that these disturbances began with the development of folds in the rocks. The folding was followed by flat westward-dipping fractures along which great masses of the rocks moved eastward over much younger rocks. The evidence indicates that the first of these fractures was the Bird Spring thrust, followed successively by the Contact thrust, the Keystone thrust, and the Sultan thrust. Late in the epoch of thrust faults there were intrusions of granite porphyry, which record local fractures of the thrust epoch. There were then normal faults, some of which were localized along the earlier thrust faults. The deposits of sulphides of lead and zinc were laid down after these earliest normal faults. After a period of great erosion other normal faults developed, and then, after further erosion, several bodies of igneous rocks were intruded, and some of these reached the surface to form flows and breccias. This period of intrusion is regarded as Miocene. Since the second group of igneous rocks were intruded still other normal faults have been developed, but these are best displayed near the borders of the major depressions outside the Goodsprings quadrangle. Obviously, erosion has been active throughout late Tertiary and post-Tertiary time.

In recording the structural details of the region a better picture will be presented if the details are grouped separately for each of the four outstanding structural units, the blocks bounded below and above by thrust faults. For each of these blocks the limiting thrust faults are traced and described. These descriptions are followed by descriptions of the minor thrust faults, the normal faults, and the folds. These descriptions must necessarily be brief in an economic report, though it is hoped that the picture will be found adequate. Finally, a summary of the probable relations of the principal thrust faults and the chronologic succession of events is presented.

BIRD SPRING BLOCK

The northern and southern parts of the Bird Spring Range lack not only topographic continuity but structural continuity. The Bird Spring thrust lies along the east front of the range beyond the limits of the Goodsprings quadrangle. Along that thrust beds as old as the upper part of the Goodsprings dolomite are thrust over those of the Kaibab and Moenkopi formations. Beds of the Bird Spring formation crop out along the southern half of the range and almost coincide with a northward-trending anticline slightly modified by several folds. The Cottonwood fault rises in the Spring Mountains, trends southeast through Cottonwood Pass, enters the southern part of the Bird Spring Range, and passes southward into Ivanpah Valley. As shown on Plates 1 and 11, it forms the northeast boundary of a great wedge of which the Ninety-nine fault marks the southwest boundary. This wedge has dropped 2,000 feet or more, and as it contains parts of the Contact and Potosi faults, the Cottonwood and Ninety-nine faults are younger than the thrusts. Where the Cottonwood fault enters the Bird Spring Range, its dip-slip is only about 1,000 feet, but this increases steadily southward, and 15 miles farther south it is probably at least 5,000 feet. The other normal faults of the southern part of the range have dip slips of several hundred feet.

The northern part of the Bird Spring Range is largely underlain by the Kaibab limestone, which presents an impressive escarpment eastward. (See pl. 8, *A*.) This formation dips gently westward, but it is broken by many small normal faults, none of which has a dip slip of more than 250 feet. Most of these faults appear to reflect the minor adjustments of a thin layer of brittle limestone between thicker masses of softer, more yielding shales, sandstones, and thin limestone, both below (Supai formation) and above (Moenkopi and higher beds).

In a strict sense the mass of Aztec sandstone shown in the escarpment under the Keystone thrust is a part of the Bird Spring block, because the intervening Contact thrust passes under the Keystone thrust and is therefore not shown north of the Cottonwood fault.

There are no ore deposits or intrusive rocks recorded in the Bird Spring Range.

CONTACT BLOCK

The Contact block is limited downward by the Contact thrust fault, which lies along the east base of the Spring Mountains, and upward by the Keystone thrust fault, which lies largely along the west base of the range. Both on the north, near Mountain Springs Pass, and on the south, near Columbia Pass, the Contact thrust passes under the Keystone thrust. The block also contains two impressive thrust faults, the Potosi and Wilson, as well as several other minor thrust faults. In contrast with the underlying Bird Spring block and overlying Keystone block this block is intricately folded; the general trend of the folds is northward.

On the north the Contact thrust is indicated by the relation of faint outcrops of red Aztec sandstone in ravines in the foothills adjacent to Cottonwood Valley south of the Arden road. The hills that rise farther southwest are made up of locally overturned limestones of the Monte Cristo and Bird Spring formations. (See sec. C–D, pl. 2.) The thrust crops out conspicuously in the hills west of Cottonwood Pass, where thin dolomitized limestone of the Bird Spring formation rests on buff Aztec sandstone. Here the fault trends northwest and dips 10° SW. Farther south it is shown in several places near the

Pauline and Contact mines, where the dip ranges from 15° to 20° W. As shown in Plate 1, the overlying Paleozoic limestones are thrown into a broad anticline whose axial plane dips steeply west. Doubtless this is the same as the overturned anticline shown west of Cottonwood Pass, 2 miles to the northeast. East of the Contact mine the Aztec sandstone, which dips west near by, is sharply turned up under the Contact thrust, so as to form a local syncline. The position of the thrust is again indicated several miles to the south by the local relations of patches of red Aztec sandstone in ravines and the thin limestones of the Bird Spring formation in the near-by hills. (See sec. E–F, pl. 2.) Near the Lavina mine the thrust shows between patches of Shinarump conglomerate in the wash and the hills of Goodspring dolomite. Between the Ruth mine and Columbia Pass the thrust is continuously exposed at two places for several thousand feet, where limestone of the Bird Spring formation rests on folded beds of Shinarump conglomerate and red shales of the Chinle formation. Outcrops clearly show that the Contact thrust, trending south and dipping west, passes under the Keystone thrust, which trends east and dips south. The thrust is offset by the Ruth fault, and both of these, as well as the overlying Keystone fault, are displaced by a northward-trending normal fault. The normal fault contains sporadic copper minerals that have been explored by the Cosmopolitan claim (p. 111); hence it preceded the mineralization. On the Rattler claim, south of the Ruth mine, several prospects have explored lenses of galena in the breccia of the Contact thrust, and the shoot of galena ore in the Ruth mine lies in crushed beds adjacent to the Ruth fault. These occurrences, as well as several prospects near the Pauline mine which explore lead deposits in the breccia of the Contact fault, show that the mineralization followed these thrust faults as well as some normal faults.

The dike of granite porphyry in which the Lavina veins lie was intruded along the Contact fault. These relations indicate that the distribution of porphyry intrusions and ore deposits is controlled by the major thrust faults of the region.

The Potosi thrust is inconspicuous where it lies in the thin-bedded limestones of the Bird Spring formation, but once identified in the ravines north of the Red Cloud mine it is readily traced northward to the region near Potosi Mountain, where the entire Sultan limestone and part of the Monte Cristo limestone are duplicated above it. (See sec. C–D, pl. 2, and pl. 13, *A*, *B*.) Parts of the Potosi thrust are shown northeast of the Ninety-nine fault, along which the northeast side is dropped 1,800 feet. A second fault, parallel to the Ninety-nine, drops it about 400 feet more. In its northwest extension the thrust passes under the Keystone thrust. Near the Snowstorm mine the dip of the Potosi thrust is 50° W. (sec. E–F, pl. 2), but it decreases steadily northward, so that under Potosi Mountain it is only 30°. (See sec. C–D, pl. 2.) The breccia zone that marks this thrust is not conspicuous; commonly it is only about 10 feet thick, and at no place is it more than 25 feet.

The Wilson thrust crops out only in beds high above the base of the Bird Spring formation, but near Wilson Pass and west of the Red Cloud mine it is readily traceable by slight differences in the dip of the overlying and underlying beds. It may not extend as far south as the Keystone thrust; northward it disappears where it meets an extensive syncline. Under Shenandoah Peak the dip of the thrust is about 40° W., but north of Wilson Pass it increases to 65° and probably it decreases northward. (See sec. E–F, pl. 2.) Under Shenandoah Peak this thrust is overlain by a zone of crumpling of the beds (see fig. 8) above which the beds have been thrust forward at least several hundred feet. The breccia zone of the Wilson thrust in few places exceeds 10 feet in thickness.

Viewed broadly, the beds within the Contact block present more folds than those in any other block. There is a locally overturned anticline at the north end where the beds rest on the Contact thrust near the Cottonwood fault. (See sec. C–D, pl. 2.) Farther south, above a minor thrust fault, there is a broad anticline that may be traced 5 miles south to the Contact mine, even though broken by the Ninety-nine and other near-by faults. Complementary to this broad anticline, in the northern half of the Contact block, is a persistent syncline which may be traced for 6 miles along the west side of the range as far south as the ridges west of Wilson Pass. Near the Potosi mine the beds on the west limb of the syncline are vertical for several miles and are locally overturned.

In the north half of the Contact block, where the Potosi thrust dips about 30°, there are no minor folds, but in the south half, where the Potosi and Wilson faults dip 40° W. or more, there are many minor folds, most of which trend north and have axial planes that dip west. Thus, west of the Contact mine there are several closely spaced folds between the Contact and Potosi thrusts. Also, near the crest of the range north of Wilson Pass there is a closely folded belt between the Potosi and Wilson thrusts. Still farther southwest, west of Shenandoah Peak, there is a belt of folds between the Wilson and Keystone thrusts. These relations indicate that where the minor blocks moved forward readily on thrust faults of low dip, compressive stresses were relieved. By contrast, where the faults were steep, stress accumulated locally and was relieved by the formation of minor folds. This interpretation indicates that the minor folds were formed at the same time, or after the movement on minor thrust faults, whereas the major folds probably were formed at the same time as or earlier than the major thrust faults.

As noted above, the axes of the folds trend generally north. There is one outstanding exception—a pronounced anticline west of Shenandoah Peak that trends west. (See sec. G–H, pl. 2.) The position and trend of this fold indicate that it may have been formed by the local slipping on the Ironside fault, roughly contemporaneous with the Keystone thrust and appreciably later than folds of the Contact block.

STRUCTURAL GEOLOGY NEAR YELLOW PINE, PRAIRIE FLOWER, AND RED CLOUD MINES

General features.—Inasmuch as the local areal geology has a critical bearing on the interpretation of the relations of the ore bodies of the Yellow Pine and other near-by mines, it is here described in advance of the mines. In studying the area, the writer has had the benefit of a topographic and areal geologic map made by R. D. Longyear in 1920 for the Yellow Pine Mining Co.

The bedded rocks exposed in this area include the Bullion dolomite, the shaly Arrowhead limestone, 10 to 12 feet thick, and the Yellowpine limestone, 70 to 120 feet thick (members of the Monte Cristo formation); the sandstone at the base of the Bird Spring formation, 22 to 28 feet thick; and the higher thin-bedded limestones, shales, and thin sandstones of the Bird Spring. The only igneous rocks noted are the sill of granite porphyry that lies above the Yellow Pine mine and the related dikes of similar rock in that mine and near the Alice and Red Cloud mines.

The Bullion dolomite forms the crest of the ridge east of the Yellow Pine mine and is cut off on the south by the dike of porphyry that extends from the Alice mine northeastward to the mouth of Middlesex (Horseshoe) Gulch. It forms the crest of the ridge farther east (Ruth Mountain). It also crops out on the low ridge east of the Prairie Flower mine and a mile north across the flat, where it forms the crest of the ridge east of the Snowstorm mine. Throughout this area the Bullion dolomite is a coarsely crystalline bluish-gray dolomite without evidence of bedding. It contains the principal workings of the Arrowhead, Blue Jay, and Snowstorm mines on the north and the Copper Glance and several prospects east of the Yellow Pine mine. In a few places (200-foot level) the workings of the Yellow Pine mine penetrate it.

The shaly Arrowhead limestone crops out east of the Yellow Pine mine (pl. 6, *B*), but it could not be found where areal relations indicate that it should appear near the Middlesex mine and on the surface east of the Prairie Flower mine. On the other hand, it was found on the Snowstorm claims and northward, and it is exposed in cliffs west of the Arrowhead prospect. It is also exposed at many places in the Yellow Pine mine, and in Plate 36, *B*, the structure contours have been drawn on top of it. It displays the typical alternating layers of dolomitized limestone, 2 to 3 inches thick, separated by shale partings half an inch or less thick.

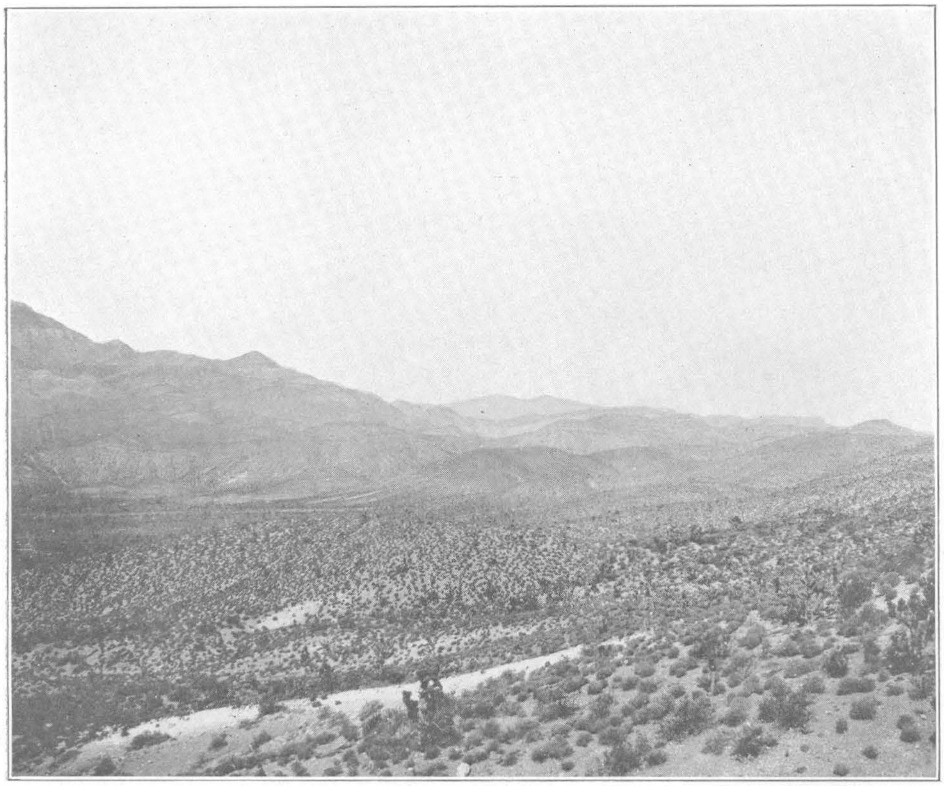
The Yellowpine limestone crops out at the Yellow Pine mine, on the hill at the Prairie Flower shaft, and on the Snowstorm claims a mile north. Patches of unaltered dark-gray limestone may be seen near the Prairie Flower shaft, but elsewhere the bed is completely dolomitized. (See analyses, p. 62.) Although traces of bedding were noted locally underground in the Yellow Pine mine, the bedding is not conspicuous on the surface. The only measurements of thickness of the bed were those obtained in the Yellow Pine mine, where they range from 70 to 120 feet. This bed contains all the ore bodies in the Yellow Pine and Prairie Flower mines.

The basal sandstone of the Bird Spring formation crops out near the Yellow Pine mine and on the Snowstorm claims, where it contains lenses of chert conglomerate (p. 22). In the Yellow Pine mine it is a fine-grained pale yellowish-brown sandstone without traces of bedding. In the southern part of that mine it is 28 feet thick, but it becomes thinner northward, and on the Snowstorm claims, where it contains lenses of conglomerate (p. 110), the total thickness is less than 20 feet. In the workings of the Hale and Prairie Flower shafts it is represented by black sandy clay, or locally by cobblestones, and the thickness is in places no more than 2 feet. Doubtless where it is thin it has been sheared during compression. It was not observed at the proper horizon near the Middlesex mine.

The beds that normally overlie the basal sandstone of the Bird Spring formation are thin-bedded limestones, largely less than 10 feet thick, and interbedded shales and sandstones (p. 22). They crop out conspicuously from the Yellow Pine mine northward nearly to the Red Cloud mine and again from the Snowstorm northward for several miles. They are sporadically altered to coarsely crystalline dolomite for a distance of several hundred feet above the Yellow Pine sill of porphyry, but locally limestone is preserved within 20 feet of it. Near the Middlesex mine and farther south, where the sill is thinner or absent, the beds are only here and there altered to a fine-grained dolomite.

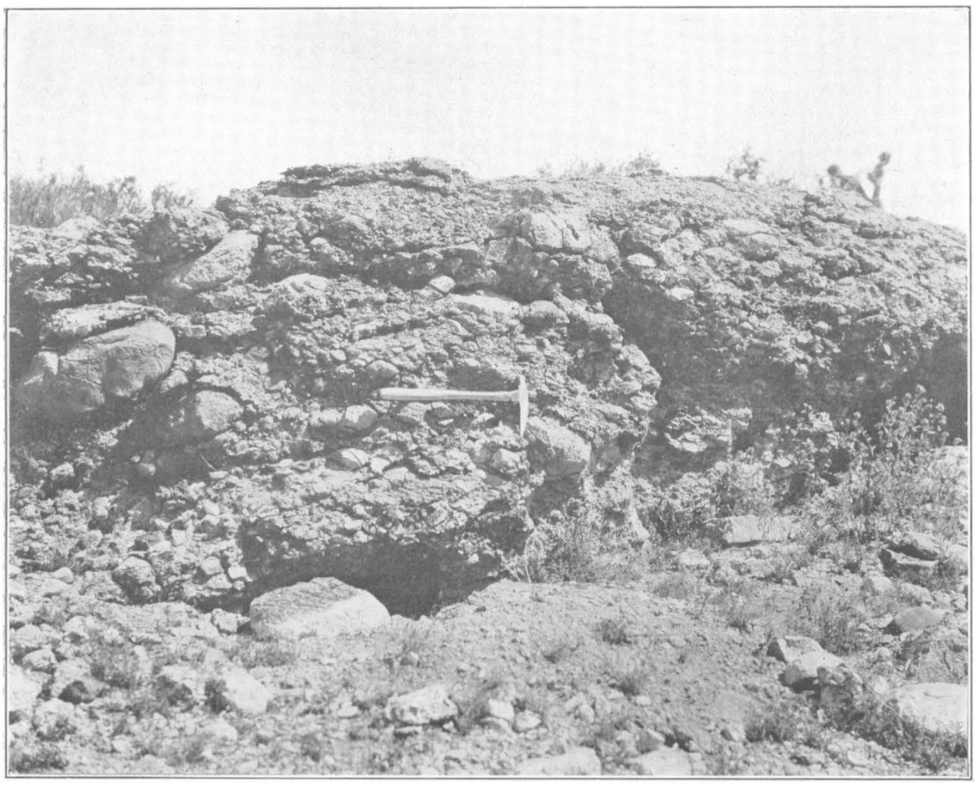
Intrusive rocks.—In studying the local structural history it will be helpful to recognize five bodies of intrusive granite porphyry in the area—the Yellow Pine sill, the Snowstorm sill, the Middlesex sill, the Alice dike, and the Yellow Pine dike.

The outcrop of the Yellow Pine sill underlies the largest area of coarse intrusive rocks in the region. It lies west of the Yellow Pine mine and is struck at many places underground. Southwest of the mine it has a maximum thickness of about 780 feet, and the



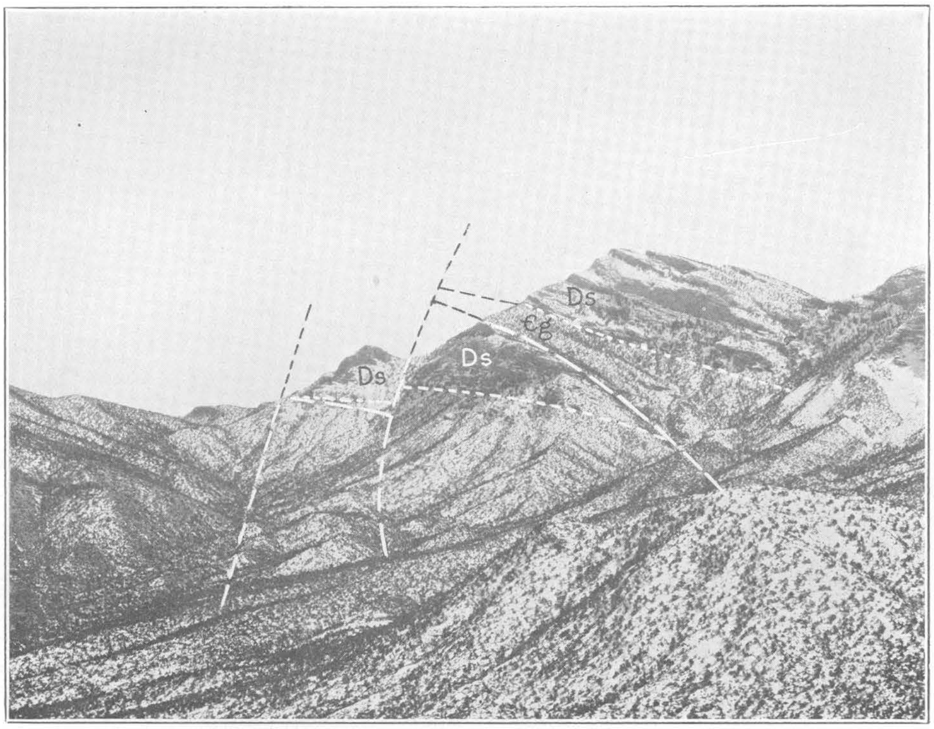
A. VIEW ALONG OLD VALLEY NORTHWEST TO CHARLESTON PEAK

Charleston Peak is 30 miles distant in center. The dark hill in center foreground is covered with quartzite boulders. The depressions between the hill and the peak are remnants of an old valley which crossed the Spring Mountains and along which the boulders were brought to their present position. The drainage of the old valley is now diverted to Pahrump, Las Vegas, and Ivanpah Valleys, which form three separate basins.



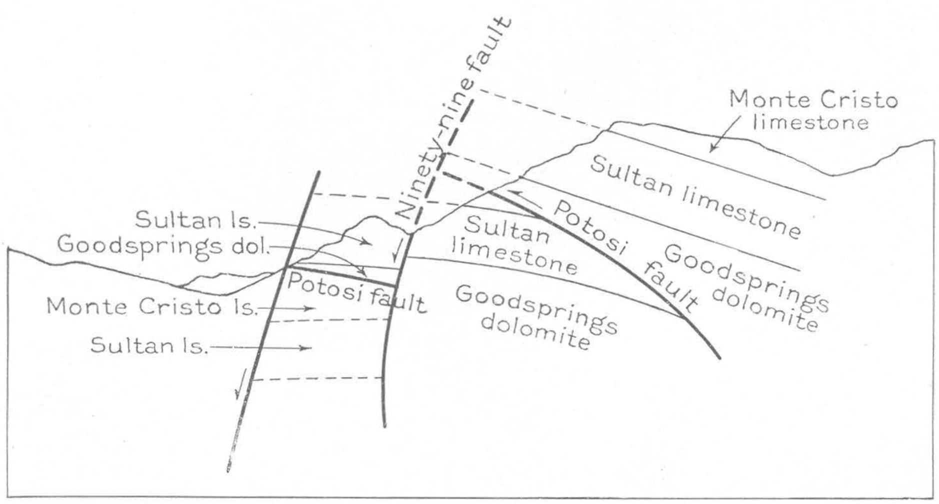
B. PLEISTOCENE CEMENTED GRAVEL, WHICH CAPS THE GROUP OF LOW HILLS WEST OF GOODSPRINGS IN SEC. 22, T. 24 S., R. 58 E.

The coarse fragments are limestone and dolomite, and the cement is crystalline calcite.



A. POTOSI MOUNTAIN FROM THE NORTHWEST, SHOWING FAULTS

View in sec. 5, T. 23 S., R. 58 E. Ds, Sultan limestone; Єg, Goodsprings dolomite.



B. DIAGRAM SHOWING FAULTS AND RELATIONS OF STRATA ILLUSTRATED IN *A*

The Potosi thrust repeats a large part of the Sultan limestone (Devonian) along the northeast escarpment of the peak (center). The Ninety-nine fault (normal) passes through the saddle in the center and its northern branch through the lower saddle on the left.

upper surface nearly coincides with the bedding, which trends N. 30° E. and dips 35° W. The lower surface is irregular in detail, and at the new shaft of the Prairie Flower claim it is parallel to the local strike of the beds but is considerably steeper than their dip. Where it has been traced northward, the sill becomes thinner

The Snowstorm sill is clearly traceable for 3,500 feet north of the Wilson Pass road. The maximum thickness is 60 feet at the south end, and it thins northward. Doubtless it is the northern extension of the Yellow Pine sill, even though that sill overlies the basal sandstone of the Bird Spring formation and the Snowstorm sill underlies the conglomeratic sandstone.

The Middlesex sill extends southward from the Middlesex mine and lies near the horizon of the Yellow Pine sill, although the sandstone under that sill is lacking here. At the mine the sill is 40 feet thick, but it thickens northward in the flat (Horseshoe Gulch) and thins southward.

The Alice dike extends 3,500 feet northeast from the mine of that name to the north end of the Middlesex sill. As exposed in several shallow shafts, the rock has the same mineral composition and texture as the Yellow Pine and other sills. Although it is not visibly sheared or crushed, the southeast wall appears to be continuous with the Alice fault, which is clearly shown on the surface and forms the southeast limit of the ore shoot of the Alice mine throughout the workings.

The Yellow Pine dike crops out on the surface east of the mine and has been explored on the 700 and 900 foot levels. (See pl. 36, *A*.) It is 60 to 80 feet thick.

Faults.—The faults of this area fall readily into three groups on the basis of their trend, dip, and direction of displacement, as indicated by offset beds and striae, which, however, are obtainable only underground.

1. Thrust faults that trend northeast and dip 45° or less west lie west of and above the Yellow Pine mine (Wilson thrust), north of it (Potosi thrust), and east of or under it (Contact thrust). What becomes of the Potosi thrust after it passes into the wash west of the Snowstorm mine is not known; it may die out, as the displacement steadily decreases in this direction. The only fault struck underground in any of the mines that closely resembles this group of thrust faults is that along which the ore bodies of the Yellow Pine mine occur.

2. Several faults that trend northeast and dip either northwest or southeast show clearly near the Alice mine. The Alice fault is a curved surface that dips southeast in the upper workings of that mine and northwest in the lower workings. It is the break along which a large block of beds on the southeast side has moved forward (northeast) 3,000 feet on the surface and appears to coincide with the southeast wall of the Alice dike. Underground the striae are uniformly horizontal. A fault that is parallel in strike but on the surface has a steep dip southeast crops out 600 feet west and appears to displace the upper surface of the Yellow Pine sill. It is not known in any underground workings. A ravine 2,000 feet west of the Alice mine marks the position of two near-by faults that trend northwest and dip steeply southeast. Doubtless these are the faults met in the Yellow Pine mine, at the bottom of the Hale shaft, and explored on the 700, 800, and 900 foot levels south. (See X, Y, Z, pl. 36, *A*.) There are abundant striae that are nearly horizontal also. These faults displace the Yellow Pine sill. In general, these faults make a large angle with the deeper thrust faults mentioned above.

3. North of the Hale shaft there are several faults that trend northwest and dip largely northeast. No less than 23 of these faults are struck in the workings of the Yellow Pine mine, and there are several on the Snowstorm claims, 1½ miles north. Underground the striae incline from 20° SE. to 50° NW. but almost all incline northwest at a smaller angle than that of the dip of the near-by beds, which is 35°. To accomplish the displacements indicated by the beds and the striae, the successive northeastern blocks adjacent to each fault must have been moved forward (southeast and upward). It is conclusively shown at some places that these faults break the Yellow Pine sill and hence are younger. The Yellow Pine dike occupies such a fault whose displacement is proved, and the Red Cloud dike occupies a parallel fracture.

Structural succession.—The foregoing observations lead to several confident conclusions. The Yellow Pine dike and probably the Red Cloud dike occupy faults that displace the Yellow Pine sill and hence are appreciably but not necessarily very much younger than that sill. Several of the northeastward-trending faults are assuredly younger than the sill, and it therefore seems probable that the Alice dike, which occupies the Alice fault, was intruded during the same structural epoch as the porphyry dikes farther north. The Middlesex sill may be a part of the Yellow Pine sill or a part of the Alice dike. The Snowstorm sill is probably the northward extension of the Yellow Pine sill, which continues northward under the wash.

It seems clear that none of the faults described above belong to the class termed normal, which are related to the settling of shallow blocks of the crust. Probably all were formed before the sulphide minerals were deposited, although there may have been further movement along some of them since the sulphides were deposited. In order to understand their place in the structural succession of this region, it will be necessary to consider the broader setting of these faults. The area under consideration lies in the curve of the Keystone thrust fault, where it turns to cross from the west side to the east side of the range. Many of the folds and faults that are clearly related to the compressive stresses that carried the main mass of Potosi Mountain eastward along the Contact thrust end southward against the Keystone thrust. South of Columbia Pass the range is made up of the block of rocks carried eastward on the Keystone thrust, which is probably younger than the Contact thrust. The northeastward-trending faults near the Alice mine seem to be transcurrent breaks produced during the eastward movement of the rocks near Columbia Pass. The group of northwestward-trending faults may be related to them but are probably related to the latest movements in the Contact block and hence may be slightly earlier.

The structural events may be summarized briefly as follows: (1) Folding and earliest thrust faulting—Contact, Potosi, and Wilson faults; (2) intrusion of Yellow Pine sill; (3) transcurrent faulting along northwest faults and Alice and other northeast faults; (4) intrusion of Yellow Pine, Alice, and Red Cloud dikes; (5) deposition of the ores.

KEYSTONE BLOCK

The Keystone thrust, which underlies the Keystone block, is readily recognized in many areas. North of the Mountain Springs road closely folded beds of the Goodsprings dolomite rest on the gently dipping Aztec sandstone. (See pl. 14, *A*, and sec. A–B, pl. 2.) In this area careful measurements show that the Keystone thrust is a plane surface for at least 2 miles. trending slightly west of north and dipping 8° W. Similarly the bedding of the Aztec sandstone, here a very massive unit about 2,200 feet thick, trends slightly east of north and dips 8° to 12° W. There can be no doubt that there is a slight but real discordance between the strike and dip of the thrust surface and those of the underlying sandstone. If this discordance were great there would be no basis for doubting that the thrust coincided with a fracture through the sandstone, but that a fracture could form so near the bedding without actually coinciding with it seems very unlikely. In the absence of other evidence the writer suggests that the thrust block moved forward on a surface of erosion rather than a fracture.[49] This conclusion was reached by Longwell [50] for the Red Spring thrust, which underlies the Keystone thrust 12 miles to the north.

The Keystone thrust is displaced several hundred feet by the Cottonwood fault, but half a mile south it is covered by alluvium. Near the divide along the road to the Potosi mine, at bench mark 6230, there is much brecciation of the beds of the Goodsprings dolomite which both overlie and underlie the fault, and its precise position is obscure. From Potosi Spring southward for 6 miles the thrust is either covered with alluvium or obscure. Its approximate position is shown along the low ridge west of Wilson Pass.

From the mouth of Keystone Wash eastward for 6 miles, nearly to Goodsprings, the thrust is clearly marked by a reddish zone 20 to 50 feet wide, the color being due to limonite that was probably formed by the oxidation of pyrite. This zone separates unlike beds of diverse structure throughout. (See pl. 14, *B*.) It has been explored by prospects at many places from the Keystone mine eastward, as it is locally reported to yield traces of gold by assay. The dip of the thrust ranges from 50° S., a mile west of Columbia Pass to about 30° W., 3 miles south of Goodsprings, where it separates limestone beds of the Moenkopi formation on the east from dolomite beds of the Goodsprings formation on the west. (See sec. I–J, pl. 2.)

Doubtless the thrust fault at the mouth of Devil Canyon, near the southwest corner of the quadrangle, where the Goodsprings dolomite rests on the Bird Spring formation, is the southern extension of this thrust. In this locality the fault dips about 20° W., and the overlying and underlying beds are almost conformable.

The upper limit of the Keystone block is the Sultan thrust, shown only in the southern part of the quadrangle. This thrust is readily traced from Singer Wash southeastward 4 miles to the point south of Devil Canyon where it meets the Tam o' Shanter fault. There are several isolated blocks of older beds resting on younger beds north and east of Singer Wash that probably mark the position of the Sultan thrust. (See p. 151.) Northeast of the Green Monster mine, which lies 10 miles west of Wilson Pass and therefore several miles west of the quadrangle, there is a thrust that may be the northern extension of the Sultan overthrust.

Within the Keystone block there are several thrust faults, of which the Puelz is the largest. It is well shown near the Puelz mine, southwest of Table Mountain. Near the Puelz mine the dip slip probably is between 1,000 and 2,000 feet, but this amount decreases rapidly southeast. The fault along which a block of the Monte Cristo limestone has been thrust upon the Bird Spring formation south of the Bill Nye mine may be a part of the Puelz thrust. The other thrust faults near by are explored within beds of the Bird Spring formation, and although they appear to be small, there is no accurate measure of their displacement.

From Potosi Wash northward 7 miles to the northern border of the quadrangle the structure of the Keystone block is very simple. The Devonian limestones form the crest of a persistent ridge, which is broken only here and there by faults of small displacement. Ten

[49] G. K. Gilbert, who crossed the range at Mountain Springs in 1872, covering the region hastily, presents a section of the range in which the dolomites of the Goodsprings formation are interpreted as Mesozoic, conformably overlying the Mesozoic sandstone.

[50] Longwell, C. R., Structural studies in southern Nevada and western Arizona: Geol. Soc. America Bull., vol. 37, pp. 565–570 1926.

of these are shown on Plate 1. Of these only two, the Ninety-nine and North Ninety-nine appear to be continuous through the Keystone fault into the underlying Contact block. The seven faults southwest of the Ninety-nine fault appear to drop the south sides and probably represent local shearing during the epoch of thrust faulting.

That part of the Keystone block which lies between Potosi Wash on the north and the Ironside fault on the south forms a structural unit sharply set off from the region southeast of the Ironside fault. Broadly the area of thin dolomite beds of the Goodsprings formation is anticlinal; in detail it is broken by many small faults and several large faults without distinctive pattern. (See pls. 1 and 2.) Probably these faults represent the local shifts of masses of thin-bedded weak rocks along the crest of an anticline caused by compression at the time the thrust faults were formed.

The belt of rocks southwest of Keystone Wash and northwest of the Ironside fault includes two simple anticlines and an intervening syncline in lower Paleozoic rocks. The western anticline is well shown near the Ironside mine, where the beds on the east limb are vertical. The Boss mine explores a mineralized fault zone that trends northwest and merges with the Ironside fault. This fault shows many horizontal grooves and striae, and the conclusion is reached that the Ironside fault was formed during the epoch of thrust faults. It seems clear that the Keystone overthrust is offset by the Ironside fault, which, however, probably does not extend downward into the beds of the Contact block. The sharp folds with northeast trend on the northwest side of the Ironside fault contrast sharply with the broad syncline with eastward trend on the southeast side.

Several hills in this part of the Keystone block are capped by masses of cemented limestone and dolomite blocks whose origin is obscure. The large hill and several smaller hills in the W. ½ sec. 2, T. 24 S., R. 57 E., are made up of such material, as is also that at the mouth of Keystone Wash, in the NW. ¼ sec. 24, T. 24 S., R. 57 E. The blocks are wholly angular and, although cemented by dense calcite, weather free and form a talus around the base of the hill. Most of them range from 1 to 5 feet in diameter, but some are 10 feet. They include materials found throughout the upper Paleozoic formations. The idea was first entertained that they were breccias related to overthrust faults, but this was abandoned in favor of the belief that, like the cemented wash in the northeast corner of the quadrangle, they represent waste from the near-by higher hills. (See p. 41.)

That part of the Keystone block which extends from the Ironside fault southeastward to the southern border of the quadrangle is structurally very complex. It may be regarded as separable into two smaller parts, roughly divided by the Fredrickson fault, which extends southeastward 4 miles from the mine of that name and westward along the road to Ripley. The rocks that lie north and northeast of this fault are folded into a sharp anticline and syncline that become open folds westward toward the Boss mine. These folds are broken by two groups of faults, one group, near the Kirby mine, trending nearly at right angles to the axes of the folds, and the other, only two of which are shown, roughly parallel to the Fredrickson fault. Mineralization was noted at some place on almost every fault of these two groups, and ore bodies have been explored on several, such as the Rose and Kirby. Probably all are premineral. The faults that cut across the folds at right angles appear to represent minor slips developed late in the epoch of overthrust faulting.

The Fredrickson fault is uncommonly interesting. It can be traced for more than a mile near the mine by a reef of dolomite breccia 20 to 50 feet wide and locally as much as 25 feet high. It probably passes by the mouth of the southern tunnel of the Argentena group, as the cut at the entrance shows 20 feet of cemented breccia. It is inconspicuous near the Lookout mine except by the offset of beds but is marked by a reef of breccia for a mile south of the Mountain Top mine. Throughout this course of 4 miles the dip is 60° to 75° SW. At the Fredrickson mine it turns abruptly west, and its outcrop coincides with the local bedding of the Goodsprings dolomite. Northwest of the Argentena mine the southwest side of the fault has dropped relative to the northeast, the apparent dip slip attaining a maximum of 400 feet near the Fredrickson mine, but south of the Argentena mine the northeast side has dropped about 100 feet. From the Mountain Top mine southeast, however, the southwest side has dropped. There is extensive dolomitization of the rocks on both sides of the fault, and although no ore deposits have been mined on it many have been explored within 800 feet of it in a distance of 3 miles. Even though for most of its outcrop it shows the relations of a normal fault, a more satisfactory explanation would assume that it is a transcurrent fault formed during the thrust epoch by the movement of the southwest side northwest, almost horizontally. West of the Fredrickson mine it probably becomes a bedding-plane thrust fault.

The northward-trending fault a mile west of Columbia Pass displaces both the Keystone and Contact thrusts near the Ruth mine (p. 139) and is mineralized at the Cosmopolitan mine. An alternative explanation might relate this fault and the Fredrickson fault by assuming that both are thrust faults along which the movement is largely horizontal. This fault and two others parallel to it near Kirby Wash are regarded as the types of "early normal, premineral faults" in the region. (See p. 93.)

In the vicinity of Crystal Pass there are two faults that trend northwest and dip steeply southwest.

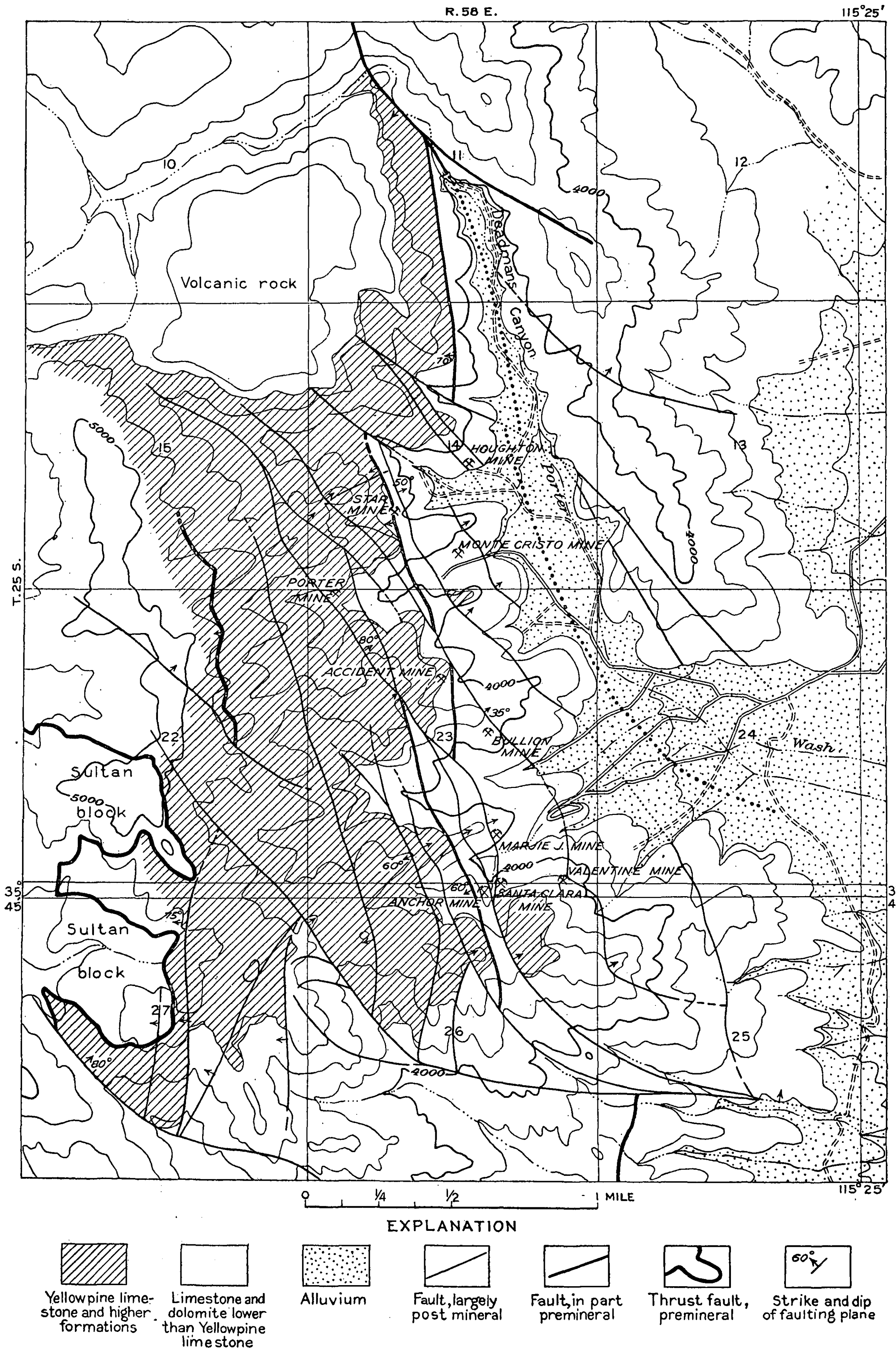


FIGURE 6.—Faults in the vicinity of Porter Wash

Along these faults the beds on the west side have dropped, and the wall rocks are extensively dolomitized. These faults also are considered to belong to the early normal premineral group, for near-by parallel faults contain granite porphyry dikes and show sporadic mineralization.

That part of the Keystone block which lies south and southwest of the Fredrickson fault contains more faults than any other area of the same size in the quadrangle, but they are largely localized around Porter Wash. (See fig. 6.) There are several reverse faults on the crest and west side of the range, but none were identified with assurance on the east side. The Puelz fault is the most impressive, but it disappears to the southeast, near the crest of the range.

The area west of Porter Wash is intricately broken by normal faults and is uncommon in presenting so many closely spaced nearly parallel faults, about half of which dip in one direction and half in the opposite direction. After the Star mine had been examined (see p. 156) and it was clear that lead and zinc sulphides had been deposited in one of the westward dipping faults, the idea was considered that all faults that dip west were premineral. It was clear from the experience in several mines, notably the Anchor (p. 160), that most if not all of the eastward-dipping faults were postmineral. In the light of the latest work it now seems that some of the westward-dipping faults are postmineral and probably contemporaneous with those which dip east. (See pl. 15, *A* and *B*.) In their southward extension all the eastward-dipping faults merge with the fault north of Devil Canyon, and the others terminate against that fault. None of the faults west of Porter Wash (fig. 6) break the flows of Table Mountain, although there are other small inconspicuous faults that do so.

The Keystone dike is limited northward by the Keystone thrust fault and was forced upward into the dolomite beds of the Goodsprings formation. Even though no contact effects were noted on the beds below the fault, it is believed that the dike is younger than the thrust. As noted in the description of the Keystone mine, the dike shows the effects of thrust faulting underground, thus indicating that pressure in this region was still effective after the intrusion.

SULTAN BLOCK

The Sultan block is much smaller than the three previously described and is otherwise unique. The Sultan overthrust is readily traced on the surface from Singer Wash southeastward for about 4 miles to the head of Devil Canyon, a short distance south of which it ends abruptly at the Tam o' Shanter fault, which trends southwest. Continuing southeast along the strike of the Sultan thrust, however, there is a sharply overturned anticline in beds of the Bird Spring formation. This anticline dies out at Diablo Grande Peak, just beyond the south boundary of the quadrangle. Near the Sultan mine the breccia zone of the fault is 800 feet wide, but it thins steadily northwest and southeast from the mine. What is undoubtedly the northward extension of the Sultan fault crops out prominently on the east end of Bonanza Hill, but here the strike is northeast and the dip 40° SE. The fault is marked by a zone of coarse angular dolomitized breccia from 50 to 75 feet thick. The near-by beds of the Bird Spring formation are sporadically altered to dolomite, but the overlying beds of the Monte Cristo limestone are more widely altered.

An overthrust fault is well shown in the hills in which the Spelter and Hoodoo mines are located. Beds of the Monte Cristo limestone rest upon those of the Bird Spring formation, and they are separated by a zone of dolomitized breccia 100 feet or more thick. This zone trends northwest, but unlike the Sultan overthrust it dips 20° to 30° NE. It is not clear whether this is the original attitude of the fault or whether it has been tilted eastward later. Probably the latter explanation is correct, even though it assumes the presence of a fault under the alluvium north of Hoodoo Hill. However, this thrust is probably the northwest extension of the Sultan fault. The Hoodoo mine workings are wholly in the fault breccia.

Two miles northeast of this hill the crest of the ridge southeast of the Bill Nye mine is a block of limestones of the Monte Cristo and Bird Spring formations, thrust eastward upon the beds of the Bird Spring formation. At the west end of this ridge the thrust surface is synclinal, but at the east end it is nearly horizontal. It is marked by a conspicuous zone of breccia. This thrust may be the northeast extension of the Sultan or a part of the Puelz fault, probably the latter.

In the area of the Goodsprings dolomite southwest of Little Devil Peak several thrust and normal faults are well exposed. One that may be called the Milford thrust crops out at the head of Milford Wash, northeast of the Milford mine. (See pl. 16, *A*, also sec. I–J, pl. 2.) In that area the entire Sultan limestone is sharply upturned under the fault, which dips 45° SW. The overlying thin dolomite beds of the Goodsprings formation are turned sharply downward over the fault. The breccia along the fault is not impressive, as it scarcely exceeds 15 feet in width at any place. There are two smaller parallel reverse faults above the Milford to the southwest. Each of these reverse faults ends on the southeast against a southwestward-trending fault that lies parallel to the Tam o' Shanter fault, against which the Sultan overthrust terminates. The thin-bedded dolomites of the Goodsprings formation contain many small reverse faults in the block above these faults. (See pl. 16, *B*.)

The relations of the principal faults near the Milford and Ingomar mines are presented in the descriptions of those mines (pp. 164, 166). Attention should be directed here to the presence of several ore-bearing faults of small displacement that trend northwest and dip southwest, which are cut and displaced by others that trend northwest and dip northeast. The former group clearly belongs to the premineral normal group, and the latter to the postmineral normal faults. Their relations are well shown both on the surface and underground at the Milford mine (p. 164).

A short tunnel west of the Tiffin mine on the north side of Singer Wash explores a fault that trends N. 10° E. and dips 70° W., on the east side of which there is dolomitized limestone of the Monte Cristo formation and on the west side a brown flow breccia much like that east of the Sultan mine. This fault is clearly younger than the lavas. Another of the same group lies east of the Sultan mine, in the SE. ¼ sec. 20, T. 25 S., R. 58 E. It trends N. 35° E. and dips 80° NW., and the west side has dropped 25 feet. The offset shows clearly at the contact of the latite flow on the tuffs.

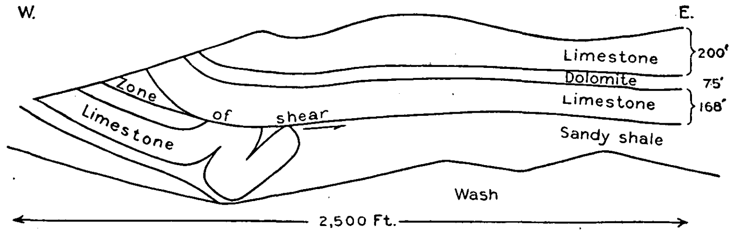


FIGURE 7.—Sketch of the southwest end of Mule Spring Mountain, in the S. ½ sec. 21, T. 22 S., R. 57 E., showing crumpled lower limestone of Kaibab formation thrust under entire Kaibab formation. The stratigraphic section given on page 31 was measured at this locality

MINOR STRUCTURAL FEATURES

Although not susceptible of proof in all places, it is commonly believed that a block of older rocks that rests upon underlying younger rocks has moved over upon those younger rocks, which have remained relatively, if not actually, fixed in position. For this reason the separating fault is called an overthrust. It is the commonly accepted belief, although debatable, that in such regions there was an active pressure from the direction of movement of the overriding block which met a resistance from the direction of the overridden block. In some regions, such as southern Nevada, where the large overthrust faults dip almost uniformly in one direction—that is, west to southwest—there are some flat faults which separate older rocks above from the younger rock below and which dip in a direction opposite to the rest—that is, east to northeast. Such faults are termed underthrusts, although it is not demonstrable that the underlying young rocks have actually been pushed under a fixed overlying block. Such underthrust faults occur in Mule Spring Mountain and in sec. 28, T. 22 S., R. 58 E. Figure 7 shows what are almost diagrammatic exposures on the southwest end of Mule Spring Mountain, in the northwest corner of the quadrangle. The lower limestone stratum of the Kaibab limestone is crumpled into a double fold, which is overlain by the entire Kaibab limestone. At the other locality mentioned the blocks of rocks involved are much smaller. A part of the Monte Cristo limestone dipping eastward underlies a block composed of both the Sultan and Monte Cristo formations. The separating fault dips 50° E.

Commonly where a block of rocks has been pushed forward over an underlying block, a fracture develops that cuts across the beds of both blocks and dips toward the source of pressure. In many parts of the Goodsprings quadrangle the fracture or zone of movement locally coincides closely with the bedding. The most impressive exposure of this condition is found on the east side of the range south of Wilson Pass, in the E. ½ sec. 18, T. 24 S., R. 58 E. Figure 8 is drawn from a photograph taken in this locality. Between two groups of beds that are nearly parallel there is a zone of confused beds about 300 feet thick. This zone contains a number of blocks which appear to be fragments of the same bed but are inclined much more steeply than the overlying and underlying beds. It seems clear that the upper zone *a*, has ridden eastward over the lower zone, *c*, thereby crumpling the beds in the intermediate zone. Probably if such a zone, *b*, were investigated below the surface, it would be found to pass into a thrust fault that cuts across the bedding of the underlying block. Although faults such as this are larger and more impressive, in general relations they closely resemble a number of bedding-plane faults of the region which contain ore deposits. Many of the ore bodies of the Yellow Pine mine occur in a breccia zone that is roughly parallel to the bedding

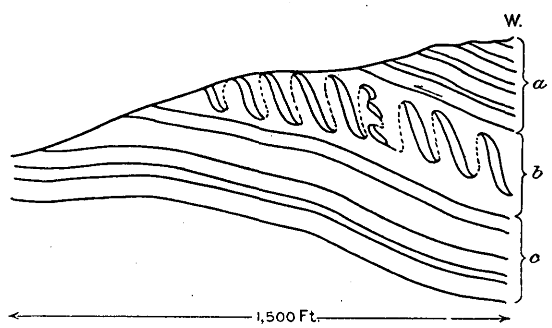


FIGURE 8.—Sketch cross section of beds on the northeast side of Shenandoah Peak, in the E. ½ sec. 18, T. 24 S., R. 58 E., showing crumpled beds between parallel beds of limestone of Bird Spring formation. Zone *a* has moved eastward over zone *c*, causing the intervening beds, zone *c*, to crumple and thicken

but is overlain by a smooth hanging wall. The ore zones of the Anchor, Azurite, and other mines occur in similar bedding-plane faults. It seems clear that the faults were formed during the epoch of thrust faults.

SUMMARY

In the preceding pages it has been the intent to describe the outstanding structural features of this region in such a way as to make clear the succession of structural events. Before there was much if any faulting in the region the bedded rocks were probably deformed from their original horizontal attitude into numerous folds. Not only are the beds locally folded on both sides of the overthrusts, but in a broad way these faults cut across many parts of large folds. Some anticlines appear to be larger features and affect much thicker sections than others. The larger folds appear to coincide with the outcrops of Devonian and lower Mississippian formations whose combined thickness, ranging from 1,000 to 1,800 feet, permitted them to act as a more competent stratum [51] than the overlying and underlying formations. In many places numerous small folds have been developed in the thin-bedded dolomites or limestones of the pre-Devonian and Pennsylvanian formations, which probably do not persist into higher or lower rocks. For example, east of Wilson Pass there is a single open syncline in beds of the lower part of the Bird Spring formation, whereas farther northwest, along the extension of this syncline, the higher, thin-bedded limestones show several close folds. The several closely spaced folds in the upper part of the Bird Spring formation southwest of Wilson Pass are probably represented by a single fold in the lower formations.

The relations of the several major overthrusts are worthy of some speculation. The areal outcrop of the Contact block is rudely elliptical, and it is surrounded on the north, west, and south by the overlying Keystone block. If, as inferred, the Keystone block has been forced over a surface of erosion cut across the Aztec sandstone, either an appreciable amount of time must have elapsed between the completion of the Contact overthrust and beginning of the Keystone overthrust, or successive thrusts reached the surface in this region. Broadly, the fact that the Contact, Potosi, and Wilson thrusts end on the surface against the Keystone fault and probably in depth pass under it indicates that the overthrust under the Bird Spring Range was the earliest and that the succeeding thrusts westward—the Contact, Keystone, and Sultan—were successively younger. Figure 9 shows the probable relations of the thrust faults in the several blocks. The question whether the upper block over a thrust fault moved across a fixed underlying block or whether the under block was thrust downward beneath a fixed overlying block will not be raised at this place. The purpose here is to consider only relative movement.

A consideration of the work done in overcoming friction on thrust faults also leads to the conclusion that the flat overthrusts were largely formed before the steeper reverse faults. Consideration of Figure 9 suggests that for a unit length of any block the thrusts consume energy almost in proportion to their extent down the dip into the crust. If that is true the block above an overthrust would move forward until the friction was too great to be overcome; after that a steeper fault would be formed and the block above it would be raised. Actually, it might be possible to raise so enormous a mass of rock in a single thrust block that movement on the lowest flat thrust might begin again.

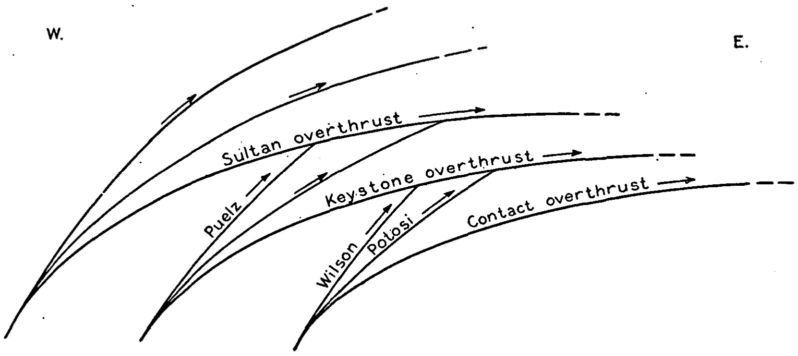


FIGURE 9.—Generalized cross section of the overthrust faults of the Spring Mountains

The flaws, or those faults that largely trend northeast, roughly normal to the trend of the folds, many of which are mineralized, were probably formed late in the epoch of thrust faulting.

There is no clear field evidence that all the mineralized normal faults coincide with thrust faults, but many probably do so. Some, such as the Fredrickson, are accompanied by large breccia zones and have such relations to the surrounding rocks that they seem to be steep reverse faults along which a renewed movement, opposite in direction to the earlier, may have taken place. Most of the assured postmineral faults have small breccias, rarely exceeding 10 feet in width. It seems significant that where there is mineralization in breccia zones along faults oblique to the local bedding, the faults either trend normal to the local folds and are clearly related to the thrusts or trend northwest and dip southwest rather than northeast.

In many places in the region mineralized faults or ore bodies are cut off by unmineralized faults, as in the Alice mine (p. 137). It is not possible to state with assurance in every case whether the unmineralized fault was formed before or after the ore minerals were in place, but no ore minerals were deposited in it. In other words, such unmineralized faults may be either premineral or postmineral. Fairly good evidence of

[51] Willis, Bailey, Mechanics of Appalachian structure: U. S. Geol. Survey Thirteenth Ann. Rept., pt. 2, pp. 262-263, 1893.

postmineral faults has been obtained in the Anchor, Milford, and Boss mines. In the Milford and Boss these faults displace earlier mineral-bearing faults. In the Alice mine the ore zone is cut by a fault that is probably premineral but is barren. In the Yellow Pine mine most of the faults along which the ore zone is displaced are barren of ore minerals but are related to the epoch of thrust faults and probably premineral.

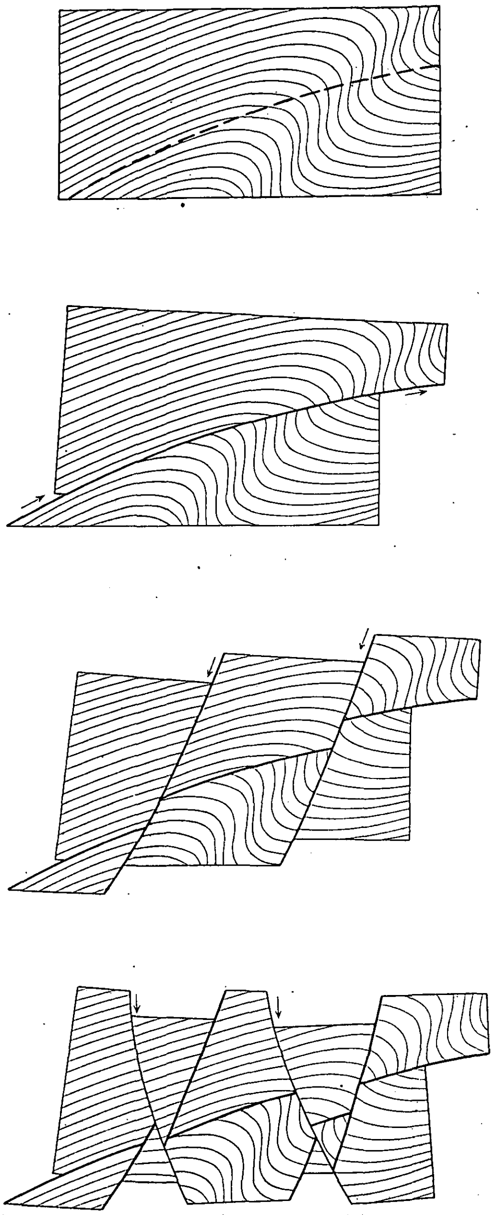


FIGURE 10.—Sketches showing effects of three successive groups of faults upon a block of folded beds

Figure 10 has been prepared to show the effect upon a simple rectangular block of each group of faults taking place in the order outlined above.

The relation of both the coarse-grained and the fine-grained igneous rocks to the faults is fairly clear. The largest body of granite porphyry, the Yellow Pine sill, is intruded near the unconformity at the base of the Bird Spring formation, but it is cut by flaws of the thrust epoch, in one of which a dike of similar rock has been intruded. The top of the Lavina dike coincides with the Contact overthrust, and the dike is clearly later than the fault. There is a series of dikes of this same rock that roughly follow the Keystone overthrust from the Keystone mine to Crystal Pass, about 7 miles southeast. These dikes lie in diverse attitudes with respect to the overthrust surface, and the largest, at the Keystone mine, abuts against it. It seems that all these bodies were intruded in the midst of the thrust epoch but before the sulphide mineralization of the region.

Most of the postmineral faults near Porter Wash do not disturb the flows of Table Mountain, although these as well as the flows near the Sultan mine are broken by small faults. East of Ivanpah Valley, however, enormous normal faults have been formed since the surface lavas were poured out.

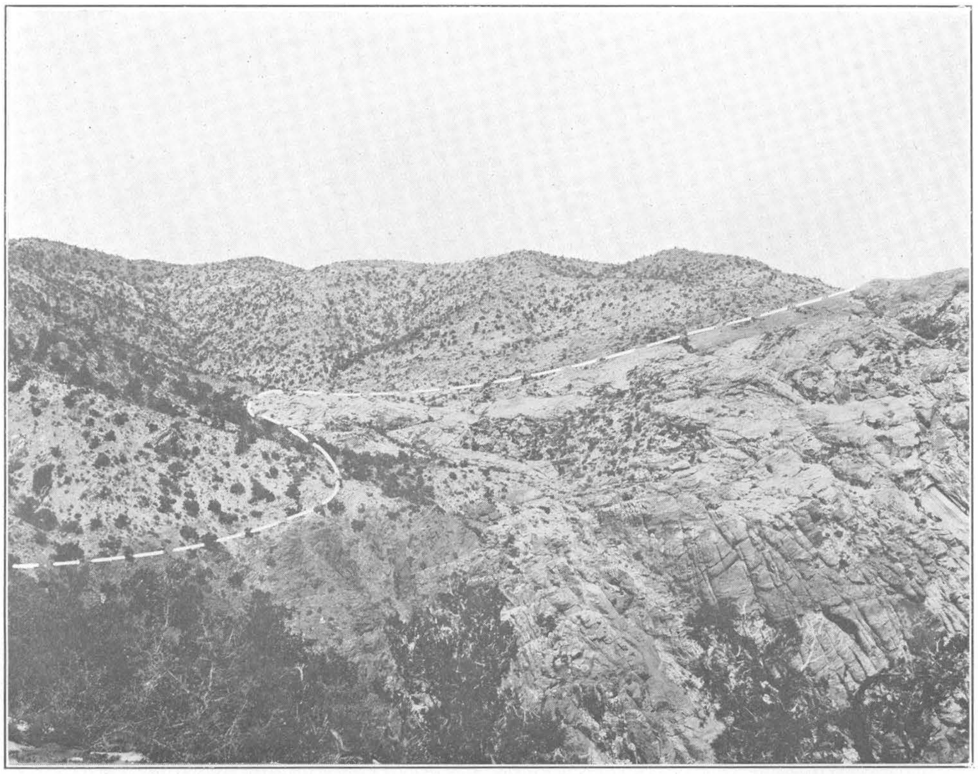
The following summary shows the succession of folds, faults, intrusion, extrusion, and mineralization of the Goodsprings region:

Folding.
Bird Spring overthrust.
Contact overthrust.
Potosi fault.
Wilson fault.
Keystone overthrust.
Ironside fault.
Puelz fault.
Sultan overthrust.
Milford and Tam o' Shanter faults.
Intrusion.
Early normal faults (some follow steep reverse faults).
Mineralization.
Late normal faults.
Flows and tuffs of Table Mountain, including intrusive rocks of Diablo Grande Peak and Sultan area.
Normal faults.

AGE OF STRUCTURAL EVENTS

As there are no fossil-bearing beds or persistent strata in the region younger than the Aztec sandstone, of Jurassic (?) age, it is not possible to place precisely the age of the structural events described above, and it will be necessary to draw inferences from the knowledge of the history of near-by regions. On the basis of his work in the Muddy Mountains, 55 miles northeast of Goodsprings, Longwell [52] concluded that the folds and overthrust faults of that region were late Mesozoic and that the region was exposed to great erosion during late Mesozoic and early Tertiary time. The gravel, limestone, magnesite, gypsum, tuff, and borax-bearing beds that make up the Overton fanglomerate and Horse Spring formation were considered to be Miocene on the basis of their similarity to the Esmeralda (Siebert)

[52] Longwell, C. R., Geology of the Muddy Mountains, Nev.: Am. Jour. Sci., 5th ser., vol. 1, p. 61, 1921.

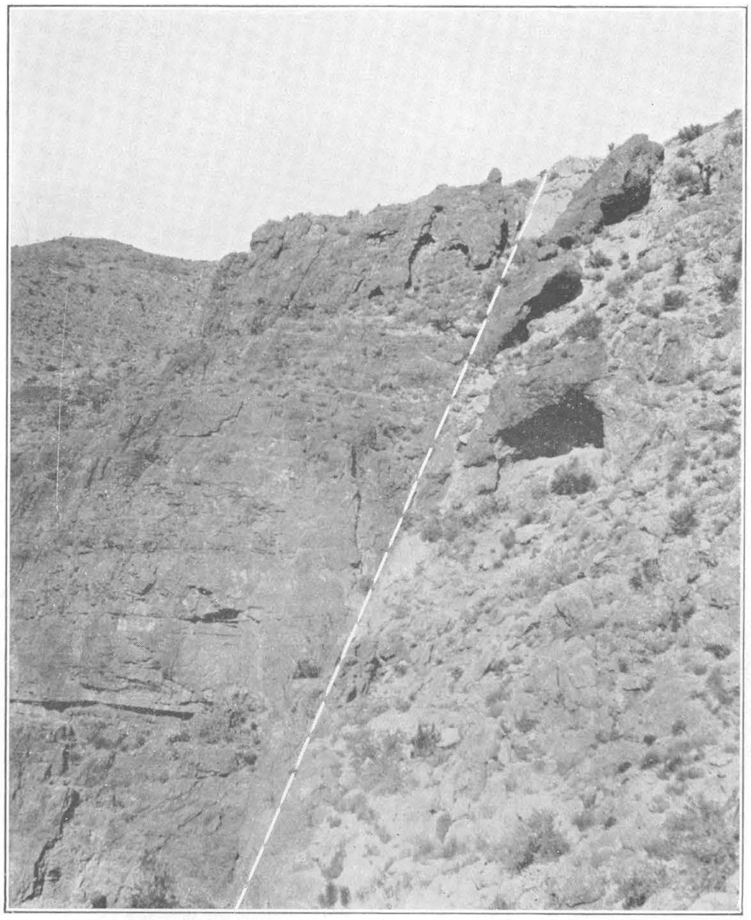


A. THIN-BEDDED DOLOMITE OF THE GOODSPRINGS FORMATION (UPPER CAMBRIAN) THRUST UPON THE AZTEC SANDSTONE (JURASSIC?) IN NORTHEAST CORNER OF SEC. 21, T. 22 S., R. 58 E.

The contact marks the trace of the Keystone thrust. The curve in the trace is due to local irregularities in the surface and to perspective.

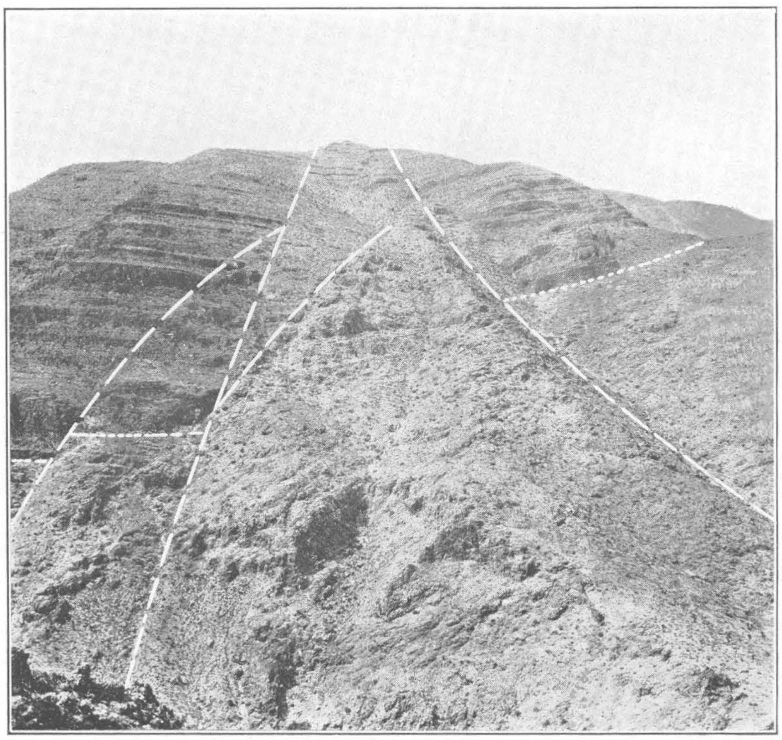
B. TRACE OF THE KEYSTONE THRUST WEST OF GOODSPRINGS IN THE SW. ¼ SEC. 29, T. 24 S., R. 58 E.

On the right crumpled limestones (now dolomitized) of the Bird Spring formation (Pennsylvanian); on the left thin-bedded dolomite of the Goodsprings formation (Upper Cambrian). The trace is marked by a reddish zone formed by the oxidation of pyrite. The curve is due to relief and perspective.



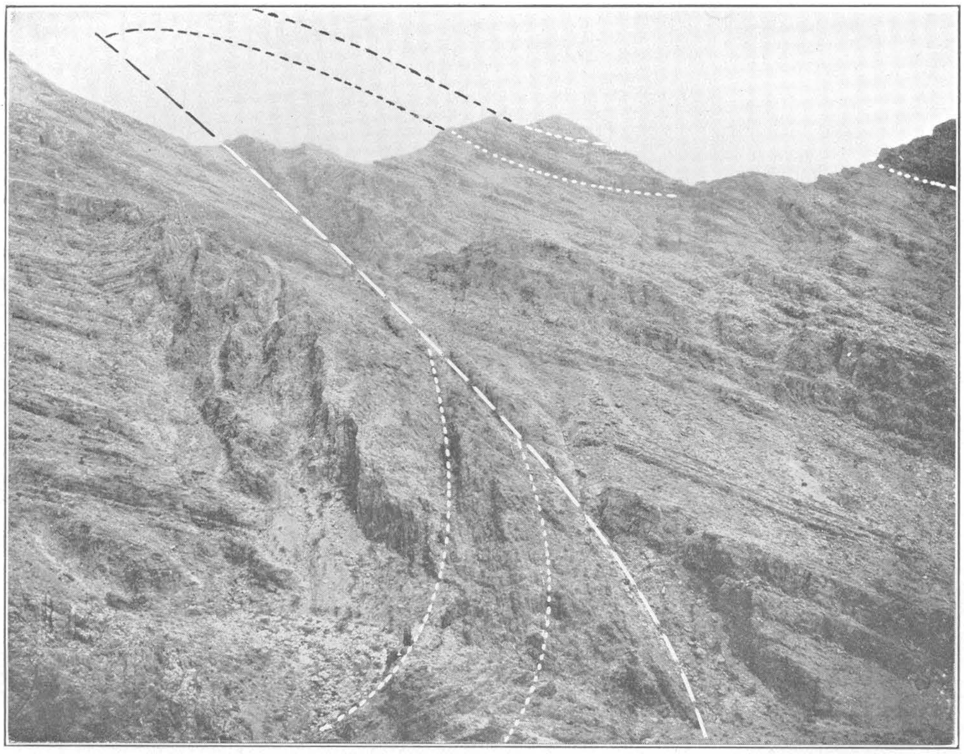
A. TRACE OF A NORMAL FAULT IN THE E. ½ SEC. 27, T. 25 S., R. 58 E.

Bullion dolomite (light) on the right; Yellowpine limestone (dark) on the left. The Yellowpine limestone is not altered to dolomite.



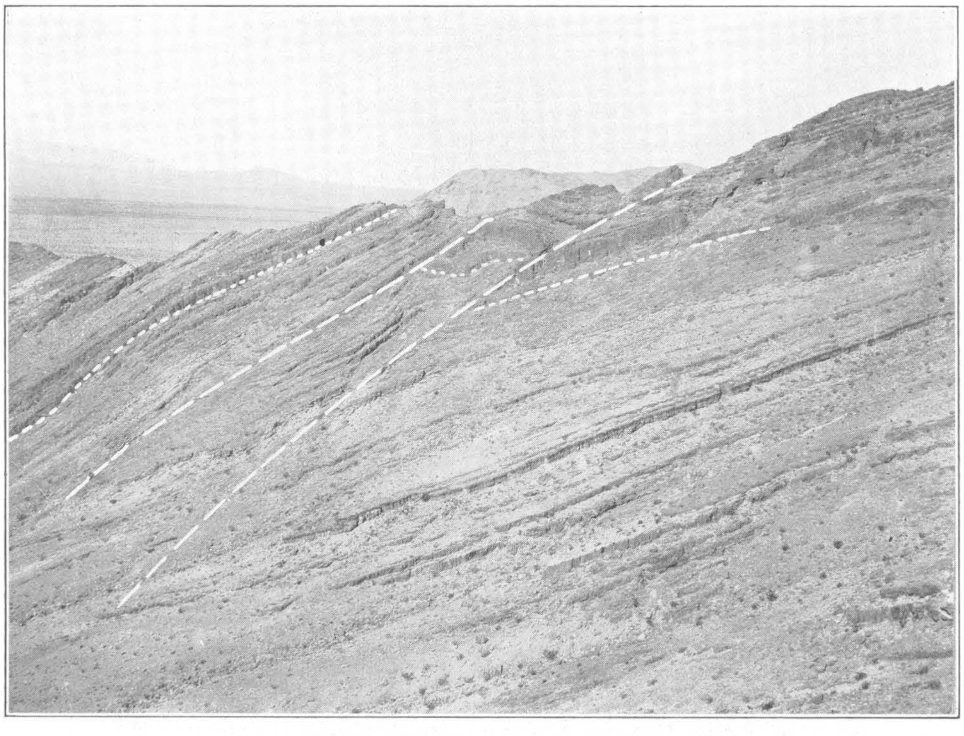
B. WEDGE OF BULLION DOLOMITE SEPARATED BY FAULTS FROM BLOCKS OF YELLOWPINE LIMESTONE

View northwest toward ridge west of the Bullion mine, sec. 23, T. 25 S., R. 58 E. The faults and the base of the Yellowpine limestone are indicated by dashed and dotted lines, respectively.



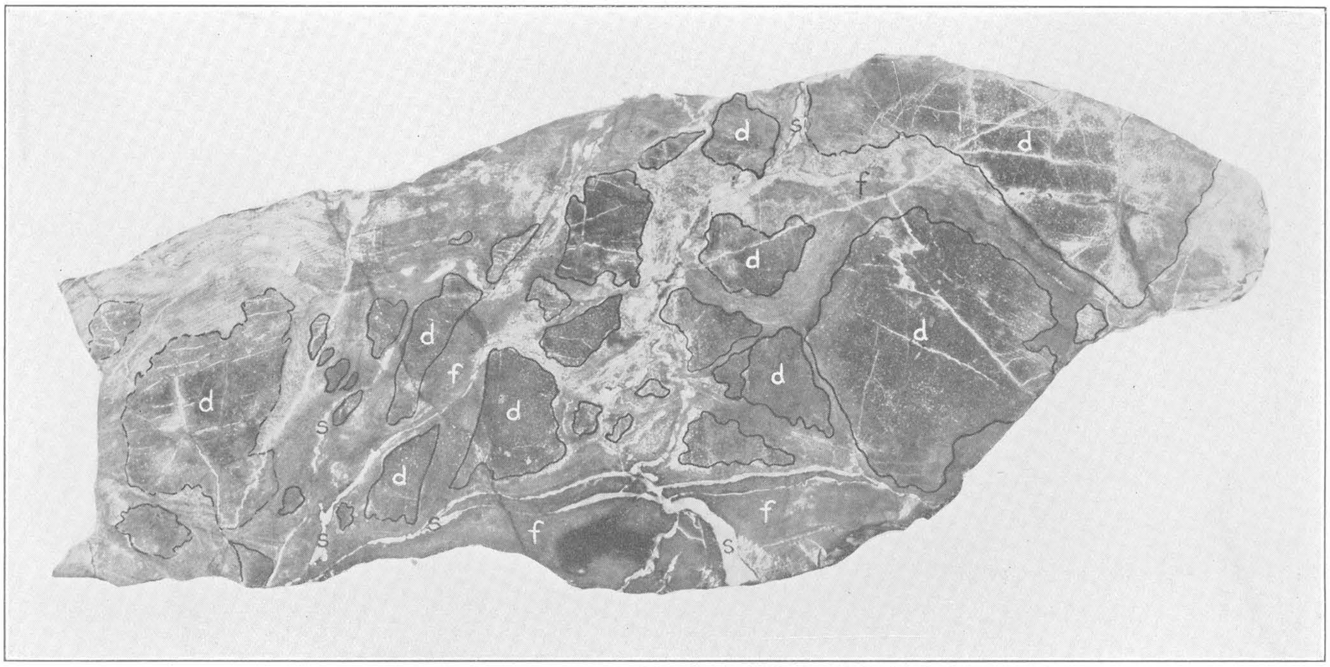
A. TRACE OF THE MILFORD THRUST AT THE HEAD OF MILFORD WASH IN SEC. 33, T. 25 S., R. 58 E.

On the left, thin-bedded limestones near the base of the Sultan formation, upturned under the fault; on the right, thin-bedded dolomites near the top of the Goodsprings formation (Upper Cambrian) turned down toward the fault. The Ironside dolomite is outlined on both sides of the fault by dotted lines.



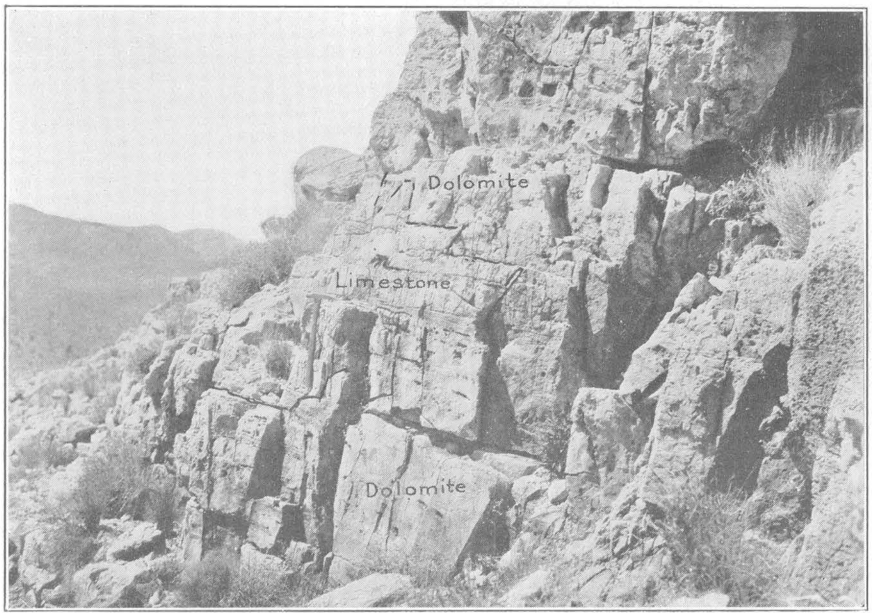
B. THIN-BEDDED DOLOMITE OF THE GOODSPRINGS FORMATION BROKEN BY TWO SMALL THRUST FAULTS

The ridge lies due west of Little Devil Peak, on the west side of the range, in sec. 30, T. 25 S., R. 58 E. Mesquite Valley appears in the distance. View northwest.

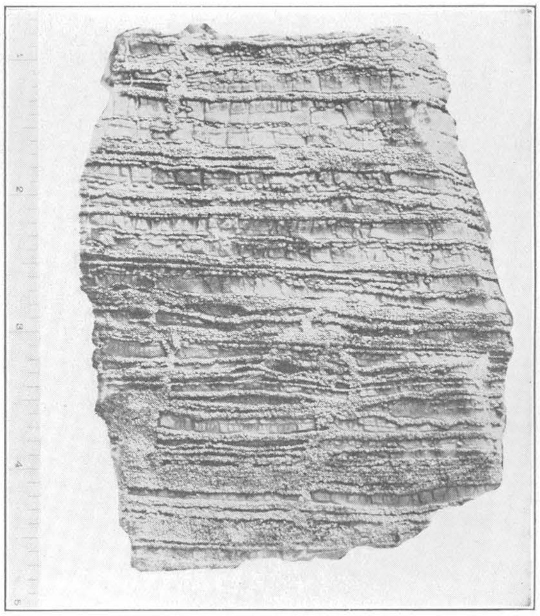


A. POLISHED SPECIMEN OF DOLOMITE SHOWING ALTERATION TO SERPENTINE

The dolomitized Crystal Pass limestone has been ferrated along fractures and the iron-bearing portion then altered to serpentine along fractures. From west side of granite porphyry dike in SE. ¼ sec. 2, T. 25 S., R. 58 E., southwest of Crystal Pass. Natural size. d, dolomite; f, ferrated dolomite; s, serpentinized dolomite.



B. BLOCK OF VALENTINE LIMESTONE MEMBER OF SULTAN FORMATION PRESERVED UNALTERED IN LARGE BODY OF DOLOMITE EAST OF CRYSTAL PASS, IN SEC. 1, T. 25 S., R. 58 E.



C. SPECIMEN OF PARTLY DOLOMITIZED LIMESTONE OF CRYSTAL PASS LIMESTONE MEMBER OF SULTAN FORMATION FROM NE. ¼ SEC. 11, T. 25 S., R. 58 E.

The limestone is uniformly thin bedded, and dolomitization has progressed along bedding planes, but local crosscutting fractures have also facilitated the process of alteration. On the weathered surface the dolomite stands in relief because the limestone is more soluble.

formation of western Nevada. These beds in the Muddy Mountains are greatly deformed but overlap the folded Jurassic and earlier beds and the overthrust faults of the area. Later work by Stock [53] led to the conclusion that slightly disturbed beds near Panaca, 145 miles north of Goodsprings, are probably Pliocene, whereas the flat beds of Muddy Valley, between Logan and Overton, which unconformably overlie the Overton and Horse Spring beds, are probably slightly older than the Panaca formation. In both these regions the Tertiary beds were laid down on a surface eroded in the folded Paleozoic and Mesozoic formations but have scarcely been disturbed since they were deposited.

On the basis of work in the western part of the Mohave Desert, 160 miles southwest of Goodsprings, Baker [54] concluded that the widely separated groups of beds made up of volcanic ash, lava flows, limestone, gypsum, and borate minerals and given the name "Rosamond series," are upper Miocene. Later Merriam,[55] summarizing field work and study of these beds from 1911 to 1918, especially near Barstow and Ricardo, concluded that they do not represent one great period of accumulation of sediments but include beds that range in age from upper Miocene to lower Pliocene. Like the Horse Spring formation, these beds are highly folded.

Beds of sandstone, tuff, and diatomaceous earth considered to be a part of the Esmeralda formation, of Miocene age, have been recognized by Ball [56] and Ransome [57] in many parts of southwestern Nevada. Although broken by faults in many places, these beds are in general nearly horizontal. In a few places, such as the Funeral Mountains and Pahute Mesa, they dip as much as 30°, or even 60°, but are not folded. In these areas, however, except for certain coarse-grained granitic rocks, inferred to have been intruded between the Jurassic and Tertiary, none of the pre-Tertiary rocks that underlie the Esmeralda formation in southwestern Nevada are younger than Pennsylvanian. It can only be said with assurance, therefore, that the folds, overthrusts, and premineral faults of the Goodsprings area are post-Jurassic and pre-Miocene. These data would indicate that the granitic intrusions are probably late Jurassic and therefore allied to those of the Sierra Nevada

From another standpoint, however, the folds, overthrust faults, and porphyry intrusions appear to be younger, possibly late Cretaceous or early Tertiary. In Utah, Arizona, Colorado, and New Mexico numerous masses of granitic rocks were certainly intruded in late Cretaceous or early Tertiary time. To quote Lindgren: [58]

> There are very many smaller batholiths [than those of Idaho and Boulder, Mont.], stocks, and laccoliths scattered through Montana, Nevada, Colorado, Utah, New Mexico, and Arizona; they are almost always quartz monzonites or granodiorites, in places grading into more acid alaskites, and are often intruded in late Cretaceous beds. * * * In Arizona the same conditions prevail—for instance, at Clifton, where rocks ranging from diorite porphyry to granite porphyry are intruded in Cretaceous and lower strata at Globe, Bisbee, Silver Bell, Bradshaw Mountains, Harquahala and Wallapai Mountains, and many other places. In the latter three cases the age of the intrusives is uncertain. At Bisbee granite porphyry was intruded previously to the early Cretaceous, and many of the Arizona intrusives may be of earlier age than those farther north.

Also the evidence is increasing that there is an extensive belt of overthrust faults that extends from northern Montana southeastward into western Wyoming and eastern Idaho and Utah. In some places these have been proved to be early Eocene and in others later Eocene. The belt of overthrusts of southern Nevada appears to be the southern extension of those known farther north and may have the same age. At present the writer favors this interpretation.

The tuffs and flows of Table Mountain and the area near the Sultan mine, as well as the intrusive masses of Diablo Grande Peak, are considered to be related in age to the upper Miocene and Pliocene volcanic rocks of southern Nevada.[59]

ROCK ALTERATION

GENERAL FEATURES

Very few sedimentary rocks now exposed at the surface or in shallow mine workings have the same properties that they had when they were deposited. Most of them have undergone consolidation or hardening to a degree that depends largely upon the depth to which they were buried and the stresses they have undergone when subsequently folded. Commonly changes in color, hardness, cementing material, or mineral constitution have taken place, the particular changes depending largely on the chemical character and temperature of the water that has moved through them since they were consolidated. Even where it is apparent that great changes in composition or constitution have occurred and it seems clear that these have been accomplished by the water that has circulated through the rocks, it is difficult or impossible to determine the source of the water, the reasons for such changes, and the time when they took place.

[53] Stock, Chester, Late Cenozoic mammalian remains from the Meadow Valley region, southeastern Nevada: Geol. Soc. America Bull., vol. 32, pp. 146–147, 1921.

[54] Baker, C. L., Notes on the later Cenozoic history of the Mohave Desert region in southeastern California: California Univ. Dept. Geology Bull., vol. 6, pp. 333–383, 1911.

[55] Merriam, J. C., Tertiary mammalian faunas of the Mohave Desert; California Univ. Dept. Geology Bull, vol. 11, pp. 435–455, 1919.

[56] Ball, S. H., A geologic reconnaissance in southwestern Nevada and eastern California: U. S. Geol. Survey Bull. 308, pp. 31–34, 1907.

[57] Ransome, F. L., Geology and ore deposits of Goldfield, Nev.: U. S. Geol. Survey Prof. Paper 66, pp. 97–102, 1909.

[58] Lindgren, Waldemar, Igneous geology of the Cordillera and its problems; in Problems of American geology, pp. 261–262, Yale Univ. Press, 1915.

[59] Ransome, F. L., Geology and ore deposits of Goldfield, Nev.: U. S. Geol. Survey Prof. Paper 66, pp. 86, 107, 1909.

In this region the sandstone and shale have undergone some changes since they were deposited, but these are slight compared with the changes undergone by the carbonate rocks, limestone, and dolomite. The mottled dolomitic limestones of the Goodsprings formation are considered to represent rearrangements or changes in composition shortly after burial, but these as well as the younger limestones have undergone later widespread alteration to pure dolomite. This alteration appears to have taken place much more recently, in late Cretaceous or early Tertiary time or later, and to be related to the intrusion of bodies of igneous rocks, in large part the coarse-grained orthoclase porphyry but also to less degree the fine-grained later rhyolites. Although not confined to the ore-bearing areas, dolomitized limestone surrounds most of the ore deposits, and the two appear to be related. For these reasons the alterations will be grouped according to their apparent association with the coarse-grained or fine-grained intrusive rocks.

Alteration of the rocks by surface weathering is meager in this region and will not be considered.

ROCK ALTERATIONS RELATED TO EARLY TERTIARY COARSE-GRAINED INTRUSIVE ROCKS

Four varieties of alteration of the limestones and dolomites have been observed in this region in the vicinity of dikes and sills of granite porphyry—garnetization, serpentinization, silicification, and dolomitization.

GARNETIZATION

In a small area southeast of the Lavina mine, in the south-central part of sec. 21, T. 24 S., R. 58 E., magnesian limestone and dolomite, probably a part of the Moenkopi formation, are locally altered to a mottled brownish rock made up of garnet and quartz. From tests of the index of refraction the garnet is probably andradite, the magnesium-calcium-iron garnet. A thin section of the rock shows microgranular garnet with here and there a druse lined with coarser crystals and filled with quartz. There are also a few quartz veinlets that cut across the garnet groundmass. The areal extent of garnet rock is only a few acres, and it is bounded on the east, north, and west by the Lavina dike. Even where the carbonate rock is completely altered to garnet, the bedding is preserved. The area is limited southward by the Ruth fault.

Garnet rock was not observed in any other locality in the region. Probably it is completely absent on the border of the Yellow Pine sill as well as along its northern extension on the Snowstorm claims and its southern extension near the Middlesex mine. None was observed near the Keystone and Boss extension dikes nor the small dikes near Crystal Pass. Clearly considerable silica has been added to the carbonate rock near the Lavina mine in order to convert it into garnet. The small wedge of garnet rock was undoubtedly subjected to a higher temperature than those masses of rock whose surfaces of contact with the porphyry were planes.

A fragment of a small boulder picked up by H. Hardy in the wash near the Blue Jay mine, in the west-central part of sec. 9, T. 24 S., R. 58 E., proved on examination under the microscope to be largely tremolite with a little magnetite. This mineral is commonly found in or near carbonate rocks that have been affected by intrusive rocks or by regional metamorphism, but it has not been found in place anywhere in the entire region. It is difficult to account for the presence of tremolite in this locality, unless, like the boulders that cap the hill near the Red Cloud mine, it has been brought by ancient streams from a region northwest of this quadrangle. The nearest intrusive rocks are the Red Cloud dike and the sill on the Snowstorm claims, but no silicate minerals were found either on the surface or underground in these localities.

SERPENTINIZATION AND FERRATION

In the SE. ¼ sec. 2, T. 25 S., R. 58 E., southwest of Crystal Pass, a dike of normal granite porphyry crops out in several gulches. It probably is about 1,000 feet long and 40 feet wide. It cuts across the Sultan limestone, and the alterations here described have taken place in dolomitized Valentine limestone. The dike trends north and is vertical; the adjacent dolomite trends north and dips gently west. On the west side of the dike there is a belt 400 feet wide and on the east side a similar belt 150 feet wide, within which the dolomite displays many cracks, along which a brownish mineral is developed by replacing the dolomite. (See pl. 17, *A*.) The brown mineral is very fine grained, even more so than the dolomite which it replaces, and it resembles a common variety of siderite. Analyses by J. G. Fairchild, of the United States Geological Survey, show that it is a dolomite which, however, contains 0.44 per cent of iron. It closely resembles the brown material found around the borders of the basalt dike in the SW. ¼ sec. 30, T. 24 S., R. 58 E., which an analysis shows to be a dolomite to which a little iron and water have been added. (See analysis 15b, p. 62.) Sporadically within the belt, but particularly in areas near the dike, there are veins and masses of pale-green serpentine that is uniformly in contact with the brown mineral and nowhere in contact with unaltered dolomite. Some masses of serpentine are 6 inches or more in diameter, but the veins are smaller. The local relations indicate that the intrusion of the dike has caused the circulation of water, which has brought about the addition of the iron to the dolomite and the addition of silica and water to the iron-bearing dolomite, for serpentine is an iron-bearing hydrous silicate of magnesia.

SILICIFICATION

In contrast with what has been observed in many mining districts, the amount of silica added to the rocks and ore deposits in this quadrangle is small. The outcrop and upper weathered zone of a number of ore deposits contain a little silica in the form of ferruginous chert, and a few (Kirby, Tam o' Shanter, and others) contain a large quantity, but this is clearly related to surface processes (p. 83). At only a few deposits is there appreciable silica, either in the ore body or in the wall rock, which has assuredly been deposited at the time of ore deposition (Yellow Pine mine, p. 129; Doubleup, p. 109; Boss, p. 114; and John, p. 144).

Silicification of the country rock is found only here and there and in slight degree. It is not possible to discriminate with great confidence the places where it is related to deep-seated processes from those where it may be related to surface processes. It seems probable that the coarsely crystalline clear varieties of quartz have a hypogene origin and that the fine-grained iron-stained varieties are supergene. In specimen 8b from the Bird Spring formation in the E. ½ sec. 32, T. 24 S., R. 58 E., an analysis of which appears in the table on page 61, the percentage of insoluble matter, largely silica, is 7.32, whereas the original limestone has none. When this specimen was polished and etched, it was found that the silica is clear, coarsely crystalline quartz that fills cavities bounded by terminated crystals of dolomite—the same relations that surround the occurrence of clear calcite in many places. Even though the specimen occurred on the surface, the opinion is held that the silica had a hypogene origin. The wall rock of the Doubleup mine is a similar dolomite with clear quartz in the same relations but also in part replacing the dolomite.

Silicification by chert, apparently deposited by surface waters, is described on page 82.

DOLOMITIZATION

FIELD RELATIONS OF DOLOMITIZED LIMESTONES

Only a brief acquaintance with the rocks of this region is required to show clearly that many large masses of limestone have been converted to dolomite. Not until a comprehensive study is made, however, do the extent of the alteration and the relations of the dolomite become apparent. Even such a study leaves much to be desired in an attempt to determine the manner by which the alteration has been accomplished and the source of the magnesia.

Beds affected.—The limestones of all the formations, from the oldest to the upper part of the Bird Spring formation, are locally altered to dolomite. Some beds as much as 300 feet thick are completely altered over large areas; others are only slightly altered in small areas. It will aid in understanding the problem if the behavior of each successive formation toward alteration is stated.

The Goodsprings dolomite forms a belt that extends from the northern to the southern boundary of the quadrangle and appears originally to have been made up of alternating thin layers of fine-grained magnesian limestone and dolomite. (See analysis 14, p. 62.) In several places, such as the areas around Devil Canyon, east of Porter Wash, from the Whale and Smithsonite mines east to Columbia Pass, west of Little Devil Peak, and west of Wilson Pass, the fine-grained bluish-gray beds are altered to medium-grained crystalline smoky-gray dolomite. In contrast, beds in a similar position in the section near the Keystone mine and northward from Potosi Wash are unaltered. The entire thickness of beds exposed at the mouth of Devil Canyon—1,375 feet—and above the Lincoln mine—1,300 feet—is medium-grained dolomite, but farther northwest only the upper 500 to 800 feet of the Goodsprings formation has this texture and composition. The conclusion seems clear that the fine-grained rocks which contained less magnesia than that required by dolomite have acquired, subsequent to deposition, additional magnesia and become more coarsely crystalline. There is a general but not a close coincidence between the areas of the Goodsprings formation that have been dolomitized and the distribution of mineral deposits. Sporadic mineral deposits occur from Kirby Wash eastward and south to Devil Canyon, but they are almost entirely absent north of Potosi Wash.

The Sultan formation was originally rather pure limestone, separable into three members on the basis of distinctive color or features of bedding—the Ironside, Valentine, and Crystal Pass limestones (p. 13). These three members have responded in a different manner to the process of dolomitization. The lowest member, the Ironside dolomite, has been so completely altered that only in two small areas have residual masses of limestone been preserved in it—on the west slope of Little Devil Peak and in sec. 34, T. 23 S., R. 57 E. Such fossils as this dolomite yields have been preserved through silicification on the surface, so that they were not destroyed by dolomitization. Curiously, in contrast to almost all the dark limestones elsewhere in the region, the color was preserved after it was altered to dolomite. The middle member of the Sultan formation, the Valentine limestone, made up of beds of limestone 5 to 30 feet thick, preserves its character throughout most of the region north of Wilson Pass. In the vicinity of the Boss mine the beds show sporadic alteration, but from the Ironside fault eastward and southward as far as Crystal Pass these beds are completely altered to dolomite. From Porter Wash southward and from Singer Wash southward, dolomitization is only sporadic. Plate 17, *B*, shows an irregular mass of limestone in the Valentine limestone bounded by minor fractures and inclosed within homogeneous dolomite. The process of dolomitization of this member of the Sultan formation has largely obliterated the fossils. The Crystal Pass limestone has resisted dolomitization more effectively than any other in the Paleozoic formations. Possibly the thinness of the layers and their persistence over large areas explain the inability of the solutions that brought in the magnesia to penetrate the rock very far. Here and there it is partly dolomitized, as shown in Plate 17, *C*. In such material the solutions largely followed the minor bedding planes, but in some places they encountered small fractures and formed veinlets that cut the bedding. The photograph shows clearly that under weathering the dolomite resists solution more than the residual limestone and hence stands in relief.

The members of the Monte Cristo limestone show a wide diversity toward replacement by dolomite.

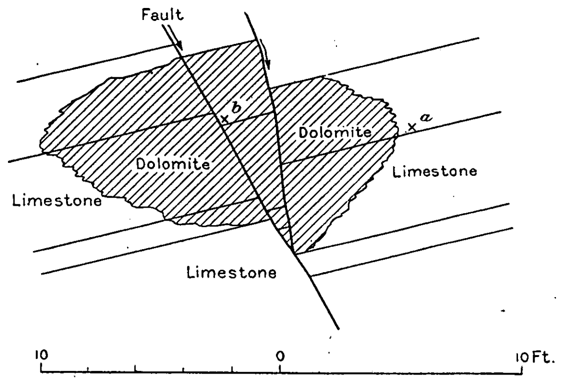


FIGURE 11.—Dolomitization of Anchor limestone adjacent to a fault. *a* and *b* represent the same horizon and indicate the source of samples 2a and 2b respectively. (See table, p. 61.)

Where the Dawn limestone is well developed, between the Ninety-nine and Contact mines, it is largely pure limestone, but on the west side of the range near the Potosi mine it is wholly dolomitized, with change in color. Furthermore, it is largely dolomite farther south on the west side of the range, in the W. ½ sec. 36, T. 23 S., R. 57 E., and on Bonanza Hill in sec. 14, T. 25 S., R. 57 E.

The Anchor limestone is largely unaltered in the southern third of the range, except in the immediate vicinity of the ore bodies. Thus it is quite unaltered south of Devil Canyon and only slightly altered near the Milford and Ingomar deposits. Although the ore deposit at the Valentine mine is not large, it is completely enveloped in dolomitized Anchor limestone, but the same bed on the adjoining ridge, 1,000 feet farther south, is unaltered. From the Ironside fault eastward across Columbia Pass to Crystal Pass, a distance of 10 miles, the Anchor limestone is almost wholly dolomite. On Ruth Mountain, west of the Lavina mine, it is sporadically dolomitized. In the northern two-thirds of the quadrangle it is widely dolomitized east of the Keystone fault, especially where the beds are overturned, but it is much less altered west of the Keystone fault. Near Mountain Springs it is unaltered. The study of many exposures indicates that the presence of layers of chert nodules has tended to hinder widespread dolomitization of the Anchor limestone. In many localities the upper limit of chert nodules coincides with the lower limit of the Bullion dolomite.

On account of the sporadic character of the dolomitized masses of Anchor limestone and the distinct differences in color, it is an easy matter to collect specimens of both limestone and dolomite from the same beds and thus determine the change in composition that has taken place. The distance from the limestone to the dolomite was 6 feet or less in four of the six pairs of specimens whose analyses appear in the table on page 61. These analyses are discussed on page 63.

Even after the Bullion dolomite had been examined over a large area in the southern third of the quadrangle, it was considered to have been deposited as dolomite. Only when it was traced southward beyond Devil Canyon to the southern edge of the quadrangle did the fact that it is an altered limestone bed become clear. Throughout the quadrangle the thickness is rather uniformly about 300 feet, and it is limited above by the shaly Arrowhead limestone and below by the cherty Anchor limestone. Southward from Devil Canyon to the saddle north of Diablo Grande Peak it becomes gradually thinner and disappears, so that it is absent on the south slope of the ridge in sec. 3, T. 26 S., R. 58 E. In the same distance the Anchor limestone becomes steadily thicker, and obviously its final thickness corresponds closely with the sum of the thicknesses of the Anchor limestone and Bullion dolomite 1 mile north. In the northern part of the quadrangle the Bullion dolomite contains no residual masses of limestone, and its limits are generally sharply marked. (See pl. 7, *A*.) In some places, however, dolomitization has progressed upward into the overlying Bird Spring formation. Whether the Bullion dolomite contained many fossils before it was dolomitized is not clear; only a few can be found in it now.

The Arrowhead limestone generally resists alteration to dolomite, but here and there, as, for example, near the Blue Jay mine and southward to the Yellow Pine mine, it is completely altered.

The Bird Spring formation occupies a larger area in the quadrangle than any other, and it is extensively altered to dolomite. Many of the detailed data concerning the process of dolomitization in this region have been obtained from areas of this formation. Sporadic patches are altered in the southern part of the quadrangle, especially near the Silver Gem mine in Devil Canyon (pl. 18, *A*, *B*), but the largest areas lie north of the latitude of Crystal Pass. The section about 300 feet thick near the Hoosier mine is almost completely altered to dolomite, as only a single bed of limestone is preserved. (See pl. 19, *A*.) In an area nearly 2 miles long and 1½ miles wide, which extends from Wilson Pass east to the Red Cloud mine, limestones of the Bird Spring formation are completely altered to dolomite. This area overlies the Yellow Pine sill of porphyry and coincides with an area of folded and fractured beds near the Potosi and Wilson thrust faults. Another area, almost as large but more irregular, lies at the mouth of Wood Gulch, in sec. 32, T. 23 S., R. 58 E. It underlies the Potosi thrust fault but overlies the Contact thrust fault. In both these areas the process of dolomitization has not produced much change in the color or texture of the rock, and the fossils are not obliterated by the alteration. The southern part of the Bird Spring Range shows only a sporadic alteration, but the entire mass of rocks north of the Cottonwood fault is completely changed to dolomite. In this area the dolomite is lighter in color and slightly coarser in texture than the original limestone, but all traces of fossils except a few echinoid spines are destroyed. The outcrops of the Bird Spring formation west of Potosi Wash are practically unaltered.

Relations of dolomitized areas to intrusive rocks.—Dolomite has developed in thick masses of limestone in the vicinity of outcrops of dikes and sills of granite porphyry, but there are several large areas of dolomite, such as Wood Gulch and the north end of the Bird Spring Range, remote from outcrops of such rocks. Also the dolomite was not necessarily formed close to such sills, because unaltered limestone lies about 20 feet above the north end of the Yellow Pine sill. There is a general areal coincidence of the area of dolomitized rocks from the Ironside fault eastward to Crystal Pass and the belt of sills and dikes. No intrusive rocks are known north of Wilson Pass, but there are large areas of dolomitized limestone.

Of the three observed necks of late Tertiary fine-grained intrusive rocks, two intruded beds that were already dolomites; one of them, northwest of the Sultan mine, intruded the dolomitized limestones of the Sultan formation, and the other, southwest of the Sultan mine, the dolomites of the Goodsprings formation. The alterations of the dolomites produced by these intrusions are described on pages 67–69. The third neck, the rhyolite of Diablo Grande Peak, intruded limestones of the Monte Cristo formation and caused the alteration to dolomite of a zone of much fractured limestone about 100 feet wide. The alteration was accompanied by a change in color of the beds from bluish gray to nearly white. (See pl. 10, *A*.) From the zone of completely altered rock outward into the limestone extend lenses of similarly altered rock 5 to 20 feet wide and 100 to 200 feet long. The lenses follow major fractures in the limestone. The change in composition of the rock is shown by analyses 16a and 16b in the table on page 62.

Relations of dolomitized areas to structural features.—Although there are local areas of dolomite near each of the three major thrust faults of the region—the Contact, Keystone, and Sultan—there appears to be a constant and significant relation with the uppermost one only, the Sultan. The base of the upper block on this fault is marked by a persistent zone of dolomitized breccia; in addition, there are sporadic masses of solid dolomite which overlie the breccia. The easternmost part of the Sultan thrust block, nearly a square mile in extent and 500 feet in maximum thickness, is completely dolomitized. The beds of the Bird Spring formation which it overlies are altered only over small sporadic areas. The surface of the Sultan thrust and the breccia zone overlying it clearly offered favorable sites for the alteration.

The large areas of dolomitized limestone around the Red Cloud mine and Wood Gulch are so distributed

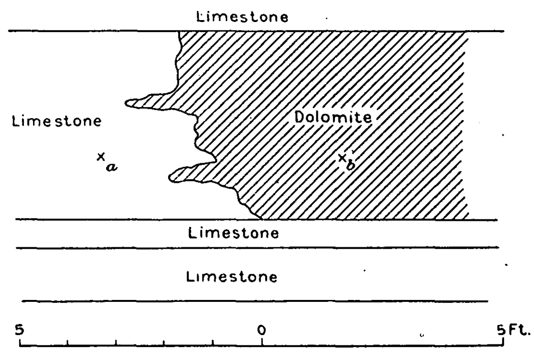


FIGURE 12.—Dolomitization of a bed of limestone in Bird Spring formation. *a* and *b* indicate the source of samples 11a and 11b respectively. (See table, p. 61.)

that the relation of the dolomitization to the masses of much folded rocks near by and between major and minor thrust faults may be inferred. The rocks at the crest of the hill (altitude 8,184 feet) in sec. 17, T. 23 S., R. 58 E., are dolomitized, although lower beds to the southeast are unaltered. The alteration appears to have been localized along parts of the Potosi thrust, the upper block of which has just been removed from this hill.

There appears to be a close areal relation between dolomitization and early normal faults in a few areas only. As these faults probably followed the thrusts it appears that the process of alteration was waning when they were formed. Beds of the Bird Spring formation are sporadically altered near several early normal faults in sec. 27, T. 25 S., R. 58 E., and in the ravine south of the Fredrickson mine, in sec. 33, T. 24 S., R. 58 E. No alteration that appeared to be related to late normal faults was noticed.

In several areas of folding—such as the sharp syncline in the upper part of the Monte Cristo limestone and the lower part of the Bird Spring formation in secs. 3 and 4, T. 26 S., R. 58 E., and the large, much fractured anticline in beds of the Goodsprings formation—the beds have been thoroughly dolomitized. Although these areas are not remote from normal and thrust faults, the alteration appears to be more closely related to brecciation coincident with the general deformation of the beds than the faults.

In detail, the process of dolomitization proceeded outward from fractures and minor partings parallel to the bedding, but here and there the fractures are very obscure. The outer limit is generally very irregular (fig. 12), although in some places it is marked by fractures also. (See pl. 17, *B*.) Thus, in the occurrence shown in Plate 19, *B*, a dense limestone has been broken by numerous diagonal fractures, from which dolomitization has proceeded outward along the bedding. The bedding is actually faulted, but close examination shows that the movement preceded the alteration. In the areas shown in Plate 18, *A*, persistent major fractures trend northeast, and the dolomitized mass is roughly lenticular, although dolomitization locally followed certain beds and left others unattacked. In the same area nearly tabular vertical masses that cut scross a number of beds are dolomitized. In many places the altered mass is small and its relations to fractures are clear (fig. 11), but elsewhere it is so large that its relations are obscure.

As set forth on page 54, the following order of events in this region has been determined: Folding, beginning of thrust faulting, intrusion of coarse igneous rocks, conclusion of thrust faulting, early normal faulting, late normal faulting, intrusion and extrusion of fine-grained igneous rocks, minor normal faulting. When the problem of dolomitization is viewed in the light of these successive events, it seems clear that the process has some relation to coarse igneous rocks, to the later of the thrust faults, to the early normal faults, and, in a very insignificant degree, to the fine-grained intrusive rocks. It is clear that the alteration began after the intrusion of the dikes and sills of granite porphyry, attained its maximum development shortly after the thrust faults were completed, and then rapidly died out, although it was not over before the early normal faulting took place. The relation of dolomitization to the deposition of metallic sulphides is discussed on pages 100–101.

Changes in color and texture accompanying dolomitization.—In the tables on pages 61–62 brief descriptions of the color and texture of the analyzed specimens of limestone and dolomite are presented. Generally, the change from limestone to dolomite has been accompanied by a change in color; here and there very little change in color has taken place, as in specimens 11a and 11b. For the most part the darker (more carbonaceous?) limestones, such as the Ironside dolomite member of the Sultan formation, do not show any great change in color, but they form a small part of the total. The bluish-gray limestones have commonly changed to cream-colored dolomites (pl. 18, *B*); only in a few places is the resulting dolomite white.

Undoubtedly the change in color depended largely on the elimination of carbonaceous matter and the addition of iron compounds, which weathered to one of the hydrous oxides near the surface and yielded a light-brown color. The veinlets of bituminous matter in the Azurite mine probably represent local concentrations of such material driven out of the limestone during dolomitization.

Where the beds are unaffected by dolomitization the freshly broken limestones of the Sultan and Monte Cristo formations and most of the Bird Spring formation almost uniformly have the fine homogeneous texture of porcelain; here and there some beds of the Bird Spring formation contain a few crystalline grains of calcite. Beds that are largely made up of coarsely crystalline calcite grains are very rare. In thin section the limestones present diverse aspects. Some are made up largely of minute unbroken organic remains and contain few fragments, whereas in others the reverse is true. The limestone in the Bird Spring formation shown in Plate 20, *A*, consists in large part of minute foraminifers and bryozoans, many of which do not exceed 0.05 millimeter in diameter. In a thin section of this rock P. V. Roundy identified fragments of *Fenestella, Nodosaria,* and *Endothyra* sp. Coral stems are also present. Another limestone about 500 feet above the base of the Bird Spring formation, a thin section of which is reproduced in Plate 21, *A*, contains more fossil fragments, and both Bryozoa (*Stenopora* sp.) and Foraminifera (*Cristellaria?* sp. and *Fusulinella?* sp.) have been identified. Angular grains of quartz sand are present in both limestones.

The crystal grains of dolomite resulting from the alteration of limestone show a wide range in size, roughly from 0.1 to 15 millimeters. The cause of this wide range is not known. The most coarsely crystalline dolomite is found in the region north of Wood Gulch and east of the range, where the massive Yellowpine limestone is locally altered to nearly pure dolomite (analysis 13, p. 61). Here the average size of grain is about 8 millimeters. In the vicinity of many ore bodies, such as that of the Yellow Pine mine, the average size of grain is about 1.5 millimeters, regardless of the beds in which they lie. The texture of the Bullion dolomite is very uniform, and the grains average about 0.5 millimeter. In several localities, where the beds from 200 to 800 feet above the base of the Bird Spring formation have been converted to dolomite, as in the areas east and south of Wilson Pass and northeast of Wood Gulch, the texture of the resulting rock is very fine; probably the average size of the grains is 0.1 millimeter.

In general, the finer the grain of the dolomite the less is its difference in color from that of the original limestone. Thus, the fine-grained dolomites are commonly light to medium gray; some are nearly black. The coarsest grained dolomite is nearly white, and those of intermediate texture are commonly cream-colored.

The change from limestone to dolomite commonly destroyed the organic remains, although there are striking exceptions to this statement. Collections 4219a and 4232a (pp. 24, 25), from the basal part of the Bird Spring formation, were obtained in an area of dolomite.

LABORATORY STUDY OF LIMESTONES AND DOLOMITES

Composition.—In order to determine the kind and degree of the changes undergone when the limestone became altered to dolomite, samples of both rocks were collected for analysis. As the appearance and presumably the composition of the limestones differed from one part of the section to another, it was the aim to collect pairs of specimens from as nearly the same bed as possible and also to have the entire assemblage of pairs cover as wide a stratigraphic range as possible. With these purposes in view, 12 pairs of specimens were collected, representing beds that range from the Anchor limestone below to the middle part of the Bird Spring formation above. The distance between most of the paired specimens was less than 6 feet, and for 6 pairs it was 2 feet or less. Commonly there was a distinct difference in color and texture between the limestone and the dolomite, and they were separated by a sharp though sinuous line. No specimens were collected from the Bullion dolomite because it was so widely altered that comparable specimens from the same bed could not be found.

Analyses of limestone and dolomite of Monte Cristo and Bird Spring formations

No.	Source	CaO	MgO	$Fe_2O_3+Al_2O_3$	CO_2	Insoluble	Total	Calculated constitution [a]		Remarks
								Calcite, $CaCO_3$	Dolomite, $(CaMg)CO_3$	
	Anchor limestone member of Monte Cristo formation									
	Theoretical dolomite	30.40	21.87		47.73					
	Theoretical calcite	56.03			43.97					
1a	Middle cherty facies, SW. ¼ sec. 11, T. 25 N., R. 58 E.	55.32	0.25	0.0	43.20		98.77	98.11	1.14	Medium gray, porcelain texture, conchoidal fracture. Traces of coral stems.
1b	Dolomitized limestone (1a), same bed, 2 feet distant.	31.40	21.11	.0	46.40		98.91	3.68	96.53	Mottled cream-colored and buff, medium crystalline.
2a	Middle cherty facies, SW. ¼ sec. 23, T. 25 S., R. 58 E., in Bullion Gulch.	55.18	Trace.	.0	43.42		98.60	98.48	Trace.	Pale chocolate-brown, porcelain texture, conchoidal fracture. No trace of fossils.
2b	Dolomitized limestone (2a), same bed, 6 feet distant.	31.98	20.22	.0	46.60		98.80	6.92	92.45	Mottled cream-colored and buff; medium and finely crystalline.
3a	Middle cherty facies, south center of sec. 14, T. 25 S., R. 58 E., above Monte Cristo mine.	55.28	Trace.	.0	43.20		98.48	98.66	Trace.	Medium gray; fracture shows crystalline coral stems in dense groundmass.
3b	Dolomitized limestone (3a)	31.52	21.00	.0	47.13		99.65	4.16	96.02	Pale gray; medium to coarsely crystalline.
4a	Upper part of cherty facies, SE. ¼ sec. 14, T. 25 S., R. 57 E., southwest end of Bonanza Hill.	54.98	.25	.0	43.80		99.03	97.40	1.14	Medium gray; medium to coarsely crystalline. Many fossil fragments.
4b	Dolomitized limestone (4a), same bed, 2 feet higher, 3 feet distant.	31.44	21.31	.0	47.07		99.82	3.25	97.44	Pale cream-colored; coarsely crystalline; weathers pale brown.
5a	Upper part of cherty facies, south center of sec. 11, T. 25 S., R. 57 E., southwest end of Hoodoo Hill.	55.68	.10	.0	43.82		99.60	99.12	.46	Dark gray; fracture shows few crystalline fossils in dense groundmass.
5b	Dolomitized limestone (5a), same bed, near by	32.32	20.58	.0	47.40		100.30	6.62	94.10	Pale cream-colored; coarsely crystalline; weathers pale brown. Yields very faintly alkaline extract.
6a	Upper facies, free of chert, center of sec. 2, T. 26 S., R. 58 E., east of New Year mine.	52.88	2.84	Trace.	44.20		99.92	87.34	12.98	Medium gray; medium to coarsely crystalline; many fossil fragments.
6b	Dolomitized limestone (6a), same bed, 2 feet distant.	32.16	20.66	Trace.	47.45		100.27	6.15	94.47	Mottled pale red and gray; coarsely crystalline.
	Bird Spring formation									
7a	Basal massive bed, NE. ¼ sec. 3, T. 26 S., R. 58 E., at mouth of Christmas tunnel.	54.76	Trace.	.10	42.82	2.05	99.73	97.93	Trace.	Dark gray; few crystalline fossils in dense groundmass; weathers lighter gray. Contains small quantity of organic matter, also trace of some sulphide; SO_3=0.3 per cent.
7b	Dolomitized limestone (7a), same bed, 20 feet distant.	29.28	19.77	Trace.	43.70	6.00	98.75	3.21	90.40	Mottled pale chocolate-brown; finely crystalline.
8a	About 150 feet above base in center of sec. 32, T. 21 S., R. 58 E., near Fredrickson mine.	55.24	.22	.0	43.80		99.26	98.05	1.00	Brownish gray; few crystalline fossils in dense groundmass.
8b	Dolomitized limestone (8a), same bed, 2 feet distant.	28.76	20.12	.0	44.44	7.32	100.64	1.41	92.00	Pale cream-colored, with pale-brown mottling; coarsely crystalline.
9a	About 300 feet above base, in NW. ¼ sec. 14, T. 25 S., R. 58 E., near Houghton mine.	55.66	Trace.	.0	43.60		99.26	99.34	Trace.	Medium gray; dense texture, conchoidal fracture.
9b	Dolomitized limestone (9a), same bed, 4 inches distant.	32.56	19.68	.0	46.63		98.87	9.28	89.99	Pale cream-colored; coarsely crystalline; weathers pale brown.
10a	About 300 feet above base in NE. ¼ sec. 33, T. 25 S., R. 58 E., north of Silver Gem tunnel.	52.92	Trace.	.0	40.99	5.91	99.82	94.45	Trace.	Dark gray; few crystalline fossils in dense groundmass. Contains small quantity of organic matter, also trace of some sulphide.
10b	Dolomitized limestone (10a), same bed, 10 feet distant.	29.90	20.46	.0	44.65	5.42	100.43	2.60	93.55	Pale cream-colored; finely crystalline; weathers darker.
11a	400-500 feet above base in north center of sec. 18, T. 24 S., R. 59 E., Bird Spring Range.	48.14	.30	.0	38.71	12.14	99.29	85.16	1.37	Pale brownish gray; dense texture; conchoidal fracture; weathers same color.
11b	Dolomitized limestone (11a), same bed, 5 feet distant.	29.24	17.47	.10	41.90	10.85	99.56	8.85	79.88	Pale brownish gray; finely crystalline; weathers same color.
12a	500-700 feet above base in north center of sec. 28, T. 25 S., R. 58 E., south of Sultan mine.	55.20	Trace.	.0	42.80	1.39	99.37	98.51	Trace.	Medium gray; few crystalline fossils in dense groundmass; weathers same color.
12b	Dolomitized limestone, same bed, 2 feet distant	32.72	18.73	.0	45.27	3.45	100.17	11.93	85.64	Cream-colored; coarsely crystalline; weathers darker.
	Monte Cristo limestone									
13	Dolomitized limestone, uppermost massive bed, in SE. ¼ sec. 10, T. 23 S., R. 58 E., north of Ninety-nine mine.	30.70	21.63	Trace.	47.13		99.46	1.12	98.90	Pale cream-colored; holocrystalline; facets ¼ to ⅜ inch in diameter; weathers same color.

[a] Differences between the sum of $CaO+MgO+CO_2$ and the sum of $CaCO_3$+(Ca, Mg)CO_3 are due to slight errors in determing CO_2.

Analyses of limestone, dolomite, and alteration products from the Goodsprings dolomite, Monte Cristo limestone, and Bird Spring formation

No.	Source	CaO	MgO	MnO	Fe_2O_3	Al_2O_3	CO_2	Insoluble	Total	Calculated constitution		Remarks
										$CaCO_3$	Ca, Mg CO_3	
14	Goodsprings dolomite, bed about 1,500 feet below top in west center of sec. 30, T. 24 S., R. 58 E., in hill north of Kirby mine.	36.88	13.48	-------	0.20		43.57	5.80	99.93	32.37	61.63	Lighter bed of two dark-gray layers. Texture of both beds is dense, fracture conchoidal.
15a	Goodsprings dolomite, bed about 1,300 feet below top in southwest corner of sec. 30, T. 24 S., R. 58 E., in gulch west of Kirby mine.	31.00	21.55	-------	Trace.		47.13	.20	99.88	1.85	98.54	Pale bluish gray, reddish on fractures. Medium crystalline. Weathers same color.
15b	Altered dolomite (15a), nearly same bed, 50 feet distant.	31.28	20.58	-------	.38	Trace.	45.80	1.40	99.44	4.76	94.10	Light chocolate-brown, mottled; finely crystalline. Weathers same color.
16a	Monte Cristo limestone, about 1,000 feet above base, southeast corner of sec. 3, T. 26 S., R. 58 E., 150 feet north of Big Devil intrusive.	55.40	.25	-------	.0		43.72	-------	99.37	98.25	1.14	Medium gray; few crystalline fossils in dense groundmass. Contains small quantity of organic matter also trace of some sulphide.
16b	Dolomitized limestone (16a), same bed, 10 feet distant, 140 feet from contact.	31.24	18.49	-------	.0		43.95	6.03	99.71	9.89	84.54	Nearly pure white; dense texture. Conchoidal fracture. Yields fair alkaline extract.
17	Monte Cristo limestone, altered dolomite, basal part of formation, SE. ¼ sec. 18, T. 25 S., R. 58 E., south of Singer mine.	36.20	22.28	-------	Trace.		34.77	-------	[a] 99.84	49.40	28.06	Few cream-colored crystalline areas in dense nearly white groundmass. Yields strong alkaline extract; contains a hydrous compound of magnesia (brucite).
18a	Bird Spring formation, limestone 400–600 feet above base in SW. ¼ sec. 17, T. 24 S., R. 58 E., prospect northwest of Yellow Pine mine.	52.72	.88	-------	Trace.		42.46	-------	96.06	91.91	4.02	Medium gray; few crystals in dense groundmass. Weathers darker.
18b	Altered limestone (18a), same bed, 6 inches distant.	53.62	.20	1.19	.48		42.10	-------	97.59	95.21	.91	Nearly black color; finely crystalline.
19	Bird Spring formation, limestone east center of sec. 5, T. 24 S., R. 58 E., 100 feet above base, northwest of Blue Jay mine.	49.02	.15	1.35	1.57	.21	35.80	8.08	98.59	87.11	.68	Very dark brown; uniformly finely crystalline, few crinoid stem casts. Organic matter+water=1.06 per cent.
20	Monte Cristo limestone near contact with latite neck SE. ¼ sec. 18, T. 25 S., R. 58 E.	31.80	22.20	-------	-------	-------	43.48	.10	99.76	-------	-------	Cream-colored dense alteration product of dolomitized limestone. Water below 212° F.=0.17 per cent; above 212°=1.99 per cent. (See p. 68.)

[a] Contains 6.59 per cent of water.

Analyses of dolomite from mines [a]

Yellow Pine mine

No.	Source	CaO	MgO	Fe_2O_3	SO_3	Insoluble	Total	Calculated constitution		Stratigraphic horizon
								$CaCO_3$	(Ca,Mg)CO_3	
21	"Lower limestone," 700-foot level, 40 feet southwest of station 7,019.	31.24	20.11	0.53	0.10	2.00	100.44	5.86	91.95	Bullion dolomite, top.
22	"Ore-bearing limestone," face of No. 728 crosscut, 85 feet from drift.	30.06	20.22	.66	.08	2.40	99.07	3.48	92.45	Yellowpine limestone.
23	"Ore-bearing limestone," 700-foot level, where drift enters stope.	30.30	20.66	.40	.11	1.70	99.49	2.81	94.47	Do.
24	"Ore-bearing limestone," 900-foot level, north crosscut, 6 feet above shale.	29.80	19.92	.79	.05	4.40	100.08	3.74	91.10	Do.
25	"Ore-bearing limestone," 900-foot level, north crosscut, upper part of formation.	31.00	19.92	.26	.11	2.40	99.68	5.88	91.10	Do.
26	Upper part of ore-bearing limestone, Snowstorm claim	30.81	20.33	.40	.15	1.60	99.58	4.54	92.98	Do.

Sultan mine

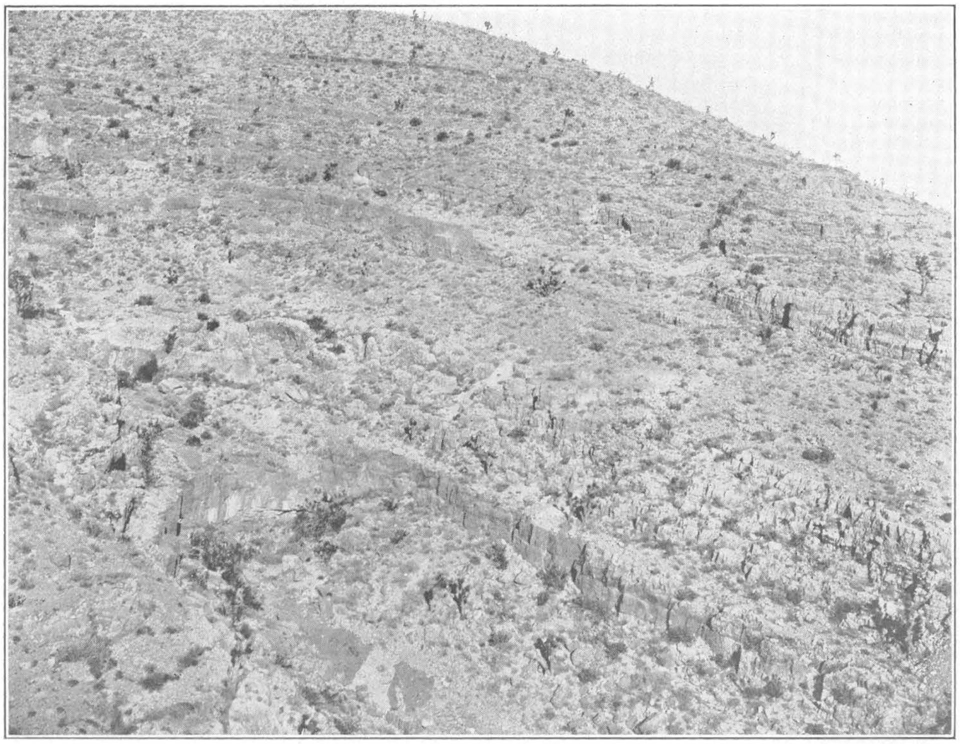
No.	Source	CaO	MgO	Fe_2O_3	SO_3	Insoluble	Total	$CaCO_3$	(Ca,Mg)CO_3	Stratigraphic horizon
27	Country rock, lowest level	30.80	19.63	.66	.20	2.30	99.18	6.26	89.76	Crushed dolomite of Bird Spring formation.

[a] Collected and analyzed by E. J. Longyear & Co.

Except as indicated the analyses were made by J. G. Fairchild, of the United States Geological Survey, and the methods used were those described by Hillebrand.[60] In these methods the powdered rock is dissolved in hydrochloric acid (1 part of acid to 3 parts of water); material designated "insoluble" in the analyses is the ignited residue after filtering the solution. The iron oxide and alumina reported represent that which is soluble in hydrochloric acid; any that may have been present in the insoluble residue was not determined.

[60] Hillebrand, W. F., The analysis of silicate and carbonate rocks: U. S. Geol. Survey Bull. 700, pp. 246–252, 1919.

The analyses of the unaltered limestones confirm the impression obtained by tests in the field that they are uncommonly pure and free from magnesia and insoluble matter. The highest percentage of magnesia is 2.84, which indicates 12.98 per cent of the dolomite molecule (No. 6a). This specimen has been polished and etched with dilute hydrochloric acid (1 part of acid to 1 of water). This treatment reveals the presence of irregular grains of dolomite sporadically distributed throughout the groundmass, and the ratio of dolomite to calcite confirms the impression obtained throughout this investigation that all the magnesia in the limestone is present as distinct grains

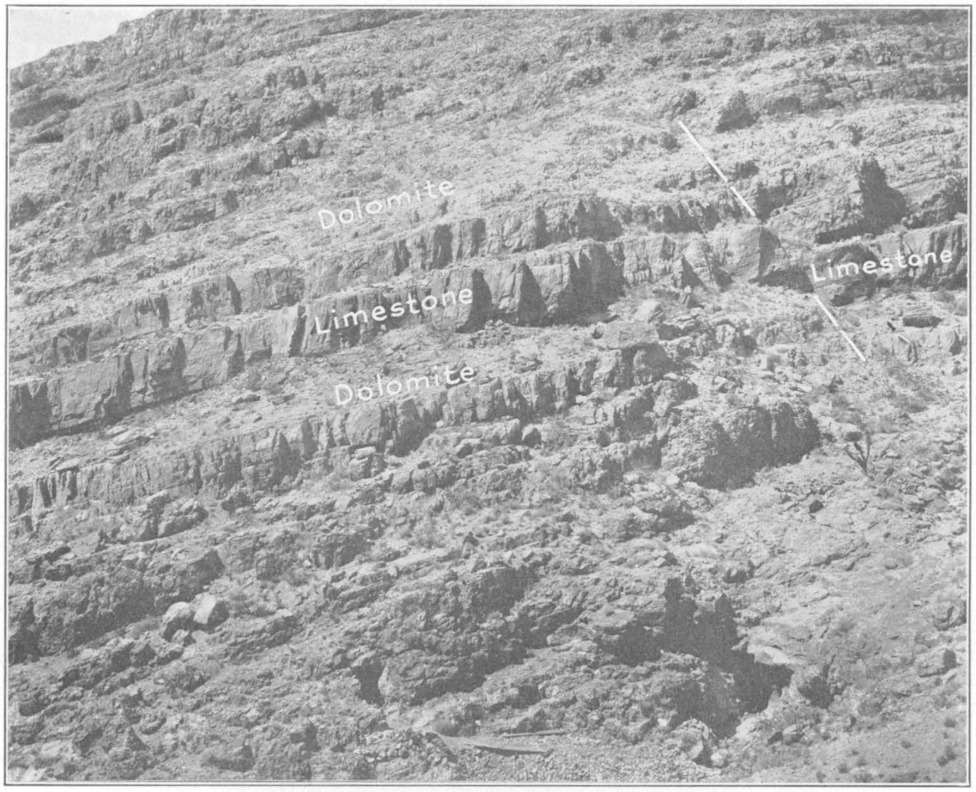


A. LIMESTONE BEDS NEAR THE BASE OF THE BIRD SPRING FORMATION LOCALLY ALTERED TO DOLOMITE (WHITE) NEAR THE SILVER GEM MINE IN DEVIL CANYON, IN SEC. 33, T. 25 S., R. 58 E.

Dolomitization has progressed outward (to the left) from a series of minor fractures (largely to the right of the field).

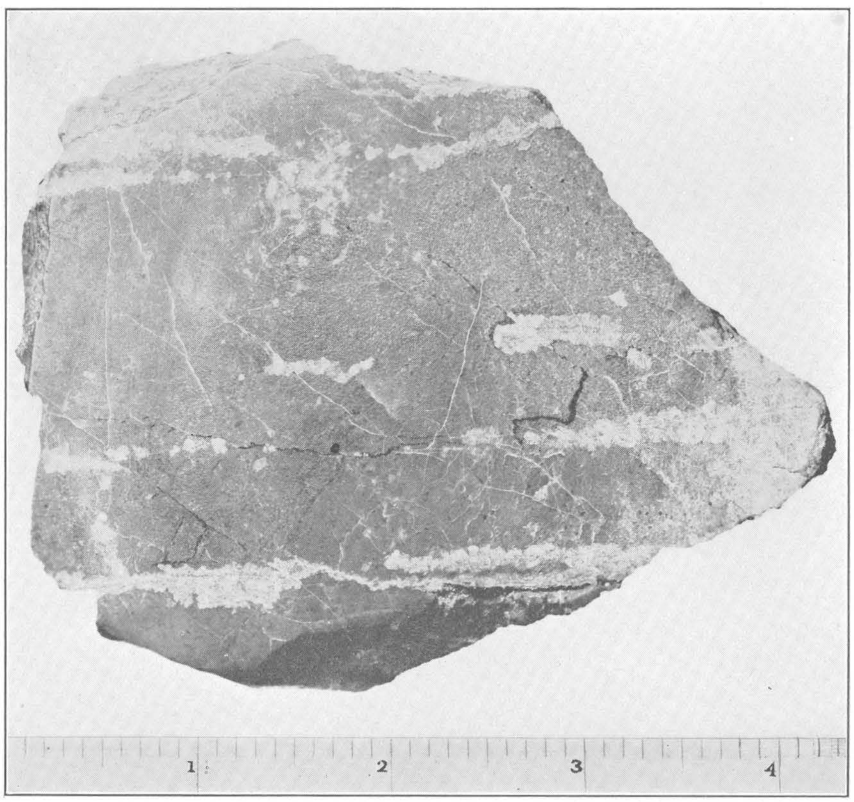
B. DOLOMITIZED ZONE (LIGHT) IN BED OF LIMESTONE OF THE BIRD SPRING FORMATION IN SEC. 33, T. 25 S., R. 58 E.

View taken diagonally downward toward a bedding plane. Dolomitization has progressed outward from a median fracture 4 feet to the right and to the left (limit is shown by head of hammer). Sample 10b was collected from the center of the dolomitized zone and sample 10a 10 feet to the right. See analyses, page 61.



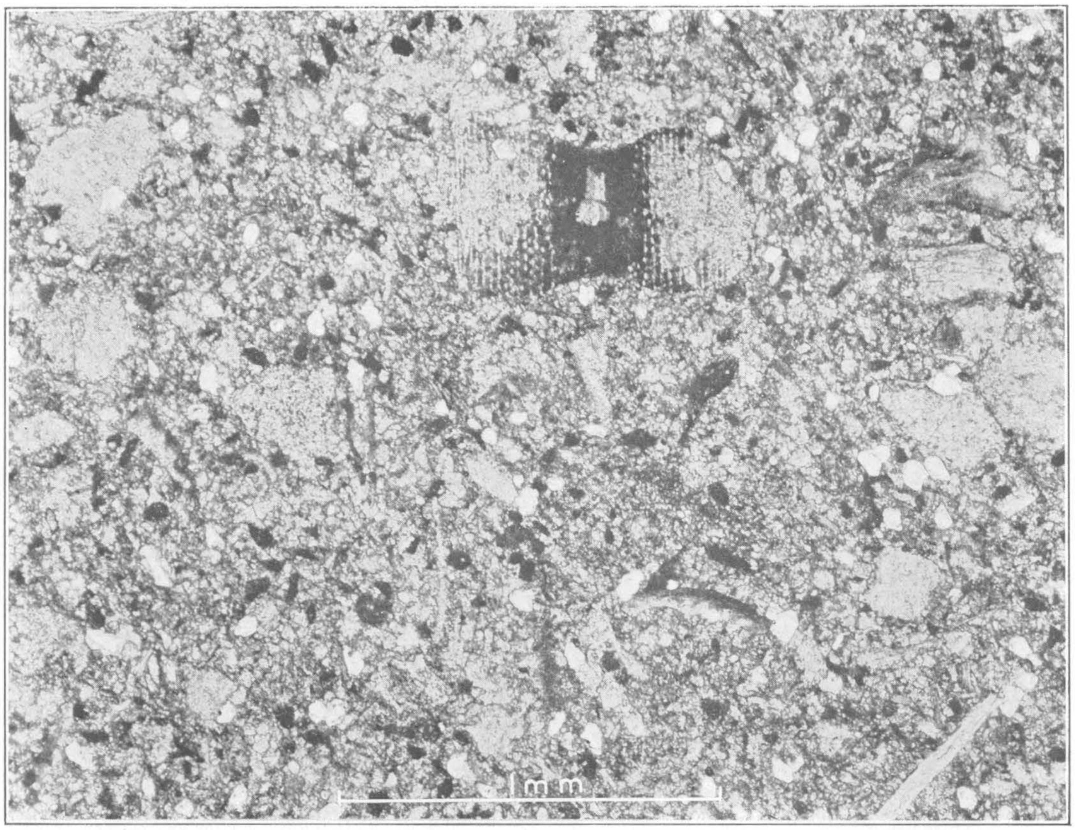
A. STRATUM OF LIMESTONE PRESERVED UNALTERED IN MIDST OF DOLOMITIZED LIMESTONE 200 FEET ABOVE THE BASE OF THE BIRD SPRING FORMATION IN SEC. 4, T. 25 S., R. 58 E.

The workings of the Hoosier mine lie in the foreground.

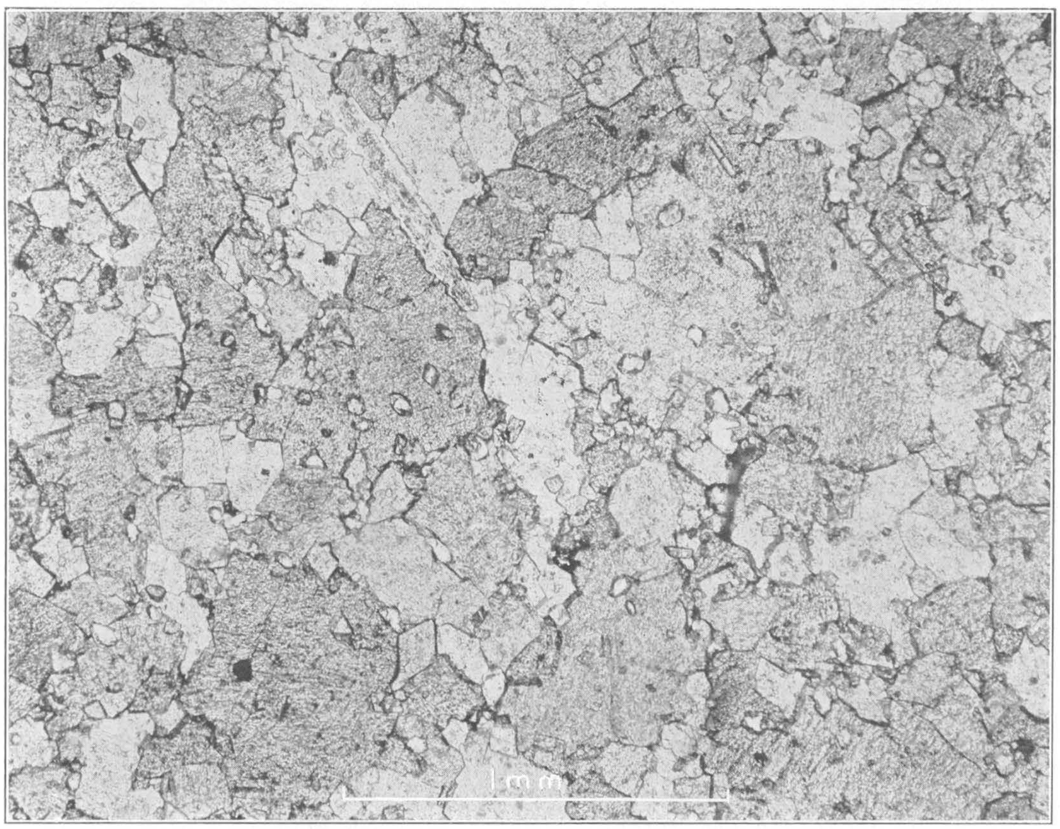


B. DOLOMITIZED ZONE IN BED OF LIMESTONE OF THE BIRD SPRING FORMATION IN NE. ¼ SEC. 5, T. 24 S., R. 58 E.

The surface is cut normal to the bedding and shows parallel zones of coarsely crystallized dolomite developed along bedding planes. The growth of dolomite crystals is locally determined by diagonal fractures.



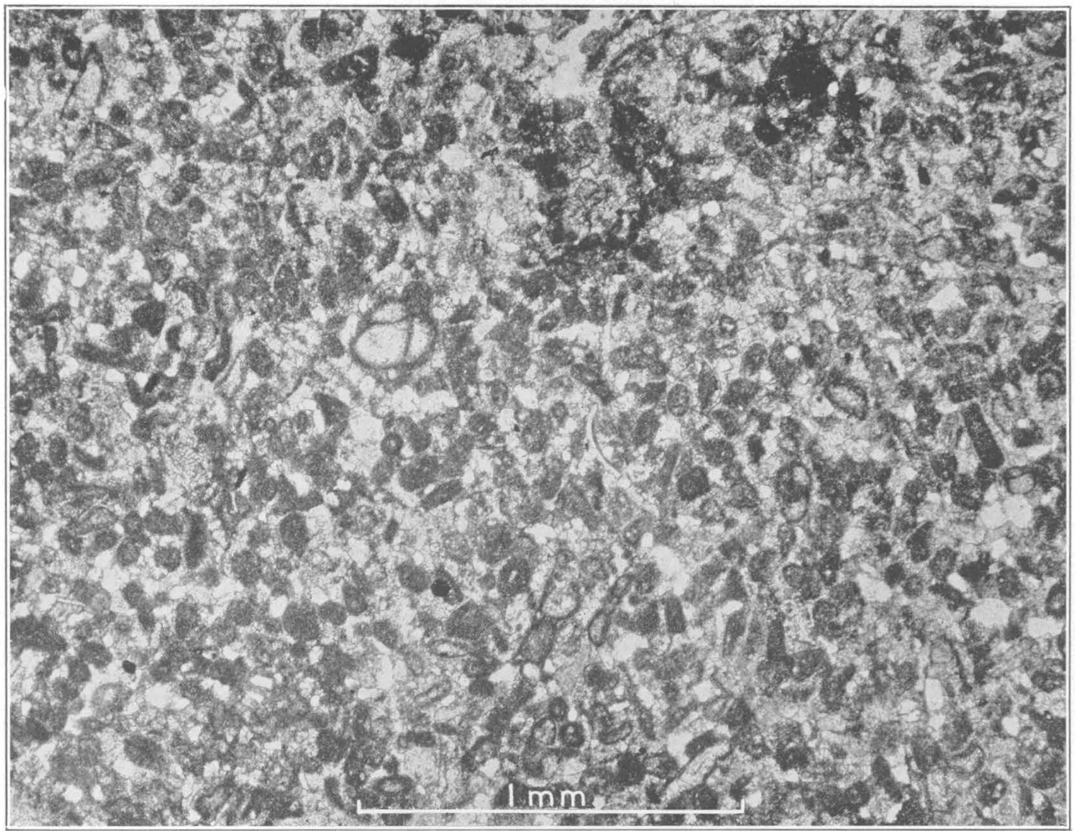
A



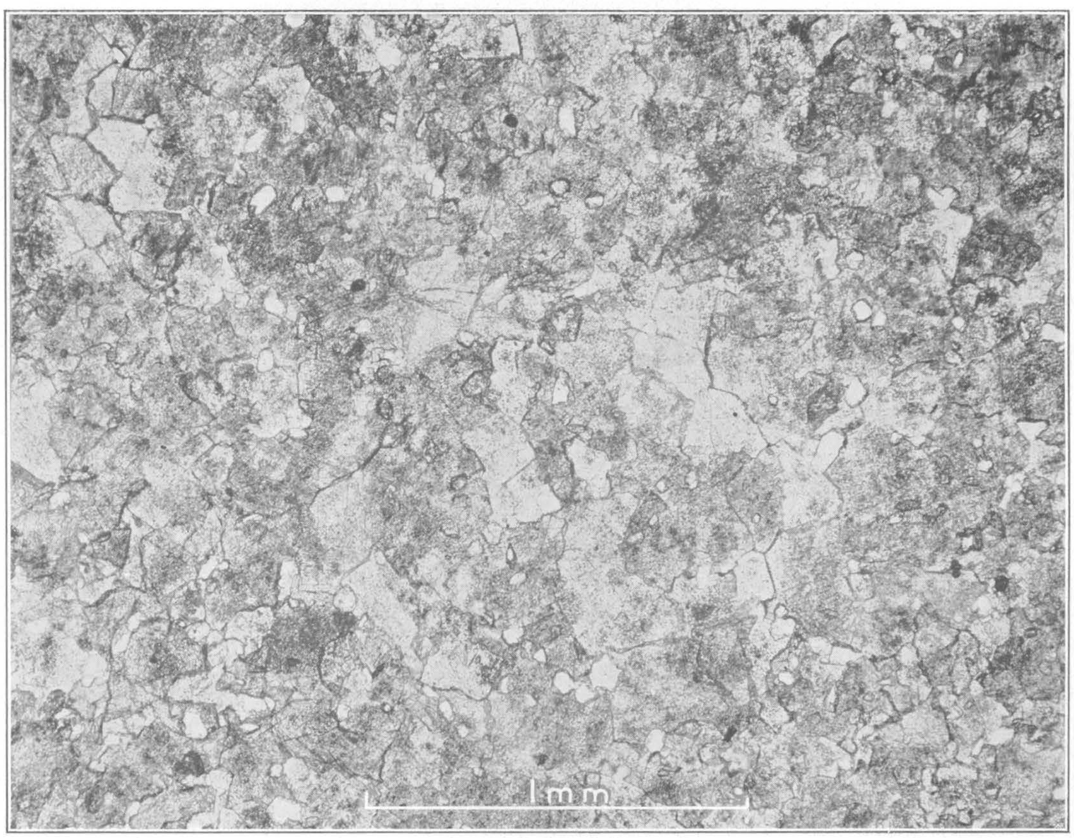
B

THIN SECTIONS OF SPECIMENS OF LIMESTONE (*A*) AND DOLOMITIZED LIMESTONE (*B*) FROM A BED 300 FEET ABOVE THE BASE OF THE BIRD SPRING FORMATION IN THE NE. ¼ SEC. 33, T. 25 S., R. 58 E., NORTH OF THE SILVER GEM TUNNEL

A shows specimens of Bryozoa (Fenestella?) and Foraminifera (Nodosaria sp. and Endothyra? sp.), as well as other undetermined minute organisms; clear angular grains are quartz. (Analysis 10a, p. 61; pl. 18, *A*, *B*.) In *B* the gray areas are dolomite, the nearly clear areas are calcite, and the small clear angular grains are quartz. (Analysis 10b, p. 61; pl. 18, *A*, *B*.)



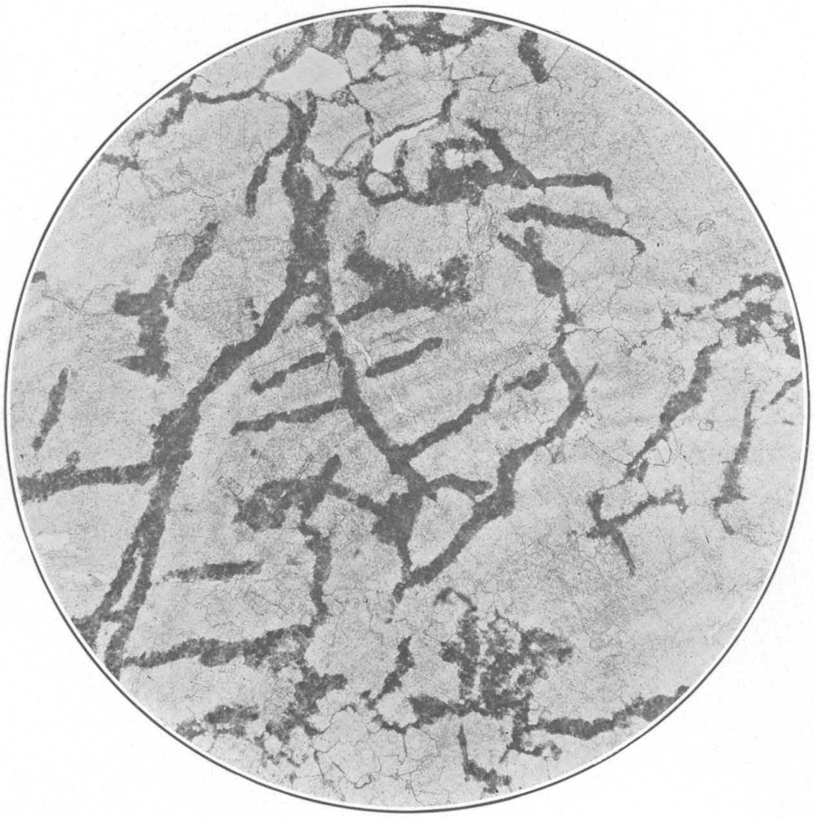
A



B

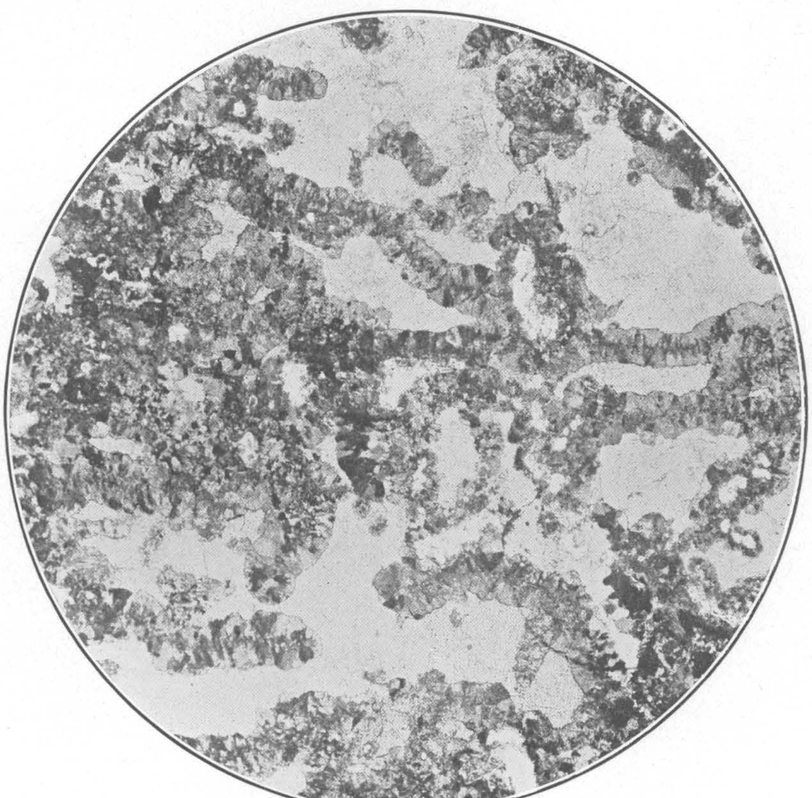
THIN SECTIONS OF SPECIMENS OF LIMESTONE (*A*) AND DOLOMITIZED LIMESTONE (*B*) FROM A BED 400 TO 500 FEET ABOVE THE BASE OF THE BIRD SPRING FORMATION IN THE NORTH CENTER OF SEC. 18, T. 24 S., R. 59 E.

A shows species of Bryozoa (Stenopora sp.) and Foraminifera (Cristellaria? sp. and Fusulinella? sp.), as well as other undetermined minute organisms. The clear angular grains are quartz. (Analysis 11a, p. 61.) In *B* the gray areas are dolomite, the nearly clear areas are calcite, and the small clear angular grains are quartz. (Analysis 11b, p. 61.)



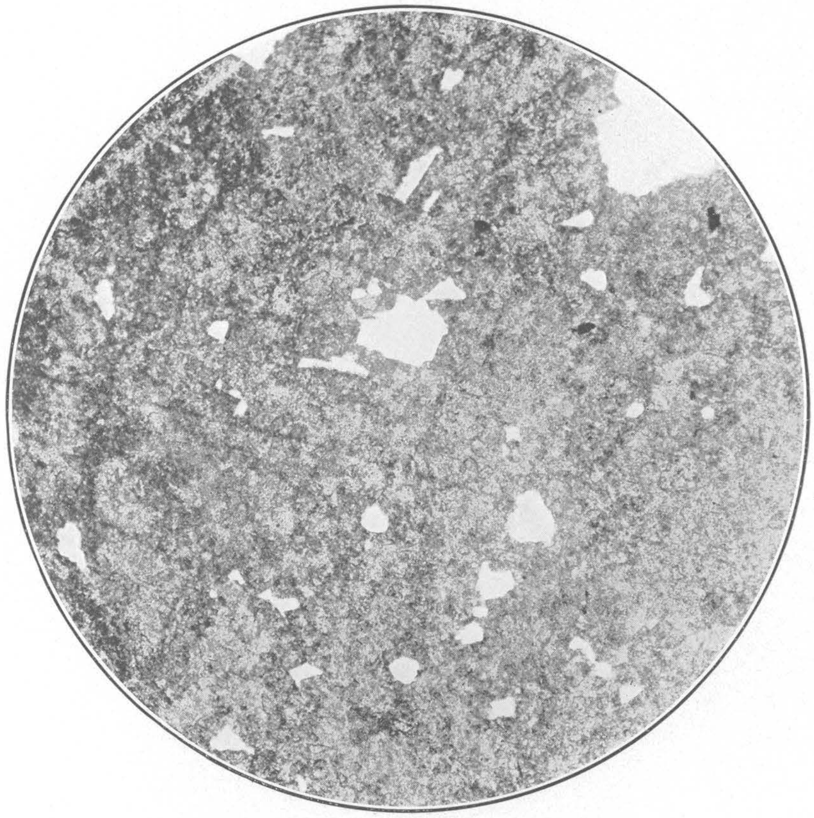
A. FIRST STAGE OF ALTERATION OF DOLOMITE TO HYDRATED DOLOMITE

Dolomite of the Monte Cristo formation in contact with the latite neck in NE. ¼ sec. 19, T. 25 S., R. 58 E. Polarized light, enlarged 30 diameters.



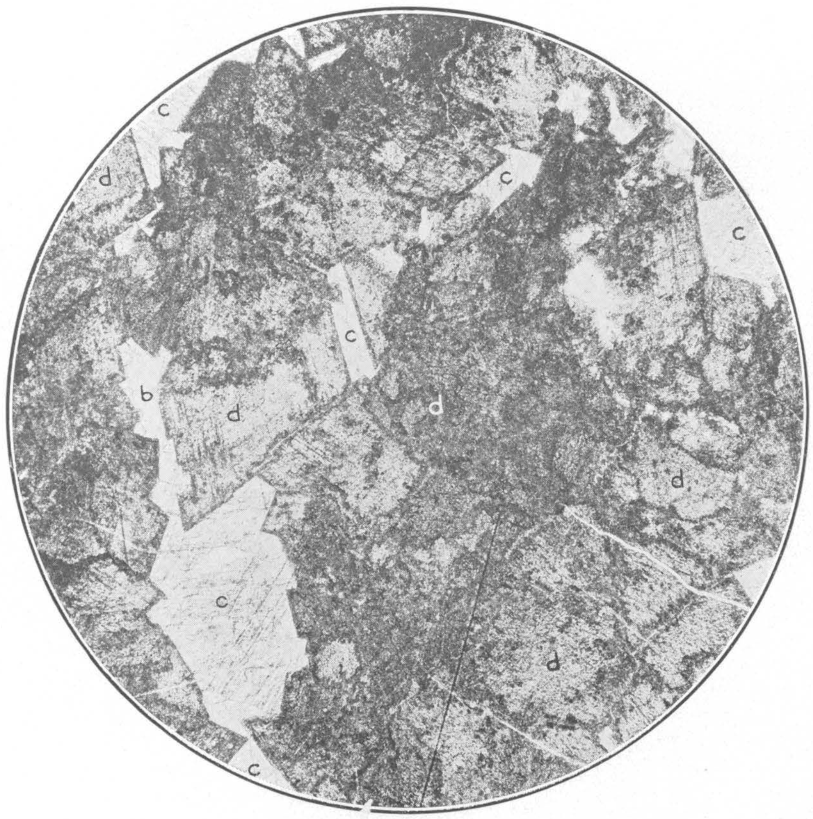
B. SECOND STAGE OF ALTERATION OF DOLOMITE TO HYDRATED DOLOMITE

Dolomite of the Monte Cristo formation in contact with the latite neck in NE. ¼ sec. 19, T. 25 S., R. 58 E. Polarized light, enlarged 30 diameters.



A. THIRD STAGE OF ALTERATION OF DOLOMITE TO HYDRATED DOLOMITE

Dolomite of the Monte Cristo formation in contact with the latite neck, in NE. ¼ sec. 19, T. 25 S., R. 58 E. Polarized light, enlarged 30 diameters.



B. ALTERED DOLOMITE OF THE MONTE CRISTO FORMATION, 1,000 FEET NORTH OF THE LATITE NECK, IN THE SE. ¼ SEC. 18, T. 25 S., R. 58 E.

Polarized light, enlarged 30 diameters. b, Brucite; c, calcite; d, dolomite.

of nearly if not quite pure dolomite. The close proximity of this specimen (No. 6a) to the corresponding dolomite (No. 6b) raises the question whether its magnesia (2.84 per cent) has not been added to the limestone during the general process of dolomitization, even though the color does not indicate alteration.

Several specimens that contain smaller percentages of magnesia, ranging from a trace to 0.35 per cent and indicating the presence of a trace to 1.37 per cent of dolomite, also contain small quantities of a carbonate not readily etched by dilute hydrochloric acid, but the texture of these specimens has not been studied exhaustively.

The quantity of magnesia in the dolomites ranges from 17.47 to 21.63 per cent; if it is present as the dolomite molecule the range of that mineral is 79.88 to 98.90 per cent. The analyses show clearly that the process of alteration to dolomite has been exceptionally complete, up to the very border of the adjacent limestone. In this respect the conditions appear to be different from those found in the Aspen district of Colorado by Spurr,[61] who concluded that transitions from pure limestone to dolomite existed.

Concerning the iron oxide and alumina, it is impressive that the quantity of both in the limestones and dolomites is uncommonly low. Certainly there is no evidence of an increase in their content coincident with the process of dolomitization, such as is common in many regions. Several of the methods for the identification of dolomite by staining depend upon the assumed constant presence of small quantities of ferrous oxide.[62] In the present investigation none of the staining tests have been tried. It should be remembered that only the iron and alumina soluble in hydrochloric acid is reported, and in some specimens the total quantity may be fractionally higher. Some of the specimens of dolomite, notably No. 2b, have sporadic brownish patches that undoubtedly represent iron oxides and may possibly represent weathered pyrite. The data show that there is no great difference in the quantities present in the beds of the Anchor limestone and Bird Spring formation.

The material reported as insoluble shows a wide range in both limestones and dolomites. None of the specimens of Anchor limestone show appreciable quantities of silica, and this confirms the field impressions, even though parts of the limestone contain characteristic chert lenses. The quantity of insoluble material in the specimens of limestone from the Bird Spring formation ranges from nothing to 12.14 per cent. Several specimens collected higher in the formation, 2,000 feet or more above the base, undoubtedly contain as much as 25 per cent of insoluble material. An examination of the sand grains remaining after dissolving fragments of the limestone in acid, as well as the evidence of thin sections (see pls. 20, *A*, and 21, *A*), shows that the insoluble material is largely if not entirely grains of quartz sand, here and there with a little feldspar, that were incorporated in the limestone at the time of deposition. Such is certainly true of the insoluble material in specimens 10a and 11a, as well as others not represented by analyses.

In some of the specimens of dolomite (10b, 11b, 12b, and 14) the insoluble material represents, as in the limestone, grains of quartz and other minerals that were laid down with the limestone and have survived its alteration to dolomite unchanged. On the other hand, the insoluble material in some specimens (7b, 8b, and 16) represents silica that was added during or soon after the alteration to dolomite. The polished surface of one specimen (8b) shows a groundmass of crystalline dolomite through which are distributed patches and veins of quartz. As the borders of the quartz patches are almost entirely outlines of dolomite crystals, it seems clear that the quartz has filled drusy cavities in the dolomite after the process of dolomitization was completed.

In order to study the nature and distribution of calcite in the dolomites, many speciemns have been polished and etched with dilute hydrochloric acid (1 : 1). Each specimen studied contains calcite, and the quantity closely corresponds to that indicated by a recalculation of the analyses. This conclusion is important, as it shows that under these conditions of dolomitization there is little if any isomorphism between calcite and dolomite. This subject has received considerable thought and experimental study, and it is stated by Foote and Bradley[63] that crystals of dolomite may contain as much as 20 per cent of isomorphously mixed calcite.

The size, shape, and distribution of the calcite areas in the dolomitized limestones have some bearing upon the interpretation of the mechanism of alteration of the limestone, as they seem to be persistent features of the dolomitized limestones in this region. Most of the calcite areas are either lenticular or irregular in shape, and, like the areas of quartz, they are bounded by terminated dolomite crystals, many of which show zonal growth. They commonly range from 1 to 3 millimeters in length, but some are as much as 2 centimeters long, and they are very unevenly distributed throughout the mass. The calcite is limpid clear and free from carbonaceous or other inclusions, so that it does not resemble the original limestone that occupied the same space. It can not be composed of residual grains of limestone but appears to consist of calcium carbonate deposited after the process of dolomitization was complete. In

[61] Spurr, J. E., Geology of the Aspen mining district, Colo.: U. S. Geol. Survey Mon. 31, p. 210, 1898.

[62] Steidtmann, Edward, Origin of dolomite as disclosed by stains and other methods: Geol. Soc. America Bull., vol. 28, p. 434, 1917.

[63] Foote, H. W., and Bradley, W. N., On solid solution in minerals; V, The isomorphism between calcite and dolomite: Am. Jour. Sci., 4th ser., vol. 37, p. 339, 1914.

this respect the calcite resembles the secondary quartz, with which, in fact, it is here and there associated. The analyses made by the E. J. Longyear Co. show that the process of dolomitization persisted to considerable depths near ore deposits and was not in any sense an alteration related to the present surface or to circulation of local surface waters.

Change in volume.—In many localities in this region there is abundant evidence that the process of alteration of limestone to dolomite has not involved any appreciable change in volume of the original rock. In some places hand specimens, such as that illustrated in Plate 19, *B*, show crystals and crystalline masses of dolomite that have grown without producing any distortion of the bedding of the near-by limestone. Dolomitized fossils do not show any distortion. Also, in many localities wedge-shaped masses of dolomite bounded by minor joints project into masses of limestone without involving distortion of the limestone. (See pl. 17, *B*.) Finally, on a larger scale, as in the locality shown in Figure 12, there is no difference between the thickness of a bed of limestone and its adjacent dolomitized equivalent. It is a fundamental concept of the process of dolomitization in this area that it has been accomplished without change in the volume of the original rock.

Gains and losses of material.—Most processes of rock alteration involve gains or losses of material, and it is interesting as a measure of the degree of alteration to know the quantities that are involved. In the present investigation it became readily apparent that large quantities of magnesia have been gained by the rocks and that similar large quantities of lime have been lost.

In order to calculate gains and losses of rocks that have been altered without change of volume there must be obtained, first, analyses of the unaltered rock and of the altered product; second, the specific gravity of the original rock and of the altered product, both free of pore space; and third, the porosity of the original rock and of the altered product. These data have been obtained for six pairs of specimens, and the results, as well as the calculated gains and losses of materials, are presented in the following table.

Gain and loss of constituents of limestones by dolomitization

[Numbers of specimens same as in tables of analyses, pp. 61-62]

Anchor limestone

	Limestone, 3a (per cent)		Dolomite, 3b (per cent)		Components per 1,000 cubic centimeters (grams)			Limestone, 4a (per cent)		Dolomite, 4b (per cent)		Components per 1,000 cubic centimeters (grams)		
	Found	Corrected	Found	Corrected	Limestone	Dolomite	Gain or loss	Found	Corrected	Found	Corrected	Limestone	Dolomite	Gain or loss
Calcium oxide	55.28	55.28	31.52	31.46	1,487.4	880.3	−607.1	54.98	54.98	31.44	31.22	1,470.2	862.5	−607.7
Magnesium oxide	Trace.	Trace.	21.00	20.96	Trace.	586.5	+586.5	.25	.25	21.31	21.16	6.7	584.5	+577.8
Carbon dioxide	43.20	43.38	47.13	47.58	1,167.2	1,331.4	+164.2	43.80	43.31	47.07	47.62	1,158.1	1,315.5	+157.4
Silica (insoluble)	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Iron and aluminum oxides	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Calcite, calculated	98.66	98.66	4.16	4.15				97.40	97.40	3.25	3.23			
Dolomite, calculated	Trace.	Trace.	96.02	95.85				1.14	1.14	97.44	96.77			
					2,690.6	2,798.3						2,674.0	2,762.5	
Porosity, per cent					0.56	1.96						1.49	3.201	
Weight of specimen, grams					335.118	466.576						80.215	149.215	
Density of powder					2.706	2.854						2.713	2.854	

Bird Spring formation

	Limestone, 9a (per cent)		Dolomite, 9b (per cent)		Components per 1,000 cubic centimeters (grams)			Limestone, 10a (per cent)		Dolomite, 10b (per cent)		Components per 1,000 cubic centimeters (grams)		
	Found	Corrected	Found	Corrected	Limestone	Dolomite	Gain or loss	Found	Corrected	Found	Corrected	Limestone	Dolomite	Gain or loss
Calcium oxide	55.66	55.66	32.56	32.56	7,502.5	909.4	−592.1	52.92	52.73	29.90	29.43	1,418.1	824.1	−594
Magnesium oxide	Trace.	Trace.	19.68	19.68	Trace.	549.7	+549.7	Trace.	Trace.	20.46	20.14	Trace.	563.9	+563.9
Carbon dioxide	43.60	43.68	46.63	47.03	1,179.1	1,313.5	+134.4	40.99	41.39	44.65	45.09	1,113.3	1,262.6	+149.3
Silica (insoluble)	0	0	0	0	0	0	0	5.91	5.89	5.42	5.34	158.4	149.5	−8.9
Iron and aluminum oxides	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Calcite, calculated	99.34	99.34	9.28	9.28				94.45	94.11	2.60	2.56			
Dolomite, calculated	Trace.	Trace.	89.99	89.99				Trace.	Trace.	93.55	92.10			
					2,699.5	2,793.0						2,689.8	2,800.1	
Porosity, per cent					0.361	1.784						0.635	1.690	
Weight of specimen, grams					144.407	100.935						384.317	192.661	
Density of powder					2.709	2.8357						2.707	2.848	

Gain and loss of constituents of limestone by dolomitization—Continued

Bird Spring formation—Continued

	Limestone, 11a (per cent)		Dolomite, 11b (per cent)		Components per 1,000 cubic centimeters (grams)		
	Found	Corrected	Found	Corrected	Limestone	Dolomite	Gain or loss
Calcium oxide	48.14	48.14	29.24	29.24	1,296.3	807.3	−489.0
Magnesium oxide	.30	.30	17.47	17.47	8.1	482.3	+474.2
Carbon dioxide	38.71	38.09	41.90	42.02	1,025.6	1,160.1	+134.5
Silica (insoluble)	12.14	12.14	10.85	10.85	326.9	299.5	−27.4
Iron and aluminum oxides	0	0	.10	.10		2.8	2.8
Calcite, calculated	85.16	85.16	8.85	8.85			
Dolomite, calculated	1.37	1.37	70.88	79.88			
					2,692.7	2,760.8	
Porosity, per cent					0.58	2.20	
Weight of specimen, grams					286.880	372.758	
Density of powder					2.708	2.823	

	Limestone, 12a (per cent)		Dolomite, 12b (per cent)		Components per 1,000 cubic centimeters (grams)		
	Found	Corrected	Found	Corrected	Limestone	Dolomite	Gain or loss
Calcium oxide	55.20	55.20	32.72	32.39	1,484.0	897.7	−586.3
Magnesium oxide	Trace.	Trace.	18.73	18.54	Trace.	513.8	+513.8
Carbon dioxide	42.80	43.31	45.27	45.66	1,164.3	1,265.5	+101.2
Silica (insoluble)	1.39	1.39	3.45	3.41	37.3	94.5	+57.2
Iron and aluminum oxides	0	0	0	0			
Calcite, calculated	98.51	98.51	11.93	11.81			
Dolomite, calculated	Trace.	Trace.	85.64	84.78			
					2,688.4	2,771.5	
Porosity, per cent					0.836	2.273	
Weight of specimen, grams					249.739	102.533	
Density of powder					2.711	2.836	

In making these calculations the following procedure was used: Where the sum of the percentages of the ingredients exceeded 100, each was corrected proportionately, so that the total should be 100. For the determinations of the density of the rock powders the writer is indebted to Mr. A. F. Melcher, formerly of the United States Geological Survey, who also gave many helpful suggestions concerning procedures in determining the porosity of large specimens.[64] The unused portions of the powdered specimens used in the chemical analyses were dried at 110° C. for 24 hours, and approximately 5-gram samples were weighed out and placed in weighted pycnometers. To these distilled water was added while the pressure was kept reduced to about 700 millimeters. Then the filled pycnometers were held at 29.45° C. for two hours before weighing. The weight of the sample divided by the weight of the displaced water yields the density at 29.45° C.

To make determinations of porosity specimens were held at 108° C. for 48 hours and at 165° C. for 24 hours, and then, after cooling, weighed as recorded in the table. Each specimen was then dipped in melted paraffin and after cooling was reweighed, the difference showing the weight of the paraffin coating. Later, after weighing the specimens in water, it was a simple matter to calculate the volume of the coated specimen, and then, from the density of the powder, to determine the percentage of pore space. In the table the porosity is expressed in percentage of the total volume. The range in porosity of the six specimens of limestone is from 0.361 to 1.49 per cent and of the six dolomites from 1.690 to 3.201 per cent. The porosity of the dolomites is from 2 to 4 times that of the corresponding limestones, and there is a tendency for the most porous limestone to yield the most porous dolomite. Curiously, the porosity of the limestones is higher than one would suspect from casual examination, and that of the dolomites is lower, although both are lower than in most specimens of such rocks. If the calcite in the dolomites were removed or had not been deposited, the porosity of the dolomites would be appreciably higher. If 5 per cent of calcite were represented by pore space, it would be equivalent to a porosity of 1.841 per cent; similarly 10 per cent of calcite would equal a porosity of 3.688 per cent. Under such an assumption, the porosity of the dolomites would range from 2.632 per cent (No. 10b) to 6.618 per cent (No. 12b).

In a broad way, the field evidence indicates that the pore space is rather uniformly distributed through the dolomites, but in hand specimens 3 or 4 inches long it is irregularly distributed. Determinations on specimens weighing less than 100 grams would probably be slightly misleading. In most specimens cavities that range from 0.5 to 1.0 millimeter in diameter are present, but only a few are larger; undoubtedly most of the pore space is represented by smaller cavities.

These calculations show that when the limestone was altered to dolomite it lost lime and gained magnesia and carbon dioxide. The loss in lime was about 40 per cent of that present in the limestone. Inasmuch as the gain in magnesia coincided with a gain in carbon dioxide, it is concluded that the solutions which brought in the magnesia contained carbon dioxide and that the magnesia was present as the bicarbonate rather than any other compound. The following equation expresses the replacement of a volume of calcite (1,000 cubic centimeters) by an equal volume of dolomite:

1,000 cubic centimeters (2,715 grams) of $CaCO_3$ (a solid) + 443 cubic centimeters (1,313 grams) of $MgCO_3$ in solution = 1,000 cubic centimeters (2,870 grams) of $CaMgCO_3$ (a solid) + 426 cubic centimeters (1,158 grams) of $CaCO_3$ in solution.

This equation represents an ideal condition that is probably not attainable in nature because it does not provide for porosity or any residual calcite. The analyses in the table on pages 61–62 probably represent average conditions in this field.

[64] Melcher, A. F., Determination of pore space of oil and gas sands: Mining and Metallurgy, No. 160, April, 1920.

The specimens that were tested yield inconclusive results concerning the gain or loss of silica. The examination of thin sections as well as polished sections of specimens 10a, 10b, 11a, 11b, and 12b shows that all the silica is present as subangular grains of quartz and that none resembles the secondary silica referred to on page 57. Actually, two pairs of the analyses (10a and 10b, 11a and 11b) show slight losses of silica, and the third (12a and 12b) shows an appreciable gain. The evidence justifies the conclusion that these differences reflect original variations in the sand content of the limestones and do not indicate gains or losses of silica during alteration. The questions of the addition of silica during dolomitization and its recent migration and rearrangement as a result of weathering are further considered under Ore deposits (p. 98).

Manner of replacement.—At this place the probable significance of the foregoing data is briefly summarized, so far as it bears upon the manner of replacement of the limestone by dolomite. A comparison of the structure of the limestone with that of dolomite shows that except for a few fossils the minute texture of the limestone is destroyed and coarser dolomite crystals have taken its place. It seems significant that the calcite which remains in the dolomite is limpid clear, is free from inclusions, and does not possess any of the features of the limestone that originally occupied the space. It therefore does not appear that the terminated dolomite crystals which adjoin the calcite areas were replacing the limestone molecule by molecule but rather that the limestone was being dissolved slightly in advance of the growing dolomite crystals and that when their growth was complete there remained several per cent of pore space, which was later filled up by the calcite dissolved near by. As one of the consequences of this process, the porosity of any part of the mass would be a minimum at the beginning, attain a maximum at the end of dolomitization, and then decrease rapidly when the pores finally filled up with the eliminated calcite.

The principal channels of access of magnesium-bearing solutions undoubtedly were faults, fractures, and bedding planes. Considering the degree of alteration of large bodies of rock, the fractures seem few and widely spaced. Certainly, in many places there are masses of dolomite 5 to 10 feet or more from a conspicuous fracture. This condition is repeatedly shown in the area represented by Plate 18, *A*. If it is general, the active circulation which produced alteration probably took place along a few fractures, and any liquids that permeated the rocks moved very sluggishly, if at all. It would follow that dissolved magnesium carbonate was transferred from the fractures into the rock by diffusion rather than by active circulation of water. Similarly, the calcium carbonate was diffused outward to the fissures and then on to the surface.

Source of the magnesia.—Dolomites have been observed and studied in many parts of the world under many circumstances, and various explanations have been offered to account for the source of the magnesia and the manner of its introduction into carbonate rock. The problem has been well summarized by Van Tuyl,[65] although his attention was largely directed to the processes of dolomitization remote from ore deposits.

The writer has recently reviewed the literature on dolomitization near ore deposits [66] and attempted to evaluate the possible sources of the magnesia which produced the alteration. Five general sources deserve consideration—(1) the waters of the sea, (2) the shell of sedimentary rocks, (3) the underlying crystalline rock complex, (4) the shallow intrusions in the crust, parts of which are revealed by erosion, and (5) the deeper magma reservoirs from which the shallow intrusive rocks have been derived.

1. As the result of the classical studies of Judd at Funafuti, it is now widely believed that the magnesia of sea water may partly replace the limestone forming on the sea bottom before burial. Also certain animals withdraw from sea water the magnesia in their hard parts, but so far as known this is not sufficient to form dolomite.[67] It does not seem possible that the magnesia of sea water is a direct source for the alterations considered here.

2. Most limestones contain some magnesia, and there are extensive beds of dolomitic limestone, not to mention other sediments, that contain considerable quantities. Many investigators believe that the magnesia in such limestones may migrate within a short time, if not long, after burial to form segregated bodies of dolomite in the midst of limestone. Also it is believed that the magnesia that has dolomitized limestone in some metalliferous districts was derived from bedded dolomites, having been first dissolved in some remote area and then transported by deeply migrating ground water. The circulation imagined is essentially artesian, the source of the magnesia being near the region of intake of the water and the site of deposition being near the outlet. This explanation, advanced by Siebenthal [68] to explain the origin of the dolomite as well as the zinc and lead in the Joplin region, has much to commend it in regions where the structure of the rocks would permit an artesian circulation. In

[65] Van Tuyl, F. M., The origin of dolomite: Iowa Geol. Survey, vol. 25, pp. 257–406, 1916.

[66] Hewett, D. F., Dolomitization and ore deposition: Econ. Geology, vol. 23, pp. 821–863, 1928.

[67] Clarke, F. W., and Wheeler, W. C., The inorganic constituents of marine invertebrates: U. S. Geol. Survey Prof. Paper 124, pp. 55–62, 1922.

[68] Siebenthal, C. E., Origin of the lead and zinc deposits of the Joplin region: U. S. Geol. Survey Bull. 606, pp. 183–184, 1916.

a district like Goodsprings, where the beds are highly folded and fractured, an artesian circulation of water seems highly improbable.

In some regions dolomitic limestones are known to have been replaced by manganiferous iron carbonates (Leadville [69] and Red Cliff,[70] Colo., and Pioche, Nev.[71]) or by silica (Tintic, Utah,[72] and Aspen, Colo.[73]) in the vicinity of ore deposits. If the beds in which dolomitization is observed are underlain by lower beds that may have undergone replacement by such manganiferous iron carbonates or silica, it seems probable that the magnesia may have migrated upward or outward and produced the observed dolomitization. In the opinion of the writer this source of magnesia deserves consideration.

3. The ancient crystalline rocks show a wide range in composition, and all contain an appreciable quantity of magnesia. The common gneisses and schists contain from 0.3 to 3.0 per cent of magnesia, and there are many varieties of less siliceous and more magnesian gneissic rocks. These rocks are possible sources of magnesia, but their general structure does not favor lateral circulation, and they are not widely replaced in such a way as to yield their magnesia. All composite rocks break down into a few simple minerals under the influence of weathering on the surface, but where they are deeply buried, a part of their ingredients is set free only by recombination or substitution through interaction with new substances.

4. The intrusive rocks exposed at the surface show a wide range of magnesia content as well as in the other constituents. Many granites and aplites contain as little as 0.2 per cent of magnesia; the quartz monzonites from 0.3 to 2.5 per cent; the intermediate andesites and diorites from 2.0 to 5.0 per cent. A few basic rocks contain as much as 45 per cent. In most metal-mining districts large masses of intrusive rocks show a high degree of alteration, which is reflected by the development of new minerals. In the western United States the sericitic and propylitic types are common, and by these processes magnesia, lime, and some other ingredients are commonly eliminated. Good quantitative data of the kind and degree of alteration of the intrusives are on record for a number of districts—Nevada City and Grass Valley, Calif.;[74] Wood River, Idaho;[75] Tonopah,[76] Goldfield,[77] and Ely,[78] Nev.; and Breckenridge, Colo.[79] In all but one of these districts, as well as in many more that have been less thoroughly studied, the alteration of the intrusive rock has caused the elimination of most of the magnesia that it once contained. It seems that this magnesia, driven out of the intrusive rock by its alteration, may be considered available to accomplish dolomitization of the higher limestones. It is characteristic of the intrusive porphyry of the Goodsprings district that although small in number and area of outcrops, it is widely altered by sericitization.

5. Magmatic sources of many elements that accomplish rock alteration and form ore deposits are attractive in an attempt to explain such deposits, because they appear to impose no further burdens in the way of speculation or inquiry. Without doubt, magmas are the source of considerable water and some other substances, but it seems unwise to consider them the sole or principal sources of many elements until other possible sources have been carefully considered.

In the present state of knowledge of the Goodsprings district, as well as some similar districts, it seems that although magmatic sources and underlying dolomitic limestones, such as those of the Goodsprings formation, may have been the source of some of the magnesia now present in the dolomitized limestone, a more productive source was the shallow masses of intrusive porphyry.

ROCK ALTERATIONS RELATED TO LATE TERTIARY FINE-GRAINED INTRUSIVE ROCKS

The types of alteration related to the fine-grained intrusive rocks include dolomitization, hydration, and ferration.

Dolomitization.—For a distance of at least a mile around the northern border of the Diablo Grande intrusive mass, the adjacent limestones of the Monte Cristo formation are intricately fractured and bleached over a belt 100 feet or more wide. (See pl. 10, *A*.) The line of contact between gray limestone and bleached rock is sharp and clear but highly sinuous,

[69] Emmons, S. F., Irving, J. D., and Loughlin, G. F., Geology and ore deposits of the Leadville mining district, Colorado: U. S. Geol. Survey Prof. Paper 148, pp. 151-154, 1927.

[70] Crawford, R. D., and Gibson, Russell, Geology and ore deposits of the Red Cliff district, Colorado: Colorado Geol. Survey Bull. 30, pp. 55-56, 1925.

[71] Westgate, L. G., and Knopf, Adolph, Geology of Pioche, Nev., and vicinity: Am. Inst. Min. and Met. Eng. Trans., vol. 75, pp. 834-835, 1927.

[72] Lindgren, Waldemar, and Loughlin, G. F., Geology and ore deposits of the Tintic mining district, Utah: U. S. Geol. Survey Prof. Paper 107, pp. 154-159, 1919.

[73] Spurr, J. E., Geology of the Aspen mining district, Colorado: U. S. Geol. Survey Mon. 31, pp. 206-216, 1898.

[74] Lindgren, Waldemar, The gold-quartz veins of Nevada City and Grass Valley districts, California: U. S. Geol. Survey Seventeenth Ann. Rept., pt. 2, pp. 146-153, 1896.

[75] Lindgren, Waldemar, The gold and silver veins of Silver City, De Lamar, and other mining districts in Idaho: U. S. Geol. Survey Twentieth Ann. Rept., pt. 3, pp. 218-231, 1899.

[76] Spurr, J. E., Geology of the Tonopah mining district, Nev.: U. S. Geol. Survey Prof. Paper 42, pp. 207-252, 1905.

[77] Ransome, F. L., Geology and ore deposits of Goldfield, Nev.: U. S. Geol. Survey Prof. Paper 66, pp. 176-186, 1909.

[78] Spencer, A. C., The geology and ore deposits of Ely, Nev.: U. S. Geol. Survey Prof. Paper 96, pp. 55-64, 1917.

[79] Ransome, F. L., Geology and ore deposits of the Breckenridge district, Colorado: U. S. Geol. Survey Prof. Paper 75, pp. 95-101, 1911.

and in several places there are lenses of bleached rock 5 to 20 feet wide and 100 to 300 feet long that extend out into the limestone normal to the igneous contact. Analyses of the fresh gray limestone (16a) and of the bleached rock (16b), presented in the table on page 62, show that the former is nearly pure calcium carbonate, whereas the latter is largely dolomite that carries 6.03 per cent of insoluble matter. It is clear that the effect of the intrusion has been to convert the limestone to dolomite and to add a little silica.

To a less degree a similar alteration appears to have taken place around the southern border of the volcanic neck northwest of the Sultan mine, where it is in contact with limestones of the Sultan formation, but no analyses have been made.

Hydration.—The northern part of the volcanic neck northwest of the Sultan mine is in contact with dolomitized limestone of the Monte Cristo formation, a light-gray medium-crystalline rock. Between this gray dolomite and the intrusive rock there is a zone of finely crystalline cream-colored rock 15 to 30 feet wide, which, when tested with dilute hydrochloric acid, effervesces much more freely than normal dolomite. Three stages in the alteration of the dolomite are shown in Plates 22, *A*, *B*, and 23, *A*, which represent thin sections of the materials. The outer part of the zone is made up of normal crystalline dolomite, along certain cleavages of which a very fine-grained mineral has developed. (See pl. 22, *A*.) Plate 22, *B*, shows the next stage of alteration, where the new mineral, having grown along the cleavages, forms nearly half the entire mass. The rock adjoining the intrusive neck is wholly made up of the new mineral. (See pl. 23, *A*.)

An analysis of the dense, most altered rock, made by J. G. Fairchild, of the United States Geological Survey, together with the calculated molecular ratios, is shown in the following table.

Analysis of altered limestone of Monte Cristo formation

	Analysis	Molecular composition		Ratios
CaO	31.80	5.67	5.18	5×1.04
MgO	22.22	5.51	4.96	5×0.99
CO_2	43.48	9.88	8.90	9×0.99
H_2O-	.17	1.11	1.00	1×1.00
H_2O+	1.99			
Insoluble	.10			
	99.76			

This calculation indicates that the constitution of the material is $5CaCO_3.4MgCO_3.Mg(OH)_2$.

The material has been examined carefully by H. E. Merwin, of the Geophysical Laboratory, Washington, who has found that it is essentially uniaxial negative, ω=1.675–1.680, ϵ=slightly lower than 1.51. These indices of refraction are close to those of dolomite. It is concluded that the material is largely dolomite; that a part of the water is represented by brucite and a part may be occluded by the fine-grained material. It is regarded as fortuitous that the molecular ratios so closely accord with the formula given. The material dissolves rapidly in dilute acids, but this may be due to the extreme fineness of grain.

Some light on the nature of this alteration is derived from observations near by. At the head of the ravine in the SE. ¼ sec. 18, T. 25 S., R. 58 E., there are several areas, one as large as 200 by 500 feet, within which the dolomite has been bleached. A specimen from one of these localities has been polished and etched; another has been examined in thin section (pl. 23, *B*) and analyzed (No. 17, p. 62). The thin section shows a normal dolomite, partly altered to the hydrated product, with drusy cavities largely filled with calcite but in part with brucite. The brucite bears the same relation to the dolomite as the calcite widely noted in the dolomitized limestones of the region, but that calcite generally belongs to the period of the coarse-grained intrusive rocks and the brucite to the later period of the fine-grained intrusives. Hence it seems that the brucite has displaced calcite.

If in the analysis of this rock (No. 17, p. 62) all of the water is calculated as brucite, it is found that 21.26 per cent of that mineral is present—much more than is shown in the thin section. It is clear that this rock contains the four minerals dolomite, calcite, brucite, and hydrated dolomite. A hydrous carbonate of calcium and magnesium containing 37.13 per cent of lime, 23.75 per cent of magnesia, 32.41 per cent of carbon dioxide, and 6.63 per cent of water has been described by Fucan [80] and named gajite. The material studied came from talus under a cliff of Carboniferous limestone and dolomite in Croatia. The properties of gajite closely resemble those of the hydrated dolomite in the Goodsprings region, both in masses as well as in thin section.

Ferration.—On page 40 there is brief reference to the zone of altered dolomite that surrounds the basalt dike in the SW. ¼ sec. 30, T. 24 S., R. 58 E., west of the Kirby mine. The dike trends N. 5° E., and the adjacent dolomites of the Goodsprings formation strike N. 70° W. and dip 40° S. The unaltered dolomite at the south end of the dike is gray and medium crystalline. It appears to have been a magnesian limestone originally but to have been converted to a nearly pure dolomite during the process of early Tertiary dolomitization (No. 15a, p. 62). Within the altered zone, which is about 20 feet thick, the dolomite has been converted to a brown rock of fine grain that weathers lighter and locally shows reddish-brown iron stains. Here and there the rock has been intricately fractured and cemented by veins of calcite. An analysis is shown as No. 15b in the table on page 62. A comparison of the analyses

[80] Fucan, F., Gajit, ein neues Mineral: Centralbl. Mineralogie, 1911, pp. 312–316.

shows that the only distinct difference is a slight increase in the content of iron oxide and silica in the brownish rock; but the amount of the iron oxide is much less than one would estimate from its color. There is a possibility that the differences in the content of iron oxide and silica may be due only to fortuitous differences in the specimens, but this seems unlikely.

COMPARISON OF ALTERATIONS PRODUCED BY COARSE AND FINE GRAINED INTRUSIVE ROCKS

A review of the field and analytical evidence on the composition of the limestones and dolomites of the region leads to the conclusion that the effect of the two types of igneous rocks differs more in degree than in kind. Dolomitization that is apparently related to the intrusions of granite porphyry is widespread; that related to the Big Devil intrusion of rhyolite is local. Silicification, which is present only to a slight extent, appears to have been caused by both the early granite porphyry and the later rhyolite and basalt. Ferration, also present to a slight extent only, is associated with one dike of granite porphyry and with a dike of later basalt. Perhaps the greatest difference in the effects of the two types of rock is concerned with hydration—the amount of water added. The only evidence of hydration of wall rocks by granite porphyry is that indicated by the presence of serpentine in one locality. The latite intrusions have caused the addition of considerable water to small areas of near-by dolomites.

Unless the iron stains in the altered dolomite are considered evidence of the presence of pyrite in the unweathered zone, which is possible, there are no sulphide minerals related to the fine-grained intrusive rocks, whereas the bodies of lead, zinc, and copper sulphides, whose weathered parts are now mined, appear to be closely related to the intrusions of coarse-grained granite porphyry.

HISTORY OF MINING [81]

The geologic make up and environment of mineral deposits are basic factors that determine what they may yield in the course of time, but other factors, such as the tides of human migration and the provision of transportation facilities, tend to determine the time of their development, and many other factors, such as prevailing prices and the improvements in the arts of mining and metallurgy, determine the parts that are removed from time to time. Even the climate and the other resources of the region affect the cost of operation and therefore the capacity to produce in competition with other sources. It will be helpful to review the development of the mineral deposits of this region in order to understand the part that some of these factors have played.

The ore deposits in the Goodsprings district remained unworked until 1856, although apparently they were known to the Paiute Indians and possibly to the old Spanish priests employed at different missions in California. Neither Frémont [82] nor Beale and Heap,[83] who crossed the Mountain Springs Pass, 4 miles north of the Yellow Pine mine, in 1844 and 1852, respectively, make any reference to them.

Reports of the Mormon missionaries sent out by Brigham Young to find lead [84] include the announcement, made on May 9, 1856, that an Indian had reported the occurrence of lead 35 miles southwest of Las Vegas, just a short distance south of the Salt Lake and San Bernardino emigrant trail, in the vicinity of Cottonwood Springs. Nathaniel V. Jones visited the locality and returned May 11 to report a great quantity of ore exposed. The name "Potosi" was no doubt given to the locality by Jones, who in 1839, at the age of 17, lived in the Potosi lead and zinc district of southwestern Wisconsin. From Wisconsin he went to Utah and California in 1847, to Iowa in 1848, and back to Utah in 1849. In 1856 he was called by Brigham Young to open up the mines near Las Vegas.

At a meeting held on July 29, 1856, at Las Vegas, 15 men whose names are on record formed an association to work the mines and elected A. L. Fullmer their president. Owing to delays caused by lack of blasting powder and provisions, no work was started until August, when Jones appeared before the Las Vegas Mission with the following letter from Brigham Young:

> This is to certify that the bearer, Bishop Nathaniel V. Jones, is counseled to forthwith proceed with the company to the neighborhood of the Las Vegas and to engage in manufacturing lead, and the said Bishop Jones is hereby empowered to call to his aid in the said manufacture and transportation of lead, building of furnaces, the mining of ore, etc., such persons as his judgment and necessities may dictate, not only southern missionaries but others of the brethren in the southern settlements if need be. Bishop Jones is a brother well and favorably known to us and many of the saints. He enjoys our confidence in his faithfulness, skill, judgment, and integrity and will keep a strict and accurate account of all services and aid rendered him in compliance with these instructions and report the same at my office in Great Salt Lake City.
>
> Done in Great Salt Lake City, Utah Territory, this 7th day of July, A. D. 1856.

On September 1 George Bean, one of the men of the association, started for Provo with a load of lead ore, which he was to trade for provisions. In December three wagons loaded with supplies, including horsepower bellows, furnace, hearths, and other apparatus, arrived at the lead "diggings." Early in January, 1857, Jones smelted the first ore and produced about 9,000 pounds of lead. The crude ore is said to have yielded 20 to 30 per cent of metal and was described as being of poorer grade than it looked when

[81] The account of the early work at the Potosi mine has been prepared by V. C. Heikes, U. S. Bureau of Mines, San Francisco, Calif.

[82] Frémont, J. C., Report of the exploring expedition to the Rocky Mountains, 1842-43-44, p. 265, Washington, 1845.

[83] Beale, E. F., and Heap, G. H., Central route to the Pacific, pp. 101-108, 1854.

[84] Historian's Office, Church of Jesus Christ of Latter-day Saints, Salt Lake City, personal communication.

mined, owing to much "dry bone, blackjack, and sulphur." The efforts of Jones to smelt more ore proved futile, and several loads of the ore were shipped to Salt Lake City. After this failure to make bullion Jones and most of his men, with one wagon, started to make lead locations some 30 miles northwest of Las Vegas in the Amber Mountain district. In February lead prospecting was abandoned.

The history of the district, as reviewed by Lincoln,[85] credits Dudd Leavitt and Isaac Grundy with the production of 5 tons of lead in 1855 or 1856 from a furnace constructed in a fireplace at Las Vegas and with thus beginning lead smelting in Nevada. Lincoln has probably confused Grundy's operations in the Lincoln district, Beaver County, Utah,[86] with those carried on in the Goodsprings district. Eissler [87] credits to Grundy "in the fifties" the production in a small furnace near the Lincoln mine[88] of "the first parcel of silver-lead ore on the Pacific coast smelted." Possibly Grundy attempted to smelt also some of the ore from the Potosi mines, but on account of the zinc he could not have succeeded any better than Jones.

The earliest specific reference to the Potosi mine in print is probably that found in a report by J. R. N. Owen to the Commission of the United States and California Boundary Survey, dated April 15, 1861, and quoted by Whitney [89] as follows:

> Leaving this range [Providence] and proceeding northwestward across a low valley to the next range [Clark or Spring Mountains], we enter a district in which limestone is not only the prevailing rock but appears to form entire ranges of lofty and boldly defined mountains, among which are comprised the Kingston, Mountain Spring, and Las Vegas Ranges, the latter extending farther to the northward. It is in this Mountain Spring Range that the Potosi mines, which are now exciting considerable attention (1861), are situated, a few miles south of the present Salt Lake road, on the western slope of the mountains, and several hundred feet above the level of the plain.

The first description of the Potosi deposit appears to be that by C. A. Luckhardt,[90] who examined it about 1870. At that time it was known as the Comet and was operated by the Silver State Mining Co. It was examined and described briefly by G. K. Gilbert [91] in 1871. According to Burchard,[92] the Yellow Pine mining district was organized in 1882. At that time the nearest railroad point was Goffs (Blakes), on the Atchison, Topeka & Santa Fe Railway, about 80 miles south of Goodsprings.

For the period 1870 to 1880, when there was considerable activity in the Clark Mountain district, 30 miles southwest of Goodsprings, there is meager record for this district. S. E. Yount went into the district in 1884 to do assessment work on the Keystone, Boss, Columbia, and Doubleup deposits, previously located by his father, Joseph Yount, but work had been done on two of these by John Moss, possibly as early as 1865. It was reported to Yount that about 1880 10 tons of copper ore was mined and sent out to the railroad. When Yount first saw the site of Goodsprings, there was an open spring in a patch of grass east of the present hotel of the Yellow Pine Mining Co., but there was not a single tree in the flat. The spring had been named earlier for Joe Good, a cattleman, and was located by Yount as a mill site. A. G. Campbell went to the district in 1886, and in 1887 he built the first house, a stone cabin that still stands in the center of the settlement. Campbell prospected throughout the district, and by 1892, when rich gold ore in the Keystone mine attracted attention, he and his associates, A. E. Thomas, John Kirby, and W. H. Smith, had located the Rose, U. S. (one of the Alice group), Empire, Golden Chariot, May, Commercial, South Side, and Hoosier claims. During 1892 and 1893 a number of men went into the district, and many claims were located, partly because of the construction of the branch railroad from Goffs to Purdy in 1893. About 1893, according to local report, the first shipment of lead ore to a western custom smelter was made by A. G. Campbell, who assembled material from several deposits, largely the Kirby, and hauled it to Purdy for shipment to El Paso.[93] The silver content of the lead ore appears to have been too low to make this profitable, and except for another shipment of 100 tons from the Potosi about 1900, little effort was made to mine lead ore until the San Pedro, Los Angeles & Salt Lake Railroad (now Union Pacific) reached Jean in 1905.

Up to this time most of the claims had been located (1) on iron gossans that yielded assays for gold, such as the Keystone, Golden Chariot, Chaquita, and Clementina, (2) on copper-stained gossans, such as the Boss, Columbia, Doubleup, Ironside, Copper Chief, Alice, and Rose, or (3) on the iron-rich gossans of lead veins, such as the May, Lucky, Tam o' Shanter, and Ruth. A few lead deposits without conspicuous gossans had been located—the Potosi, Shenandoah, Lookout, Hoosier, and Root. Of all these, only a few were destined to become very productive, and many more that were to become notable sources of ore later were not located, even if they were known.

From 1893 to 1898 interest centered largely in the gold-bearing deposits,[94] the Keystone, Boss, and Clementina, although many claims were located on lead deposits and some work was done. A few deposits in rather inaccessible situations, later to become productive sources of lead and zinc ores, were located

[85] Lincoln, F. C., Mining districts and mineral resources of Nevada, p. 29, Reno, Nev., 1923.
[86] Butler, B. S., and others, The ore deposits of Utah: U. S. Geol. Survey Prof. Paper 111, p. 530, 1920.
[87] Eissler, M., Metallurgy of argentiferous lead, 1891 ed., preface.
[88] The Lincoln mine in Beaver County, Utah, not the Lincoln mine in the Goodsprings district.
[89] Whitney, J. D., Geological Survey of California, vol. 1, pp. 469–474, 1865.
[90] Raymond, R. W., Statistics of mines and mining in the States and Territories west of the Rocky Mountains for 1871, pp. 168–174, 1872.
[91] Wheeler, G. M., Preliminary report concerning explorations and surveys, principally in Nevada and Arizona, 1871, p. 523, 1872.
[92] Burchard, H. C., Report of the Director of the Mint, 1882, pp. 163–164, 1883.
[93] Eng. and Min. Jour., vol. 56, p. 61, 1893.
[94] Keeley, J. R., A promising district: Min. and Sci. Press, vol. 67, p. 113, 1893; vol. 66, p. 260, 1893.

during this period—the Anchor, Sultan, Mobile, and Hilo (one of the Yellow Pine group). In 1898 an option was taken on the Columbia and Boss mines, a mill was built on the hillside south of Goodsprings, and 200 tons of copper ore was shipped from the Boss mine to the mill. The ore was never treated in this mill, but it later served as the nucleus for the original Yellow Pine mill. At this time, according to C. A. Beck, there were three buildings of stone and adobe at Goodsprings. This activity led to further prospecting, and between 1898 and 1901 many more deposits were located—the Ninety-nine, Azurite, Bullion, Bill Nye, Bybee, Prairie Flower, Accident, and Red Cloud. The Bybee claim was later the scene of the work that led to the discovery of the first zinc ore body of the Yellow Pine mine.

Two notable events in the history of the district were the completion of the railroad between Los Angeles and Salt Lake City in 1905, and the recognition of oxidized zinc minerals in many mines by T. C. Brown in 1906. The railroad had been built outward from Salt Lake City and Los Angeles, and the two parts met north of Jean late in 1905. The tractor road along the west side of Mesquite Valley through State Line Pass to Roach was built in 1904, largely to haul borax from the Death Valley region, but it also served to permit easy shipment of the ores from mines in the southwestern part of the district. Previously, the white and pale-brown earthy mineral, hydrozincite, commonly associated with the well-known lead minerals, was considered to be a lead mineral. Brown had known the oxidized zinc minerals at Magdalena, N. Mex., and readily recognized the hydrozincite. Had much lead ore of average grade been shipped out of the district earlier, the presence of zinc would doubtless have been recognized. As zinc minerals exceeded those of lead in most of the deposits, considerable material was readily minable at many places, and the presence of the railroad permitted its shipment. From this time onward the district made steady progress, and even before 1914, when war in Europe brought high prices for zinc ore, it was attracting wide attention, as is shown by the sale of some of the most promising mines to outside groups, notably the Potosi, Anchor, and Boss. The narrow-gage railroad from Jean to Goodsprings and the Yellow Pine mine was built in 1910 and permitted that mine to lower costs greatly. The discovery of high-grade platinum ore in the Boss mine in March, 1914, attracted further attention in the mining world and led to the location of the town site of Platina, near the old Keystone mill on the edge of Mesquite Valley. The town grew quickly and in a few months had a hotel, stores, houses, and a population of several hundred. Within a year the boom collapsed, and in 1924 none of the structures remained.

When the price of zinc reached its peak in 1915 there was feverish activity in the district, and about 1917 the population of Goodsprings reached 800. Since then, with lower prices for the metals, it has ranged from 50 to 200. Although the town depends largely on the activities of the mines, it also has the largest supply of good water in many miles, so that it may be regarded as a permanent settlement.

A review of the discovery and development of the mineral deposits of the district leaves the impression that the outcrops of most of them were readily recognized by the first prospectors who saw them but that their development was retarded by the high cost of transportation. When railroads drew near, many deposits were quickly exploited. Until recent years, however, most of the claims were unpatented but held by annual assessment work, which shows that most of the claims were found and exploited by poor men who could not afford the costs of patenting but were content to work them and live near by. Compared with many mining districts elsewhere in Nevada and other western States, the Goodsprings district has profited little by the investments of nonresidents. Had more of these investments been made, many of the mines would have profited by the wider range of experience brought to bear on the local problems, among which the faulting in many mines is outstanding.

PRODUCTION [95]

SUMMARY

Although this report is concerned with the geologic features and ore deposits of the Goodsprings quadrangle, the statistics of production are assembled for an organized mining district, the Yellow Pine district, which includes a slightly larger area and therefore several mines that lie outside the quadrangle.

The ore produced from the mines of the Yellow Pine district from 1902 to the end of 1929 amounted to 477,717 tons. Of this ore 7,656 tons was treated in amalgamation and cyanidation plants with a bullion recovery of 9,497.38 ounces of gold and 2,445 ounces of silver. The gold and silver bullion was largely recovered from Keystone ore and tailings, between 1902 and 1909; also in 1919 and 1920. The tailings treated by cyanidation amounted to 7,843 tons, or more than the ore treated in the amalgamation mill. Between 1911 and 1929, during the operation of the concentration mills, 230,452 tons of ore was treated, yielding 58,641 tons of zinc-lead concentrate and 32,742 tons of lead concentrate. The crude ore shipped from the district from 1903 to 1929 amounted to 227,952 tons, containing in recovered metal 3,186.97 ounces of gold, 422,379 ounces of silver, 3,085,675 pounds of copper, 34,655,460 pounds of lead, and 110,833,051 pounds of zinc.

The highest average value per ton of ore produced in this district amounted to $76.22, in 1915, and the lowest average was $21.34, in 1902.

[95] Prepared by V. C. Heikes, U. S. Bureau of Mines, San Francisco.

Gold, silver, copper, lead, and zinc produced in Yellow Pine mining district, Clark County, Nev., 1902–1929, in terms of recovered metal

Year	Ore mined (short tons)	Gold		Silver		Copper		Lead		Zinc		Total value
		Fine ounces	Value	Fine ounces	Value	Pounds	Value	Pounds	Value	Pounds	Value	
1902 [a]	2, 078	2, 137. 10	$44, 174	342	$181	------	------	------	------	------	------	$44, 355
1903 [a]	2, 092	2, 583. 04	53, 396	695	375	21, 800	$2, 255	28, 000	$700	------	------	56, 726
1904 [a]	1, 929	2, 316. 10	47, 878	146	85	------	------	------	------	------	------	47, 963
1905 [a]	2, 394	725. 62	15, 000	3, 707	2, 239	------	------	290, 063	13, 633	685, 659	$40, 463	71, 335
1906 [a]	9, 481	442. 63	9, 150	1, 573	1, 054	67, 341	12, 996	625, 175	35, 350	2, 885, 246	176, 000	234, 550
1907 [a]	4, 400	364. 46	7, 534	2, 976	1, 964	92, 690	18, 538	172, 800	9, 158	1, 878, 732	110, 845	148, 039
1908	4, 627	377. 21	7, 791	10, 247	5, 431	42, 144	5, 563	720, 285	30, 252	1, 115, 851	52, 445	101, 482
1909	8, 664	277. 67	5, 740	18, 461	9, 600	392	51	406, 353	17, 473	3, 013, 352	162, 721	195, 585
1910	5, 878	58. 97	1, 219	16, 826	9, 086	122, 925	15, 611	1, 263, 837	55, 609	2, 707, 071	146, 182	227, 707
1911	8, 677	117. 27	2, 424	47, 072	24, 948	173, 719	21, 715	1, 617, 224	72, 775	3, 548, 032	202, 238	324, 100
1912	28, 386	1. 63	34	223, 013	137, 153	103, 398	17, 061	6, 544, 917	294, 521	13, 254, 860	914, 585	1, 363, 354
1913	29, 060	61. 32	1, 268	192, 339	116, 173	283, 592	43, 957	6, 204, 065	272, 979	14, 363, 709	804, 704	1, 239, 081
1914	24, 537	388. 60	8, 034	122, 703	67, 855	156, 389	20, 800	4, 185, 208	163, 223	11, 862, 149	604, 970	864, 882
1915	38, 391	40. 29	833	100, 146	50, 774	262, 600	45, 955	4, 620, 243	217, 151	21, 061, 182	2, 611, 587	2, 926, 300
1916	71, 155	693. 36	14, 333	156, 492	102, 972	494, 604	121, 673	8, 349, 850	576, 139	28, 889, 282	3, 871, 164	4, 686, 281
1917	64, 260	515. 50	10, 656	219, 789	181, 106	764, 733	208, 772	9, 298, 706	799, 688	20, 535, 768	2, 094, 648	3, 294, 870
1918	40, 614	235. 52	4, 869	140, 211	140, 211	400, 792	98, 995	6, 459, 836	458, 648	15, 444, 731	1, 405, 470	2, 108, 193
1919	19, 273	563. 55	11, 650	139, 656	156, 415	130, 395	24, 253	4, 217, 739	223, 540	5, 974, 219	436, 118	851, 976
1920	18, 611	158. 33	3, 273	96, 557	105, 247	76, 567	14, 088	3, 927, 280	314, 182	9, 381, 503	759, 902	1, 196, 692
1921	287	1. 09	22	2, 195	2, 195	119	15	186, 169	8, 378	69, 397	3, 470	14, 080
1922	1, 861	. 95	19	6, 618	6, 618	52	7	316, 125	17, 387	891, 174	50, 797	74, 828
1923	14, 758	5. 26	109	31, 678	25, 976	1, 855	273	1, 472, 113	103, 048	8, 755, 427	595, 369	724, 775
1924	21, 383	7. 00	145	123, 650	82, 845	16, 267	2, 131	7, 710, 851	616, 868	7, 909, 042	514, 088	1, 216, 077
1925	20, 435	14. 39	298	72, 045	49, 999	6, 900	980	5, 287, 587	460, 020	6, 230, 664	473, 530	984, 827
1926	8, 931	15. 75	326	19, 549	12, 199	10, 994	1, 539	1, 904, 766	152, 381	2, 181, 686	163, 626	330, 071
1927	10, 192	6. 44	133	12, 619	7, 155	7, 523	986	1, 652, 186	104, 088	3, 546, 078	226, 949	339, 311
1928	10, 745	6. 77	140	25, 793	15, 089	43, 955	6, 329	2, 209, 087	128, 127	1, 425, 285	86, 942	236, 627
1929	4, 618	22. 68	469	11, 067	5, 898	33, 382	5, 875	1, 070, 718	67, 455	1, 236, 702	81, 622	161, 320

[a] Recorded under Lincoln County.

PRODUCTION BY ORES

Dry or siliceous ores.—The dry or siliceous ores mined in the Yellow Pine district came chiefly from the Keystone, Boss, and other properties leased to miners who shipped or treated the ore in 1914, 1918, 1919, 1920, 1922, and 1924. This ore amounted to 1,654 tons and contained an average of $13.64 in gold and 2.93 ounces of silver to the ton. Small quantities of copper and lead were contained in some of the shipments. This average does not include the ores mined prior to 1910.

Copper ore.—The copper ores included those carrying over 2.5 per cent of copper. Shipments were made most frequently from the Ninety-nine, Red Streak, Highline, Azurite, New Year, Mountain Top, Copperside, Columbia, and Boss, and less frequently from the Golden Treasure, Pilgrim, Prairie Flower, Ajax, Clementina, Alice, Doubleup, Fitzhugh Lee, Blue Jay, Hoosier, Mobile, Smithsonite, Tam o' Shanter, Lincoln, Combination, Kirby, Oro Amigo, Ironside, Lucky Strike, Yellow Pine, Hillside, Bonanza, Bill Nye, and Annex.

Content of crude copper ore produced in the Yellow Pine district and shipped to smelters, 1910–1929

Year	Ore (short tons)	Gold (fine ounces)	Silver (fine ounces)	Copper (pounds)
1910	689	492. 63	5, 055	205, 041
1911	509	2. 79	2, 763	172, 723
1912	337	1. 03	1, 453	98, 249
1913	960	13. 80	2, 037	270, 610
1914	553	4. 00	1, 106	152, 430
1915	934	39. 31	1, 786	262, 600
1916	2, 084	445. 43	3, 531	490, 619
1917	2, 469	507. 94	5, 739	758, 850
1918	1, 441	196. 94	4, 982	398, 303
1919	353	18. 13	477	126, 609
1920	200	10. 66	257	68, 216
1921	1	. 04	750	97
1923	1	------	139	148
1926	23	. 70	41	8, 073
1928	14	. 42	73	2, 963
1929	81	3. 82	120	24, 993

The average yield of 10,531 tons of copper ore shipped was $3.39 in gold and 2.86 ounces of silver to the ton and 14.26 per cent of copper.

The Rose group was the chief producer of copper-lead ore, which, together with several small lots from another mine, amounted to 72 tons shipped to the smelter in 1916 and 1917. This ore averaged 4 cents in gold and 11.66 ounces of silver to the ton, 5.30 per cent of copper and 25.26 per cent of lead.

Lead ore.—In general the crude lead ores are those containing over 4.5 per cent of lead. Shipments were made most frequently during the last decade by the Yellow Pine, Potosi, Anchor, Hoosier, Bullion, Ingomar, Hoodoo, Accident, Milford, Addison, Sultan, Christmas, New Year, Mountain Top, Dividend, Bill Nye, Kirby, Mongolian or Puelz, Bonanza, Mobile, Pilgrim, Singer, Shenandoah, Alice, Smithsonite, Contact, Tiffin, Eureka, Annex, Ninety-nine, Rover, Azurite, Fredrickson, Tam o' Shanter, Combination, Dawn, and Whale.

Content of crude lead ore produced in the Yellow Pine district and shipped to smelters, 1910–1929

Year	Ore (short tons)	Gold (fine ounces)	Silver (fine ounces)	Copper (pounds)	Lead (pounds)
1910	869	9. 54	4, 231	2, 157	716, 120
1911	231	. 32	2, 166	232	284, 568
1912	686	. 60	12, 763	5, 149	663, 898
1913	1, 215	47. 52	10, 518	12, 982	1, 074, 209
1914	365	1. 11	3, 549	1, 982	386, 048
1915	1, 134	. 98	6, 575	------	998, 008
1916	17, 028	247. 77	32, 276	8	3, 903, 708
1917	23, 121	7. 56	61, 526	2, 229	4, 676, 652
1918	10, 476	------	38, 809	2, 476	2, 551, 395
1919	5, 232	8. 74	36. 924	3, 745	1, 148, 213
1920	1, 302	3. 98	10, 013	8, 325	915, 009
1921	147	1. 05	1, 445	22	141, 430
1922	239	. 92	2, 076	------	173, 474
1923	592	5. 26	3, 223	1, 707	477, 227
1924	2, 447	------	45, 654	16, 267	2, 618, 364
1925	3, 429	. 98	41, 413	42	2, 497, 456
1926	915	. 15	5, 401	315	782, 103
1927	290	. 18	3, 259	1, 045	242, 558
1928	477	1. 46	3, 394	1, 784	487, 960
1929	553	2. 37	4, 947	3, 756	503, 334

The average content of the 70,748 tons of lead ore shipped was 0.10 cent in gold and 4.67 ounces of silver to the ton, 0.04 per cent of copper, and 17.84 per cent of lead.

Ore was first calcined at the Potosi mine in 1915 by the Empire Zinc Co., which acquired the property from Mahoney Bros., of San Francisco, December 10, 1913. The calciner was built in 1914 and had a capacity of 30 tons in 24 hours and was equipped to calcine the ore in an oil-fired stack and rotary calcining furnace. At the Yellow Pine mill 4,866 tons of zinc concentrate was calcined in 1924 at a cost of $2.20 a ton, yielding 3,683 tons of calcined zinc concentrate that netted $11.86 a ton. The Yellow Pine concentrator was completely destroyed by fire September 19, 1924, but was reconstructed and ready for operation in 1926. It was again destroyed by fire June 10, 1928, and a flotation mill was under construction in 1929.

Zinc-lead ore.—Most of the crude zinc-lead ore was separated into lead concentrate and zinc-lead concentrate. The Yellow Pine mine was the chief producer of such ore. Other mines producing concentrating ore were the Bullion, Anchor, Sultan, Tiffin, and Fredrickson. Producers of zinc-lead ore of shipping grade were the Potosi, which calcined most of its output, and others shipping crude ore were the Ingomar, Shenandoah, Milford, Addison, Hoosier, Hoodoo, New Year, Mountain Top, Christmas, Bill Nye, Silver Gem, Root or Bonanza, and Dawn.

Content of crude zinc-lead ore produced in the Yellow Pine district, 1910–1929

Year	Ore (tons)		Silver (fine ounces)	Lead (pounds)	Zinc (pounds)
	District	Yellow Pine mine			
1910	1, 663	1, 505	5, 863	428, 055	817, 803
1911	4, 654	4, 561	32, 870	1, 151, 750	1, 598, 134
1912	20, 054	20, 054	208, 797	5, 881, 019	9, 105, 865
1913	16, 749	16, 687	176, 411	5, 036, 829	8, 071, 639
1914	16, 039	15, 472	115, 138	3, 716, 856	7, 130, 399
1915	16, 839	16, 136	84, 976	3, 088, 029	8, 213, 714
1916	23, 146	20, 581	99, 558	3, 986, 116	10, 530, 082
1917	20, 922	20, 027	150, 089	4, 575, 599	9, 080, 938
1918	19, 418	8, 200	89, 748	3, 838, 183	9, 617, 792
1919	11, 562	10, 900	101, 269	3, 059, 336	5, 296, 304
1920	15, 443	14, 353	83, 600	3, 009, 685	8, 629, 463
1921	139			44, 718	69, 397
1922	1, 412	1, 272	4, 115	140, 240	714, 374
1923	10, 371	9, 740	28, 316	990, 880	5, 570, 784
1924	18, 395	17, 620	77, 959	5, 092, 411	7, 882, 042
1925	12, 964	12, 439	16, 174	2, 131, 384	5, 300, 184
1926	3, 980	2, 400	3, 237	418, 667	2, 004, 911
1927	5, 883	4, 027	2, 881	1, 006, 559	2, 628, 970
1928	3, 978	2, 239	2, 489	519, 911	1, 405, 891
1929	2, 225	1, 476	3, 210	448, 631	1, 118, 089

The average content of the 225,856 tons of zinc-lead ore at the mines was 5.70 ounces of silver to the ton, 10.75 per cent of lead, and 23.20 per cent of zinc.

Zinc ore.—Zinc ore was shipped to eastern works for reduction between 1910 and 1929, most frequently from the Yellow Pine, Potosi, Monte Cristo, Milford, Addison, Bill Nye, Green Mountain, Sultan, New Year, Anchor, Prairie Flower, Ingomar, Shenandoah, and Whale mines. Shipments of zinc ore were made less frequently from the Mobile, Bullion, Valentine, Accident, Hoodoo, Dividend, Contact, Fredrickson, Hoosier, Alice, Christmas Consolidated (Silver Gem), Bonanza, Smithsonite, Azalia, Pilgrim, Columbia, Singer, Tam o' Shanter, Tiffin, Eureka, Valentine, Dawn, and Annex.

Content of zinc ore produced in the Yellow Pine district and shipped to smelters, 1910–1929

Year	Ore (short tons)	Silver (fine ounces)	Lead (pounds)	Zinc (pounds)
1910	3, 038	5, 281	118, 428	1, 889, 268
1911	3, 013	9, 216	180, 910	1, 949, 898
1912	7, 309			4, 148, 995
1913	10, 136	3, 373	93, 027	6, 298, 070
1914	7, 550	2, 761	82, 271	4, 731, 750
1915	19, 464	6, 809	533, 486	12, 847, 468
1916	28, 840	19, 432	427, 068	18, 359, 200
1917	17, 733	2, 290	43, 027	11, 454, 830
1918	9, 270	6, 200	70, 069	5, 826, 939
1919	1, 062		10, 190	677, 915
1920	1, 118		2, 560	752, 040
1922	208		2, 400	176, 800
1923	3, 794		3, 979	3, 184, 643
1924	41			27, 000
1925	55			38, 030
1927	1, 465			917, 108
1928	34		943	19, 394
1929	177	378	12, 536	118, 613

The average metallic content of the 114,307 tons of zinc ore shipped was 0.49 ounce of silver to the ton, 0.69 per cent of lead, and 32.1 per cent of recovered zinc.

OUTLOOK FOR MINING IN THE DISTRICT

In a purely technical sense mining is the term applied to the group of operations by which minerals are recovered from the ground; in a broader economic sense it includes the art of making money by those operations. In other words, the interest of the public or the Nation in a resource is measured largely by the possibility of exploiting it at a profit in competition with other similar resources, at home or abroad. The purpose of these statements is to emphasize the economic problems of this district in contrast with the geologic problems, to which this report is largely devoted. It may be profitable to review briefly the history of the district in so far as this concerns production, prices, and the events that affected them.

Fortunately, except for the early production of gold from the Keystone mine, there is a very complete record of the production of the mines of this district in the United States Bureau of Mines. The figures in this record have been carefully segregated and checked for compilation in the tables of production for each mine. Figure 13 presents curves showing the

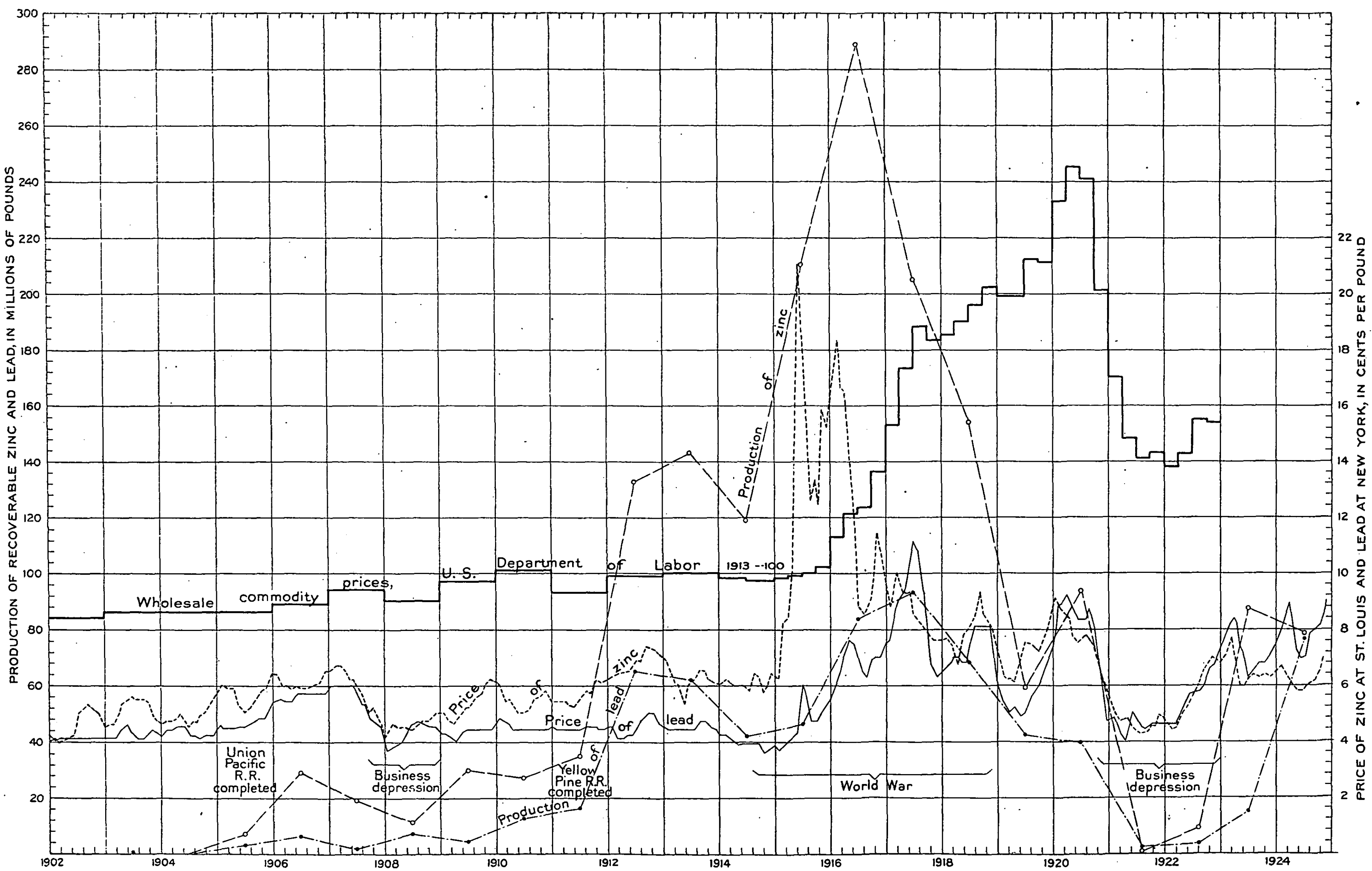


FIGURE 13.—Curves of metal prices and annual production from Yellow Pine district, also curve of wholesale commodity prices (1913=100)

prices of zinc and lead since 1902 and the annual recoverable content of these metals in the ore produced in the Yellow Pine district, as well as the curve of wholesale commodity prices. From what has been said on page 71 concerning the discovery of the ore deposits, as well as the accounts of the individual mines, it seems that the value of the zinc, lead, and copper ores was too low to permit their shipment before the Los Angeles & Salt Lake Railroad was completed to Jean. The low value of the ores was due to the meager amounts of accessory gold and silver that they contained. It is doubtful whether any shipments prior to 1905, except those of gold bullion, yielded a profit to the miners. Even after the railroad was in operation through Jean, the cost of the 8 to 25 mile wagon haul from the mines probably wiped out for several years the margin of profit for most mines on all except occasional carefully selected shipments. The great increase in production in 1912 was due to the completion in 1911 of the Yellow Pine Mining Co.'s narrow-gage railroad from Jean to the mine, a distance of 12 miles. The further increase during 1913 and 1914 represents largely the mining of reserves in the Yellow Pine mine, developed in anticipation of the completion of its railroad. The decline in zinc production during the business depression of 1907 and 1908 indicates the sensitiveness of mine operations to slight declines in prices.

Figure 13 brings out clearly the astonishing increase in production brought about by high prices for zinc during the early years of the World War—1915, 1916, and 1917. How much would have been produced by the district under normal prices is a matter for interesting conjecture. A considerable part of the increase in production of the Yellow Pine mine during these years is due to the fortunate discovery of enormous bodies of ore between the 300 and 700 foot levels north of the Hale shaft. One effect of high prices for the metals during the war was shown quickly by decline in grade of the ore shipped from many mines. Prior to 1914 most shipments of zinc ore contained from 38 to 42 per cent of zinc, but during the period of high prices much 30 per cent ore and some 25 per cent ore was shipped. One factor that increased the gross output of both lead and zinc from 1912 onward, but especially during the war, was the better prices offered for the mixed lead and zinc ores, which could be used to make pigment (leaded zinc oxide) but could not be treated profitably to make two products, one containing lead and the other zinc.

It is difficult to apportion the causes of the trend of production since 1918. Obviously the low production for 1921 and 1922 indicates that the mines could not produce ore at the prices prevailing, but on the other hand, the policy of the board of directors of one mine was a factor, for there were known ore bodies in that mine which could have been mined at a profit, but they were held for better prices. Another element, the general rise of commodity prices, enters into the general failure of a developed district to continue to produce after 1919 in accordance with the hope held out by its earlier record. Although indicated by the curves of wholesale prices and the prices of the metals in Figure 13, it is also widely known that the prices of zinc and lead are relatively lower than the wholesale commodity price since the war.[96] In other words, the products offered for sale by the mine operators have declined in real value, whereas the real prices of the materials which they must use in mining have risen.

The records of dividends is available for only three mining companies, the Yellow Pine Mining Co., the Goodsprings Anchor Mining Co., and the Boss Gold Mining Co., and these give an inadequate picture of the profit of mining in the district. A few of the mines are owned by incorporated companies, and some of these have not worked the mines on company account. The shipments from most of the mines, especially the smaller ones, have been made by groups of lessees, and the profit realized from their work is unknown. Doubtless in the aggregate their profit has been considerable, but it is also apparent that numerous lessees have done an extraordinary amount of hard work for little or no return.

The foregoing review indicates the wide range of factors that affect the production of minerals and that must be considered in estimating what may be produced from a given district, the quantity and grade of the ore as well as other local resources, mining skill, geologic understanding, luck, metallurgical advances, transportation facilities, trend of prices of the materials produced and of the materials purchased, and trend of economic and political events of national and international scope.

Of the reserves of minerals in the district very little that is precise or quantitative can be stated, as the time available for this examination did not permit careful studies. The visible zinc, lead, copper, and gold minerals are apparently exhausted from a few mines, but these are a small part of the total, for most of the mines still show sporadic patches of high-grade material and much more of a lower grade. Only here and there, however, are the assured reserves of low-grade ore in excess of a few thousand tons, though further exploration will doubtless increase these reserves.

With only a few exceptions, the ore bodies that have been exploited in the district are those that have been fortuitously exposed at the surface by erosion. As in

[96] Hanley, H. E., Diminishing value of the metals: Eng. and Min. Jour., vol. 120, pp. 622–623, 1925.

many if not most other districts in the Western States, there has been little systematic prospecting in this district (from 5,000 to 10,000 feet of work) for ore bodies other than those which cropped out. Of course, an examination of the records of production of many of the mines will show that the probable margin of profit on work to date has not been large and that in most places prospecting remote from known ore should be undertaken cautiously. Nevertheless, parts of the district, especially those in which the structural relations of the ore bodies are fairly clear, warrant careful study with a view to making comprehensive plans for underground exploration. Such studies of the smaller mines should take into account the relation of past production to current metal prices, for when the curves for both are compared it is clear that most of these mines can be operated at a profit only when the prices of lead and zinc exceed 6 cents a pound.

The problem of understanding and applying the relations of ore zones to channels of access of ore minerals and also that of discriminating between premineral and postmineral fractures need considerable attention, and upon their correct solution from place to place in the district rests the greatest hope of future production. Although the writer hopes that his studies have contributed to this end, he is quite aware that the problems encountered in a number of mines have not been considered comprehensively.

ORE DEPOSITS

DISTRIBUTION

The Goodsprings quadrangle contains most of the known ore deposits in the Spring Mountains. Most of these deposits occur in an area about 10 miles in diameter, the center of which lies about 4 miles southwest of Goodsprings (pl. 30), but a few are sporadically distributed in the north half of the quadrangle. A few productive mines lie several miles west of the quadrangle (Green Monster and Rainbow) and a few more south of it (Tam o' Shanter and Carbonate King). A few prospects lie in the part of the Bird Spring Range east of the quadrangle.

SUMMARY OF GEOLOGIC RELATIONS OF THE ORE DEPOSITS

The ore deposits of this region are found either in the Paleozoic stratified rocks or in the porphyritic rocks intrusive into them. Most of the deposits, including the most productive, occur in dolomitized zones of lower Mississippian limestone. A few deposits, in which gold and silver are the metals sought, occur in dikes of highly altered intrusive porphyry. These intrusions are localized either in or a short distance above extensive thrust faults, notably the Contact and Keystone faults. Most of the zinc and lead deposits lie in the rocks overlying the zone of intrusions. A few, such as the Potosi and others near the Ninety-nine mine, are as much as 6 miles distant from the nearest known outcropping bodies of intrusive rocks. No porphyry intrusions are known in the Spring Mountains for 40 miles north and 10 miles south of the quadrangle. There is thus a general but not precise areal coincidence of the zone of intrusives and the area which contains most of the ore deposits. For this reason it is believed that there is a genetic relation between the ore deposits and the porphyry intrusives. (See fig. 14.)

GROUPS OF ORE DEPOSITS ACCORDING TO METAL CONTENT

On the basis of their principal metal content, the ore deposits of the region are separable into four groups—(1) those which contain gold with little if any copper and silver, (2) those which contain much more silver than gold, (3) those whose principal metal is copper but which also contain some gold or platinum and palladium, though little silver, and (4) those which contain either lead or zinc or both together with a little copper. Cobalt occurs almost uniformly wherever copper is present and has been mined in four localities. Vanadium minerals occur in many of the lead and zinc deposits and have been mined in several places.

MINERALOGY

CLASSIFICATION OF THE MINERALS

In considering each of these groups of deposits the content and relations of the original minerals, unaffected by recent weathering (hypogene) should be distinguished clearly from those which have formed during weathering (supergene).[97] Not only are the minerals of the two stages largely unlike, but their relations to fractures, faults, and near-by rocks are different. In some deposits the unchanged original minerals have been mined and their relations are fairly clear, but in most of the deposits, under the influence of weathering, the metals have not only migrated from their original positions but entirely new mineral compounds have been formed. Such migrations have been accompanied by solution and decomposition of the near-by rocks with the result that the present relations of the deposits to faults and other features are very obscure. Some bodies of galena, such as the Anchor, Accident, and Ruth, are largely unaltered; but others, such as

[97] Ransome has applied the term supergene to minerals deposited by generally downward-moving and initially cold solutions. Hypogene is applied to minerals deposited by hot ascending solutions.

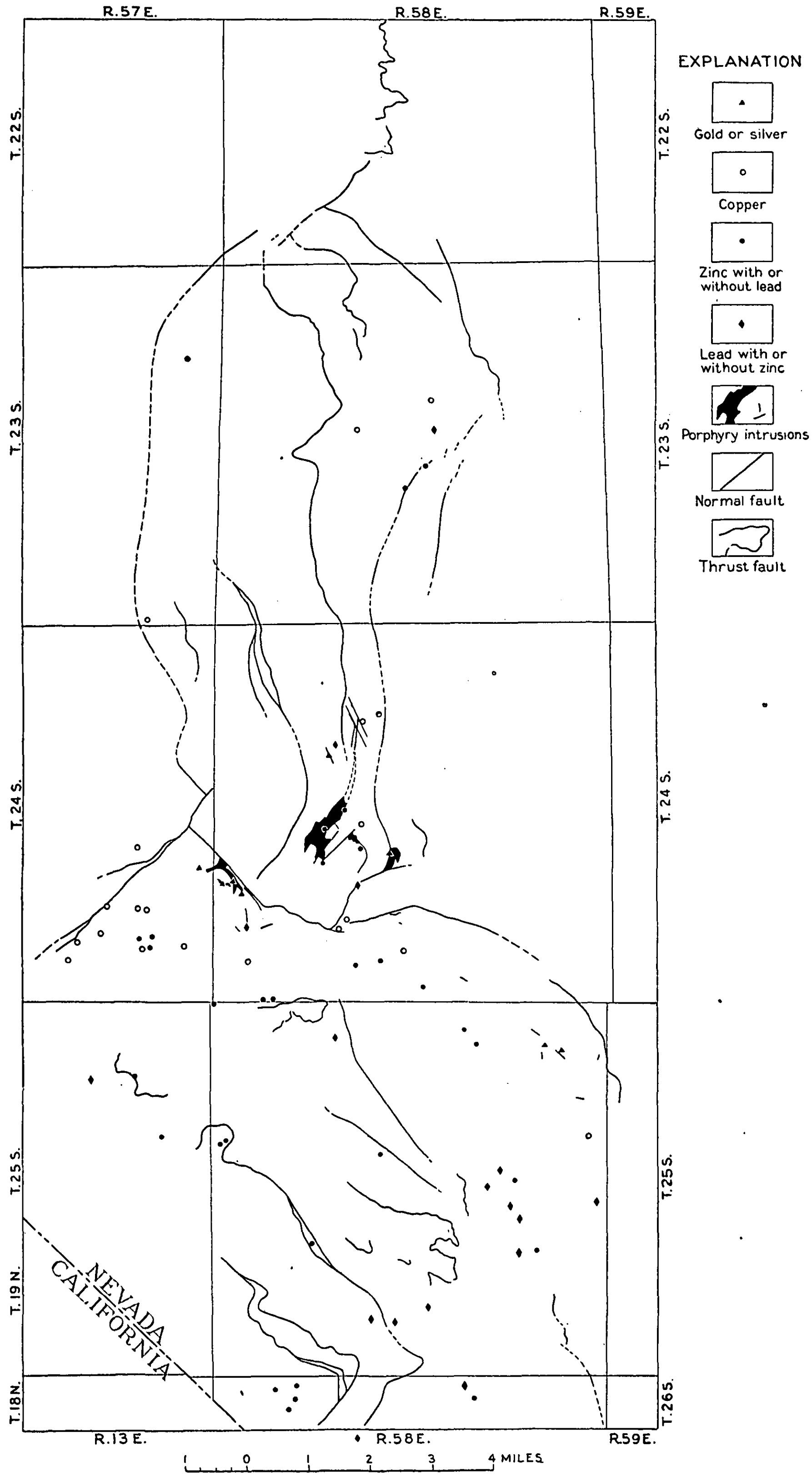


FIGURE 14.—Map showing relation of ore deposits to outcropping intrusive rocks and thrust faults

the Kirby, have been largely converted to lead carbonate and sulphate, which lie in different positions and have different relations to the near-by rocks. On the other hand, although sphalerite or zinc sulphide was the original zinc mineral in all deposits, it was found unaltered in two mines only, the Potosi and Milford. The bodies of zinc ore that have been mined are almost entirely alteration products—hydrozincite, smithsonite, and calamine—and these lie either near by or many feet from the masses of sulphide that were the source of the zinc. Similarly, the original copper mineral in most of the deposits was doubtless the sulphide, chalcopyrite, but this has been found only in traces in the mined deposits. The principal copper minerals—malachite, azurite, and chrysocolla—are clearly many feet distant from the original sulphide—chalcopyrite—although sporadic masses of chalcocite may lie near the places where it once existed.

The following table summarizes the minerals associated with the four groups of ore deposits.

Geologic classification of the principal minerals in the ore deposits of the Goodsprings quadrangle

Metallic minerals

Hypogene			Supergene		
Gold-silver deposits	Copper deposits	Zinc-lead deposits	Gold-silver deposits	Copper deposits	Zinc-lead deposits
Gold Pyrite	Chalcopyrite	Galena Sphalerite Stibnite	Gold? Proustite? Tennantite Cerargyrite Limonite Wad Malachite	Copper Platinum? Chalcocite Stibiconite Cuprite Tenorite Limonite Wad Heterogenite Malachite Azurite Dioptase Chrysocolla Olivenite Libethenite Cuprodescloizite Brochantite Jarosite Natrojarosite Beaverite	Cinnabar Bornite Limonite Turgite Smithsonite Malachite Hydrozincite Calamine Dioptase Pyromorphite Mimetite Annabergite Vanadinite Cuprodescloizite Linarite Plumbojarosite Jarosite Alunite Wulfenite

Gangue or wall rock

Quartz Dolomite	Quartz Dolomite	Calcite Dolomite Barite Chert Hydrocarbon	Chert	Quartz Chert Opal	Quartz Chert Chalcedony Calcite Aragonite Gypsum

Principal minerals in the ore deposits of the Goodsprings district

[a, abundant; c, common; u, uncommon; v, very uncommon; r, reported]

	Metals		Sulphides										Chloride	Oxides												Carbonates									
	Gold	Copper	Chalcocite	Chalcopyrite	Cinnabar	Galena	Bornite	Pyrite	Proustite	Sphalerite	Tennantite	Stibnite	Cerargyrite	Chert	Opal	Quartz	Hematite	Magnetite	Cuprite	Tenorite	Limonite	Turgite	Wad	Heterogenite	Stibiconite	Calcite	Aragonite	Cerusite	Smithsonite	Hydrozincite	Azurite	Malachite	Aurichalcite	Siderite	Cobalt dolomite
Gold mines:																																			
Chaquita	?													c							c														
Clementina	u													u							u											u			
Golden Chariot	u														u	u																c			
Keystone	c							c						c		r					a		u									u			
Lavina						u		c	u							c																			
Red Cloud	u				c			c						u							c														
Copper mines:																																			
Azurite			u	u			u							?		u			r		c			u				u			u	c			
Belle														c		c							c												
Blue Jay			r																		u			c								c			c
Boss	v	u	u	u											c	c			u		a			u							u	a			
Columbia		r	u	u			u							u		u			r		c			c							u	a			
Copper Chief			u											c							a			c								u			
Copperside			u	u			u							c		v					c			u							u	c			
Doubleup			u											c		u					a											c			
Green Copper			r											c							a			u								c			
Fitzhugh Lee														u							c			u								c			
Highline			u											c						u	c			c							u	c			
Ironside														a							a											u			
Lincoln													v	u		u					u			v								u			
Ninety-nine			c											c		u			r		a	u	c									c			
Oro Amigo														c		u					c			v							u	c			v
Rose			r											c					u		u			u				c				c			
Snowstorm														u							u											c			
Zinc or lead mines:																																			
Accident						a																						u		a					
Addison						c																						c	u	a					
Alice			r			u															c							u		a	u		c		
Anchor						a																	u			c		c		a					
Annex						a								u												c		c		c					
Bill Nye						c																						c		a					
Bullion						a																						c		a					
Christmas						c																						c		a					
Contact						u																						u	r	a			u		u
Dawn						u															u							u		c					
Eureka-Silver Gem						c																						c							
Fredrickson					u	a																						c		a			u		
Hermosa						c																						c		c					
Hoosier						a																				c		c		c					
Hoodoo						c															c							c							
Ingomar						c															c							c	c	a					
Kirby						c								a		u					c	c						a							
Lookout						a								c												c		c		c					
Middlesex						a																						c		c					
Milford						a				u											c					c		c	c	a					
Milford No. 2						a																						u		a					
Mobile						u										u											u	u		a					
Mongolian						u										u					c					u		u		c					
Monte Cristo														c												c			c	a					
Mountain Top						a								c														c		a		c			
New Year						c																						c	u	a					
Palace-Porter						a																				a		c		c					
Pilgrim						c																						c		a					
Potosi						c				a																c		u	u	a		u	u		
Prairie Flower						a																				c	c	c		a					
Pauline														c		u												u		c		u			
Root						c				r				u							c					c		c	u	a					
Ruth						a								c														a		?		u			
Shenandoah						a																					c	a		?					
Singer						a																						c		a					
Smithsonite																					a											u	u		
Sultan						a								v							c					v		c		a			u		
Spelter						a															u							c		c					
Tam o' Shanter						u								a							a							c	u			u			
Tiffin						a																						u		a					
Valentine						u															c							u		a					
Whale						u																								u			u		
Yellow Pine						a						u		u							c				u			a	c	a		u	c		
Unnamed prospects													u				c	c																u	

Principal minerals in the ore deposits of the Goodsprings district—Continued

	Silicates			Phosphates and arsenates					Vanadates					Sulphates								Molybdate
	Calamine	Chrysocolla	Dioptase	Pyromorphite	Mimetite	Libethenite	Olivenite	Annabergite	Vanadinite	Descloizite	Cuprodescloizite	Psittacinite	Undetermined	Barite	Anglesite	Alunite	Jarosite	Plumbojarosite	Natrojarosite	Beaverite	Linarite	Wulfenite
Gold mines:																						
Clementina		v																				
Golden Chariot		c																				
Keystone		u												u								
Copper mines:																						
Azurite		c					v												c			
Belle		u											c									
Blue Jay		c	c																			
Boss		c				u											c	u	c			
Columbia		c	u										u									
Copper Chief		c																				
Copperside		c															a			u		
Doubleup		u																				
Green Copper		c	u																			
Fitzhugh Lee		c											u									
Highline		u	v									u										
Ironside		u																				
Lincoln		c																				
Ninety-nine		c									c											
Oro Amigo		c																				
Rose		c	u	u																		
Snowstorm		r												c								
Zinc or lead mines:																						
Accident	u												v									
Addison	c																					
Alice	c												u		u							
Anchor	c														u							
Annex													u		u							
Bill Nye	c										c											
Bullion	c														c							
Christmas	c														c							
Contact	c•										c											
Dawn	c												u		u							u
Eureka-Silver Gem									u		c				c							
Fredrickson	c										u		u		c							r
Hermosa	c			c									u		c							u
Hoosier	c												u		c							
Hoodoo	u										c											
Ingomar	c																					
Kirby	u			u												c		a				
Lookout	u										u		u									
Middlesex	c																					
Milford	c														u							u
Milford No. 2	c																					
Mobile	c										u		u		u							u
Mongolian	c																					
Monte Cristo	a																					
Mountain Top	c	u	u										c									
New Year	c														u							
Pilgrim	c	c		c																		u
Potosi	c																u					
Prairie Flower	c				c					u			c		c							
Pauline	c										u				c							
Root	c	v													c						u	
Ruth	u														c							u
Shenandoah															c							u
Singer	c	u		c									u									
Smithsonite	a	u																				u
Sultan	c																	u				
Spelter											c				u							
Tam o' Shanter	u			u														u				
Tiffin	c												u		u							
Valentine	c														u							
Whale	a	u									c											u
Yellow Pine	a	u		r		u		u					u		u		c	c			v	
Unnamed prospects									u	c			c									

The foregoing table has been prepared to show the distribution and relative abundance of most of the minerals in the ore deposits of the district. Below are presented the properties and relations of the minerals, compiled in accordance with Dana's "System of mineralogy."

CHARACTER AND RELATIONS OF THE MINERALS

NATIVE METALS

Gold.—Although native gold (Au) was found by the writer in only one place in the district, on the 300-foot level north from the Keystone shaft, it is clear from the records of production, as well as local report, that gold is rather widespread in the region of the Keystone, Red Cloud, Lavina, and Boss mines and several prospects near Crystal Pass. In the Keystone mine the gold ranged in fineness from 0.920 to 0.930, and it was largely associated with dense limonite, dark chert, or greenish clay. In the Clementina, Chaquita, and other near-by prospects it seems to have been closely associated with limonite, doubtless derived from pyrite. According to Knopf,[98] the gold in the plumbojarosite ore of the Boss mine was blackish and spongy and the normal color developed only after treatment with acid and annealing. After this treatment the fineness was 0.928. The black color and sponginess of the gold indicate that before the deposit was thoroughly oxidized the gold was not free but combined with some other element, now removed by oxidation. According to Joe Armstrong, operator and part owner

[98] Knopf, Adolph, A gold-platinum-palladium lode in southern Nevada: U. S. Geol. Survey Bull. 620, p. 8, 1915.

of the Red Cloud mine, free gold was never seen in ore from that mine, either unoxidized or oxidized, but it could be dissolved out in solutions of potassium cyanide. It seems possible that here, also, in the unoxidized ore the gold was combined with some other element.

Copper.—Native copper (Cu) was not observed by the writer in any of the ores, but according to F. R. Crampton, small quantities were sparsely distributed through ore from one of the shoots in the Boss mine.

Platinum.—In addition to the occurrence of platinum (Pt) in the Boss mine described below, authentic assays of material from the Oro Amigo mine leave no doubt that small quantities of platinum are present there. H. Hardy, who shipped copper ore from the Golden Chariot mine, states that assays of the ore have shown as much as half an ounce of platinum to the ton, but this was not confirmed by the writer. A sample of pure jarosite from the Copperside mine, submitted to R. Perez, of Los Angeles, for assay, was reported to contain no platinum. When the difficulties inherent in the accurate determination of platinum are considered, it seems doubtful whether the presence of the metal has been determined confidently at more than three localities in the district.

According to Knopf,[69] both the platinum and the palladium of the Boss deposit occur in extremely small particles of dark color, and the metallic gray luster is revealed only by fusion with sodium carbonate. He considered the possibility that the platinum might have been derived from sperrylite, but could find no trace of that mineral by panning.

SULPHIDES

Stibnite.—At several places on the north 900-foot level of the Yellow Pine mine, where the porphyry dike abuts against the ore-bearing limestone, there are sporadic nodules of chert that range from 2 to 6 inches in diameter and contain large bladed crystals of stibnite (Sb_2S_3) that radiate from the centers. In some of these nodules the sulphide of antimony has weathered to the oxide, probably stibiconite.

Galena.—Galena (PbS) is one of the three or four most abundant ore minerals in the district, for it is the sulphide that most effectively resists oxidation. Commonly it is embedded in solid dolomite and shows only a faint suggestion of definite crystal outline. Even where, as in the Sultan mine, it occurs in a breccia containing considerable pore space, it rarely develops as well-terminated crystals. In most places, however, the cubic cleavage is well developed, and broken fragments are bounded by smooth cleavage surfaces. Only here and there, as at the New Year mine, do fragments show a feathery appearance, and material with the finely crystalline texture of steel is practically unknown.

[69] Knopf, Adolph, op. cit., p. 9.

A little silver accompanies the galena, but, in contrast with the product of many western mining districts, the ratio of silver to lead is low. Although only a few assays of pure galena are available, the assays of many shipments that contained from 65 to 75 per cent of lead (80 to 90 per cent of galena if all were present as the sulphide) indicate that the range is 1 ounce of silver to every 2 to 10 per cent of lead. (See p. 90.) The nearly constant presence of green or bluish stains or thin films in the oxidized lead minerals that surround nuclei of galena indicates that it contains a little copper also.

Chalcocite.—According to J. C. Jenson, the deeper workings of the Ninety-nine mine yielded several tons of ore in which chalcocite (Cu_2S) was abundant, but elsewhere in the district only a little of this mineral has been found. The material from the Ninety-nine mine formed large irregular masses of characteristic gray color and fine texture and was free from appreciable quantities of other minerals. Compared with that from many other western districts the silver content was very low, scarcely 1 ounce to the 100 pounds of copper.

Sphalerite.—Although there is no doubt that the oxidized zinc minerals of the district are derived from sphalerite (ZnS), the workings of only a few mines have penetrated deep enough to expose it. At the Potosi, where sphalerite is abundant in the inner, deeper workings, it forms irregular masses embedded in dolomite. None has been seen covering the walls of drusy cavities. These masses are made up of interlocking grains, each of which shows the characteristic brilliant cleavage faces. The color is uniformly dark brown, and it is estimated that the iron content is 2 or 3 per cent. Material found on the third level of the Milford mine has the same properties. On the other hand, a specimen reported to have come from the Root mine shows terminated crystals of light rosin-colored sphalerite embedded in fine sandstone. Without doubt, most of the material that originally made up the deposits of the district resembles that at the Potosi and Milford mines.

Cinnabar.—The border zones of oxidized lead minerals that surround nuclei of galena from several mines sporadically show brilliant red coatings which are locally called "red lead." Such material from the first level of the Kirby mine, the bottom of the Fredrickson shaft, and the 200 and 900 foot levels north of the Yellow Pine mine proved by chemical tests to be cinnabar (HgS). Doubtless the galena from these mines contains a little mercury, which is set free by oxidation and, after migrating a short distance, is redeposited as the sulphide. The exact cause of the precipitation is obscure, for the cinnabar is uniformly deposited on the carbonate or sulphate of lead or oxide of antimony, as much as an inch from the nearest sulphide. Otherwise, the properties and local distribution of the cinnabar resemble that at the Columbia [1] and Ibex [2] mines, near Bourne, Oreg., where the source was schwatzite, the mercurial variety of tetrahedrite.

Cinnabar was rather common in the upper workings of the Red Cloud mine, where it formed grains and irregular masses with characteristic properties. The grains were commonly embedded in brown chert, such as appears to have been formed by supergene processes, and the conclusion is here reached that the cinnabar was formed in a similar way.

Bornite.—Thin films of bornite (Cu_3FeS_3) were noted surrounding nuclei of chalcopyrite in ore from several copper mines.

Chalcopyrite.—Polished specimens from several of the copper mines show nuclei of chalcopyrite ($CuFeS_2$) disposed in the manner that has been described as "exploding bomb structure." It seems clear that the most abundant primary or hypogene mineral in the copper deposits was chalcopyrite.

Pyrite.—Pyrite (FeS_2) is surprisingly uncommon in the district, and good crystals are unknown. It is abundantly disseminated as minute grains in the granite porphyry dike at the Red Cloud mine and in the Yellow Pine sill and dike. It is less abundant at the Lavina and Keystone dikes. The shaft on the north side of the Keystone dump encountered a vein made up largely of finely crystalline pyrite with plates of barite. A 65-foot shaft on the Bedelia claim in the Bullion dolomite, east of the Yellow Pine sill, struck a small vein made up of pyrite and quartz.

If one were to judge from the amount of limonite or jarosite present, the unweathered veins at the Kirby, Ironside, and Tam o' Shanter, as well as all the copper mines, must have contained considerable pyrite or marcasite.

Proustite.—Fractures in the quartzose ore from the Lavina mine show sparse grains of proustite ($3Ag_2S.As_2S_3$). The relations suggest a supergene origin.

Tennantite.—The arsenical copper sulphide tennantite ($4Cu_2S.As_2S_3$) forms small irregular masses in quartz from the Lavina mine.

CHLORIDES

Halite (*common salt*).—The mineral halite (NaCl) was not observed within the quadrangle, although efflorescences from several mines have been shown by analysis to contain common salt. A portion of the Mesquite Dry Lake, within a mile beyond the southwest corner of the quadrangle, shows an incrustation of salt and gypsum. Some years ago the salt was recovered and shipped.

Cerargyrite.—Numerous perfect cubic crystals of cerargyrite (AgCl) were found on silicified dolomite near its contact with a dike of granite porphyry at a prospect south of Crystal Pass. The silver present in the oxidized lead minerals may be present either as the chloride or as silver-bearing jarosite, argentojarosite.

Iodyrite.—Minute yellow crystals of a sectile mineral that yielded metallic silver on charcoal were found at the prospect south of Crystal Pass, at which cerargyrite was observed. Its properties indicate that it is iodyrite (AgI).

OXIDES

The quantity of silica that is present in the mineral deposits of the district is small, whether it is compared with the other minerals in the deposits or with that found in most other mining districts. Nevertheless, some of the forms and associations are uncommon.

Quartz.—Small quantities of quartz (SiO_2) are rather common throughout the district. Clear, perfect crystals from 1 to 3 millimeters long cover many of the cavities in some oxidized ore bodies. In such associations the quartz is the latest mineral deposited and is considered to be of supergene origin. In some of the copper and gold deposits, notably the Boss, Doubleup, and Oro Amigo, however, there are lenticular bodies of gray cavernous quartz with some of which there are associated masses of white powder. The white powder consists largely of minute, perfect, doubly terminated quartz crystals. In thin sections the cavernous gray masses are seen to be made up of interlocking grains of quartz, through which there are scattered clusters of minute inclusions. The grains commonly range from 0.05 to 0.20 millimeter, and the inclusions are much smaller, 0.001 to 0.005 millimeter. A few are probably crystalline, but many are not. According to Knopf,[3] chemical tests proved that the inclusions contained much titanium, and further study by H. E. Merwin showed the presence of octahedrite and rutile. Doubtless this variety of quartz is hypogene.

Here and there the dolomite wall rock of some deposits, notably the Doubleup, is exceptionally hard. The study of polished surfaces showed that clear quartz fills the spaces between the terminated crystals of dolomite, elsewhere generally filled with clear calcite. The 7.32 per cent of insoluble matter in analysis 8b (p. 61) is largely clear quartz having these associations. Silicification of dolomite near the ore deposits is very uncommon, but it was noted in the Pilgrim mine. The quartz in both of these associations is probably hypogene.

Chert.—In this report the word "chert" is used as defined by Van Hise,[4] to include "all forms of finely crystalline nonfragmental silica, including opaline, semicrystalline, and completely crystalline varieties." As the term has been applied widely to that variety of

[1] Lindgren, Waldemar, The gold belt of the Blue Mountains of Oregon: U. S. Geol. Survey Twenty-second Ann. Rept., pt. 2, p. 664, 1901.

[2] Pardee, J. T., and Hewett, D. F., Geology and mineral resources of the Sumpter quadrangle: Mineral Resources of Oregon, vol. 1, No. 6, p. 96, Oregon Bur. Mines and Geology, 1914.

[3] Knopf, Adolph, op. cit., p. 7.

[4] Van Hise, C. R., A treatise on metamorphism: U. S. Geol. Survey Mon. 47, p. 816, 1904.

silica encountered in carbonate sediments and rarely to forms of silica in ore deposits, the propriety of using it here may be questioned. If the properties of the material here termed "chert" are reviewed, it will be seen that the other names widely applied to the silica minerals—quartz, chalcedony, opal, tridymite, and cristobalite—are not appropriate. The definition of chert given above is not as precise as those of the other names applied to the forms of silica, and for this reason if for no other, it should have a place in the literature.[5]

Like quartz, a little chert is rather widespread in the district, but several mines contain large quantities—notably the Kirby, Tam o' Shanter, and Oro Amigo. Two varieties may be distinguished, one which is light, commonly cream-colored (pl. 24, *A*, *B*), and another which ranges in color from light to dark brown and yellowish brown, the color being due to intimately mixed iron hydrate.

Cream-colored chert forms veinlike masses 6 to 24 inches wide in the Kirby, John, Tam o' Shanter, and Oro Amigo mines. In masses as well as thin chips it is opaque or only feebly translucent. It breaks with a conchoidal fracture. By the immersion method the range of index of refraction is 1.54 ± 0.005. Each of several specimens tested in a closed tube yielded a little water; a sample from the Kirby mine contained 0.78 per cent of water. Viewed in thin sections with polarized light, this chert appears to be isotropic and shows numerous minute inclusions and sporadic angular grains of clear quartz (pl. 25); but when examined with the oil immersion lens and high illumination the apparently isotropic chert is seen to be wholly granular, though the grains are extremely minute, probably most of them less than 0.002 millimeter in diameter. The quartz grains show no trace of attack by solution and probably have been preserved from the material that the chert replaced, either shale or dolomite.

Such cherts from several mines also contain crystals of jarosite. In some places myriads of perfect flat rhombic crystals of nearly uniform size (0.01 to 0.03 millimeter) are closely packed in a finely crystalline groundmass of chert. (See pl. 25, *A*, *B*.) Elsewhere, as at the prospect in the center of sec. 25, T. 24 S., R. 57 E., gradations may be found in thin sections from clear, colorless, nearly isotropic chert to that which is dark yellow. Such dark areas are not homogeneous but have a minutely granular appearance, although no crystals of jarosite larger than 0.005 millimeter can be recognized. (See pl. 26, *A*, *B*.) Here and there in the midst of the yellow chert there are clear, colorless areas of crystalline quartz in the center of which there are crystals or aggregates of crystals of jarosite 0.001 to 0.05 millimeter in diameter. (See pl. 27, *A*.) It appears that the yellow chert is an intimate mixture of minutely granular chalcedony and uncrystallized jarosite and that the clear quartz and jarosite crystals represent the segregated and recrystallized minute grains of these minerals.[6]

Although the cream-colored chert and mixtures with jarosite are found at or near the surface, they are more abundant at depths of 100 to 200 feet, as at the Kirby mine. In many places there is evidence that the chert is soluble and replaceable near the surface by cherty iron hydrate, which makes up the second variety.

Ferruginous cherts are abundant at the Tam o' Shanter, Ironside, Kirby, John, Oro Amigo, Prairie Flower, and Yellow Pine mines. Most of the material is brown and homogeneous; some is mottled light yellowish brown and dark brown. It yields a yellowish-brown streak and generally is harder than steel. All of it yields considerable water in a closed tube. Thin sections of such material are light brown but granular and translucent. They show no free silica, either quartz, chert, or chalcedony, and although largely isotropic show faint traces of birefringence. The exact iron content has not been determined in any specimen, but simple tests indicate that it ranges from 10 to 30 per cent. Commonly the ferruginous cherts are closely associated with earthy limonite, and both are most abundant in a zone that lies above the cream-colored chert.

That both varieties of chert disappear at depths of 100 to 250 feet below the surface is considered adequate proof that they have been formed by circulation of surface water.

Chalcedony.—The common mammillary forms of clear and translucent chalcedony are found sporadically in the district and appear to be one of the minerals formed by recent supergene processes.

Opal.—In some of the copper deposits, notably the Boss, thin films of clear opal ($SiO_2.nH_2O$) were noted.

Stibiconite.—At a prospect near the center of the southern border of sec. 21, T. 24 S., R. 58 E., 1,500 feet south of the Ruth mine, a quartz vein contains a pale-yellow amorphous material that has been determined by W. T. Schaller to be a hydrous antimony oxide, probably stibiconite ($2SbO_2.H_2O$). Doubtless the unweathered antimony mineral was stibnite. The quantity of such material is small.

The stibnite crystals from chert nodules on the 900-foot level north in the Yellow Pine mine are partly altered to a white powder that is probably stibiconite.

Cuprite.—Cuprite (Cu_2O) was observed at only a few mines but was probably common in the oxidized ore from most of the copper mines. At the Rose

[5] Fenner, C. N., The stability relations of the silica minerals: Am. Jour. Sci., 4th ser., vol. 36, pp. 331-384, 1913. Washburne, E. W., and Navias, L., The relation of chalcedony to the other forms of silica: Nat. Acad. Sci. Proc., vol. 8, pp. 1-5, 1922. Wherry, E. T., and Glenn, M. T., Chalcedony mistaken for an iron sulphate mineral: Am. Mineralogist, vol. 2, pp. 6-7, 1917. Adams, S. F., A microscopic study of vein quartz: Econ. Geology, vol. 15, pp. 623-664, 1920. Lindgren, Waldemar, On the deposition of the various forms of silica: Am. Inst. Min. Eng. Bull. 126, p. xvi, 1917. Van Tuyl, F. M., The origin of chert: Am. Jour. Sci., 4th ser., vol. 45, pp. 449-456, 1918.

[6] Wherry, E. T., and Glenn, M. L., op. cit., pp. 6-11.

mine grains of cuprite form nuclei in veinlets of copper pitch that cut the dolomite wall rock.

Tenorite.—Earthy black grains intimately mixed with limonite from the Yellow Pine mine were shown by test to be wholly copper oxide and undoubtedly are tenorite (CuO). In many of the copper deposits, notably the Columbia, plumose masses of malachite contain abundant black grains that are probably tenorite.

Hematite and magnetite.—About half a mile southeast of Crystal Pass there are two prospects that explore lenses of siderite in which are embedded grains and masses of hematite (Fe_2O_3) and magnetite (Fe_3O_4). One of these lenses lies between two sills of orthoclase porphyry. Neither of these minerals was observed elsewhere in the district.

Limonite.—Limonite ($2Fe_2O_3.3H_2O$) is common throughout the district but is most abundant in the deposits exploited for copper. Soft yellowish-brown ocher is abundant at the Ironside and Tam o' Shanter mines, and every transition may be found to dense hard brown cherts that contain from 10 to 20 per cent of iron. Some of the earthy limonite has clearly been formed by the decomposition of jarosite or related sulphates, and much of the earthy variety may be formed in this way. Close search at the Ironside mine failed to reveal any jarosite, however. At the Valentine mine there were stalactites of limonite as much as 0.75 inch in diameter embedded in hydrozincite.

Turgite.—The jarositic cherts that are so abundant in and characteristic of the Kirby mine are weathered to yellow-brown in the upper part of it and near the surface to a dark-brown chert that yields a red streak. Tests show that the water content of the dark-brown chert is much lower than that of the yellow-brown chert, and the conclusion is reached that the pigment of the first is turgite ($2Fe_2O_3.H_2O$).

In the same part of the mine the ore body contains lenses as much as several inches thick of very fine dark-brown powder, which, when disturbed, runs freely in the stopes. Under the microscope the grains are seen to be nearly spherical and surprisingly uniform in size, 0.005 to 0.04 millimeter in diameter. They are a hydrous oxide of iron, and, as their streak is red, the conclusion is reached that they are turgite. As the lenses have the same associations as yellow plumbojarosite in the lower levels and the range in size of the grains is nearly the same, it seems clear that the turgite has been derived from plumbojarosite.

Wad.—Manganese oxides are rather uncommon in the district, and as none of the crystalline varieties have been noted, all are considered to be wad ($Mn_2O_3.nH_2O$). The largest quantity was found in a prospect east of the Ninety-nine mine, where nodules of earthy oxide are enveloped in crusts of cuprodescloizite.

Heterogenite.—The uncommon mineral heterogenite ($CoO.2Co_2O_3.6H_2O$), the hydrous oxide of cobalt, was first recognized in the district in 1921, and after a systematic search it was found rather widely. During this investigation care was taken to note the presence of black minerals, and many specimens were tested with the blowpipe, with the result that heterogenite is now known to exist in most of the copper deposits. The purest material consists of the black mammillary crusts or stalactites found on the Blue Jay, Copper Chief, and Columbia claims, but these are not abundant. A much more common material is brownish dolomite that shows black spots or dendritic growths of hydrous cobalt oxide. Here the oxide replaces the dolomite, and locally the replacement of masses 2 or 3 inches in diameter is nearly complete. Such material was noted in the Columbia, Boss, Blue Jay, Highline, Copperside, Redstreak, Mountain King, Copper Glance, and Contact mines. (See pl. 27, *B*.)

The ultimate source of the cobalt in the heterogenite is probably some sulphide or arsenide, although most of it appears to have passed through the stage of cobalt carbonate (p. 85).

CARBONATES

Calcite.—Calcite ($CaCO_3$) is not an abundant mineral in the ore deposits, in spite of the fact that the rocks in which they are found were once largely calcium carbonate. It is common in some of the zinc-lead deposits, especially those in which lead greatly exceeds zinc. In these, pure-white calcite forms coarsely crystalline aggregates that fill drusy cavities and hence is the latest mineral deposited by the metallizing solutions. (See pl. 28, *B*.) Specimens collected below the limit of weathering at the Potosi mine show white calcite filling the cavities, which are lined with terminated crystals of dolomite and sphalerite. In a few mines, notably the Monte Cristo, the walls of open cavities near the surface are covered with thick crusts of pale-yellowish clear calcite, but it is believed that this has been deposited recently by surface waters.

As noted elsewhere (p. 63), clear calcite fills minute cavities lined with dolomite crystals throughout the areas of dolomitized limestone. Here and there, notably half a mile northwest of the Blue Jay mine, fault breccias in limestones are filled with white calcite.

Aragonite.—Aragonite ($CaCO_3$) was recognized with confidence at only three mines—the Prairie Flower, Mobile, and Shenandoah—where cavities that doubtless represent recent watercourses are lined with a layer of white calcium carbonate that is locally covered with crystals of aragonite.

Siderite.—Siderite ($FeCO_3$) was recognized with assurance at only one place in the district, a prospect in the NE. ¼ SW. ¼ sec. 1, T. 25 S., R. 58 E., where, together with hematite, magnetite, and silica, it replaces dolomite of the Goodsprings formation.

In several places in the region, notably near the dike of porphyry in the SE. ¼ sec. 2, T. 25 S., R. 58 E., the normal cream-colored dolomite is altered to light brown. (See p. 56.) This change in color corresponds with an increase in the iron content, which is doubtless present as a carbonate. The same conditions were noted near the basalt dike in the SW. ¼ sec. 30, T. 24 S., R. 58 E. (See p. 56.)

Dolomites.—Although dolomitized limestone is the country rock of most of the ore deposits of the region (see pp. 57–67), dolomite ($(Ca,Mg)CO_3$) is uncommon among the minerals deposited later than the ores. In the Potosi and many other mines crystals of gray or white dolomite covered the walls of cavities in the ore bodies before white calcite was deposited. At the Blue Jay deposit, which lies in the Bullion dolomite, the stalactitic masses of heterogenite are enveloped in white, finely crystalline dolomite, thus showing that it was locally deposited since the mineral deposits were oxidized. At one place in the north end of this mine, arborescent masses of small crystals of dolomite fill a watercourse and may have been deposited since weathering began.

Cobalt-bearing dolomite.—In several places in the district, notably the Blue Jay and Contact claims, coarsely crystalline pale-pink dolomite is found. The color is due to the presence of small quantities of cobalt carbonate. In rough masses the color seems to be uniform, but on polished surfaces it is distinctly sporadic. The color is due to the presence of thin films of pink cobalt carbonate on the cleavage surfaces of the dolomite. Although cobalt carbonate causes the color, the percentage is low, as an analysis of the deeply pink material from the Contact claim by J. G. Fairchild in the laboratory of the Geological Survey showed only 0.43 per cent of cobalt oxide. The same material also contained 0.21 per cent of nickel oxide. Doubtless both oxides are combined with carbonic oxide. Similar cobalt-bearing calcite has been noted by the writer in material from the Tantara mine, Katanga, Belgian Congo.

Cerusite.—Despite the fact that cerusite ($PbCO_3$) is very widespread, well-crystallized specimens are rather uncommon. Good specimens of the typical penetration-twin crystals were found in the Yellow Pine mine as deep as the lowest levels and sporadically elsewhere. Commonly the cerusite is either granular, as in the lenses in the chert at the Kirby mine, or dense and porcelainlike but colored dark gray or brown. In several localities, notably certain prospects on the Rose group of claims, a peculiar variety of hard carbonate ore was found. Polished and thin sections of this ore show rounded grains of cerusite embedded in a matrix of clear chert.

Smithsonite.—Small quantities of smithsonite ($ZnCO_3$) occur widely throughout the district, but in only a few mines, notably the Yellow Pine and Monte Cristo, has it been sufficiently abundant to constitute a valuable ore. Commonly it forms gray botryoidal or stalactitic masses that have grown in open spaces, generally watercourses. A gray earthy but dense variety of anhydrous carbonate of zinc, outwardly altered to white hydrozincite, was found on the south 600-foot level of the Yellow Pine mine. A somewhat similar gray carbonate from the upper part of the 700-foot stope of the Yellow Pine mine contains considerable water and is therefore hydrozincite. The rhombic crystals found in many zinc deposits are conspicuously absent here.

Malachite.—Malachite ($CuCO_3.Cu(OH)_2$) is the most abundant copper mineral in the district. At the Ninety-nine and Columbia mines it formed crusts and nodular masses made up of the typical radiating crystals. A large part of the copper in the Boss ore was present as loosely coherent masses of small crystals. A number of small mines have shipped heavily stained dolomite in which thin films of malachite lie either along cleavage planes or in veinlets. In several places, notably the Blue Jay mine, very perfect crystals of malachite pseudomorphous after azurite were found.

Azurite.—Azurite ($2CuCO_3.Cu(OH)_2$) is rather uncommon in the district but may have been more abundant in some of the ores shipped. It forms dense earthy masses in the midst of other copper or iron minerals.

Aurichalcite.—Plumose aggregates of delicate pale-blue or sky-blue crystals of aurichalcite ($2(Zn,Cu).CO_3.3(Zn, Cu)(OH)_2$) are present here and there throughout the district. In a few places, such as the upper large stopes of the Yellow Pine mine, it was the principal mineral in beautiful pale-blue masses that weighed from 1 to 5 pounds. Not uncommonly it is the only copper-bearing mineral recognizable in some of the zinc deposits.

Hydrozincite.—The most abundant zinc mineral in the ore bodies so far explored in the district is hydrozincite ($ZnCO_3.2Zn(OH)_2$). Masses of the mineral are uniformly earthy in texture, and the color ranges from pure white to dark brown. (See pl. 29.) Some specimens from the Pilgrim and a few other mines are pale lilac; this color is destroyed by heating, but its cause is unknown. Thin sections show a minutely granular texture or a felted mass of minute needles that range from 0.01 to 0.05 millimeter in length.

In part the color of hydrozincite depends upon the method of formation. The brown color is due to minute inclusions of limonite and is characteristic of those masses that have formed close to the grains or masses of the original sulphide, sphalerite, where the iron and zinc have not had an opportunity to segregate. Such masses appear to have formed where zinc and, in part, iron have replaced dolomite near the sulphide. The stopes between the 700 and 900 foot levels in the northern part of the Yellow Pine mine have yielded amazingly large masses of brown hydrozincite in which almost the only foreign minerals were galena and minor amounts of its oxidation products. (See pl. 29, *A*.) Masses 5 to 15 feet thick are not uncommon, and in one stope a lens was nearly 32 feet thick. The white variety is nearly free from iron and has been formed either by hydration of smithsonite or by replacement of dolomite remote from the original sulphide. (See pl. 28, *D*.) Here and there the structure of the hydrozincite retains traces of the rhombic cleavage inherited from the dolomite that it replaced. (See pl. 29, *B*.)

Material analyzed by Foote and Bradley[7] had a composition indicated by the formula $2ZnCO_3.3Zn(OH)_2$. The source was reported as Lincoln County, Nev., but it may have been the Goodsprings district.

SILICATES

Calamine.—Although calamine ($ZnOH_3.SiO_3$) occurs rather widely, it has probably formed a notable part of ore shipments only here and there. Some recent shipments from the Yellow Pine mine have contained many lumps made up of loosely coherent crystals of calamine stained by limonite. The thick crusts of twinned calamine crystals found in many zinc-producing districts are conspicuously absent here. Commonly it occurs as clear, colorless crystals, rarely more than 10 millimeters long, that form radiating aggregates in drusy cavities. At the Monte Cristo mine calamine replaces the cherty layers in the Anchor limestone. In most places, however, the crystals have grown in open spaces.

Dioptase.—In a few places, notably the Mountain Top and Blue Jay mines, small perfect crystals of dioptase (H_2CuSiO_4) are scattered over crusts of chrysocolla in druses.

Chrysocolla.—In a few mines and prospects, such as the Lincoln and Platina, chrysocolla ($CuSiO_2.2H_2O$) is the most abundant mineral; it is widespread elsewhere but rarely abundant. Locally it replaces dolomite; generally it forms botryoidal masses in cavities. Here and there, as at the Boss mine, it is covered by a thin layer of opal. No attempt has been made to discriminate the similar mineral bisbeeite.

PHOSPHATES AND ARSENATES

Pyromorphite.—Doubtless pyromorphite ($(PbCl)Pb_4(PO_4)_3$) was once common in the lead deposits, but it was observed in seven mines only. At the Pilgrim, Rose, and Hermosa it forms waxen-yellow masses intimately mixed with siliceous limonite. At the other localities, such as the Singer mine, small yellow and orange-colored hexagonal prisms, scattered over the surface of breccias, were identified as pyromorphite. Under these circumstances it is one of the latest minerals to be formed. Only by chemical tests can it be distinguished with confidence from vanadinite.

Mimetite.—Material from the north 900-foot level of the Yellow Pine mine, which has the yellow color and the relations of pyromorphite elsewhere, proved to be mimetite ($(Pb,Cl)Pb_4(AsO_4)_3$). At the Prairie Flower mine it was once abundant, as fragments of a greenish-yellow variety are common on the dumps.

Olivenite.—Pale yellowish-green crystals from the lowest level of the Azurite mine and from a prospect near the Lavina mine proved to be olivenite ($Cu_3(AsO_4)_2.Cu(OH)_2$).

Annabergite.—Several masses of a bright-green vitreous mineral, each weighing a pound or more, were found in the ore bins of the Yellow Pine mine and proved to be the uncommon mineral annabergite ($Ni_3(AsO_4)_2.8H_2O$). The underground source is not known, but it must have been abundant locally.

Libethenite.—The dumps of the Boss mine contain many specimens of an olive-green incrustation on porous siliceous material. Tests showed that this incrustation is libethenite ($Cu_3(PO_4)_2.Cu(OH)_2$).

VANADATES

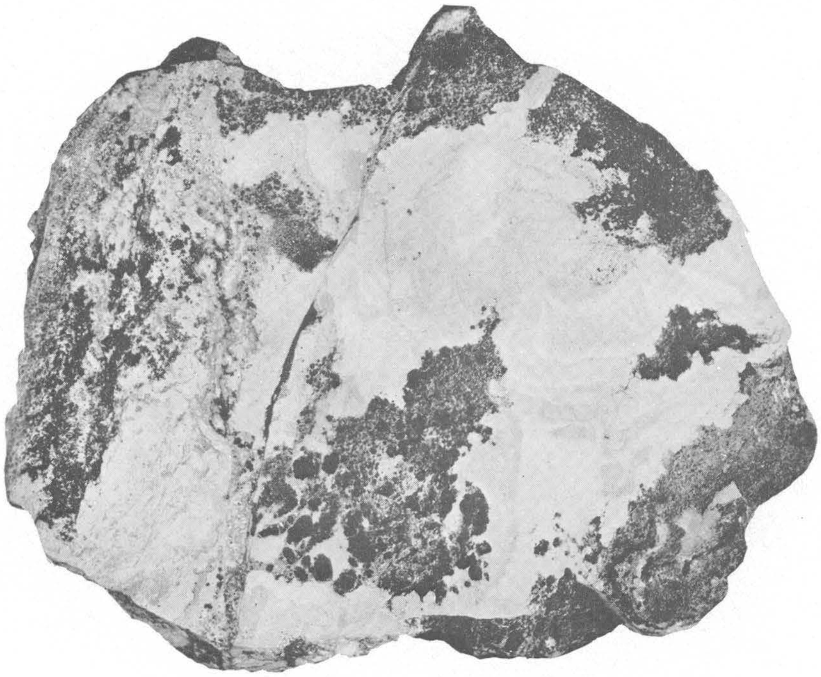
Vanadates of either lead, zinc, or copper are uncommonly widespread in the district, but only a few specific determinations of the minerals were made. During the progress of field work many specimens suspected of containing vanadates were tested with hydrochloric acid, and the presence of a vanadate was proved. According to this test, if the vanadates of lead, zinc, and copper are wet with hydrochloric acid, they turn first yellowish, then reddish brown. Specific determinations can be made only on well-crystallized material or by comprehensive chemical analyses. Concentration tests on the crude ores from the Hoodoo, Fredrickson, and Spelter mines, show the presence of vanadates, which are otherwise difficult to recognize.

Vanadinite.—Vanadinite ($(PbCl)Pb_4(VO_4)_3$) may be rather widespread but was distinguished only at one locality, in several prospects east of the Silver Gem tunnels in Devil Canyon. It forms brownish, waxy crusts and hexagonal prisms on open cracks not far from galena, the obvious source of the lead.

Cuprodescloizite.—Cuprodescloizite ($(Pb,Zn,Cu)(VO_4)_2(Pb,Zn,Cu)(OH)_2$) is probably very common in the district. A number of prospects on the Whale group yield large specimens that show crusts of the mineral covered with perfect nearly black crystals. Prospects on the Bill Nye and Ninety-nine groups yield good specimens of mammillary green cuprodescloizite. Tests indicate that the brown vanadate of the Spelter and Hoodoo claims contains appreciable copper and is probably this mineral.

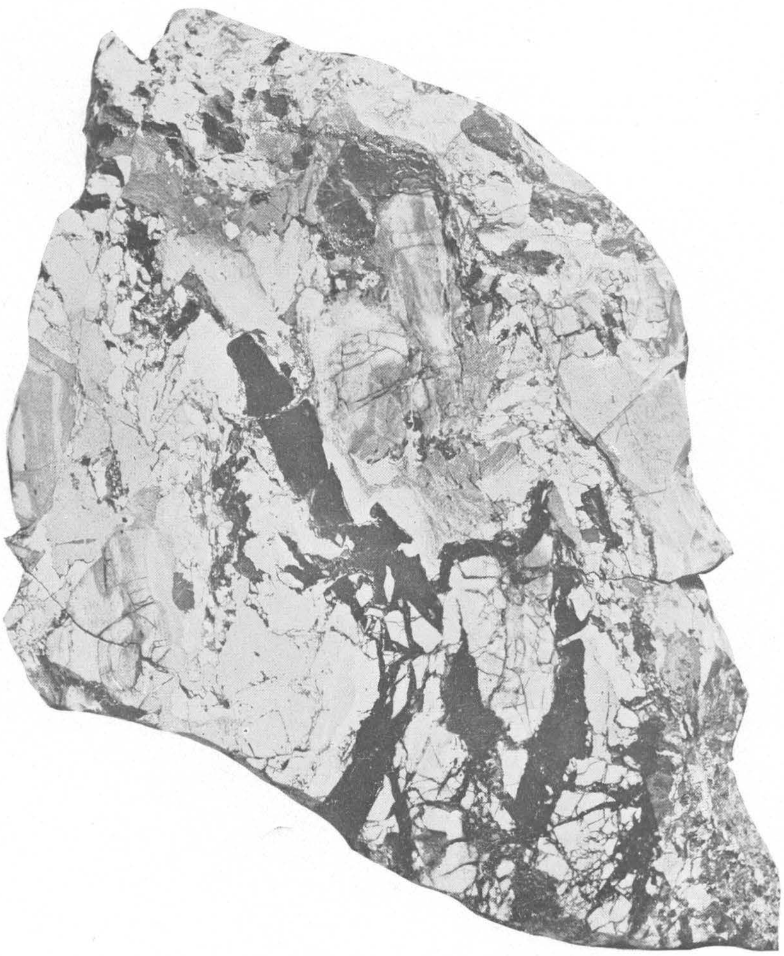
Descloizite.—Several prospects on the Argentena group show widespread thin films of a yellowish and

[7] Foote, H. W., and Bradley, W. H., On hydrozincite: Am. Jour. Sci., 4th ser., vol. 42, pp. 59-62, 1916.



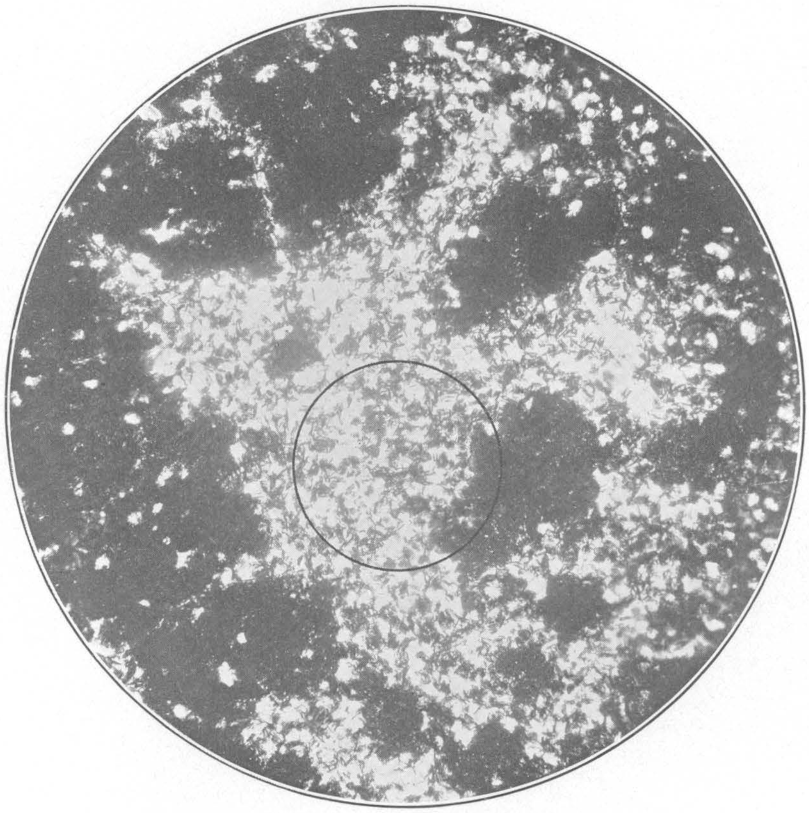
A. JAROSITIC CHERT, 100-FOOT LEVEL, KIRBY MINE

The dark round masses are nearly pure jarosite; the differences in color are due to the different content of jarosite in the chert. Natural size.



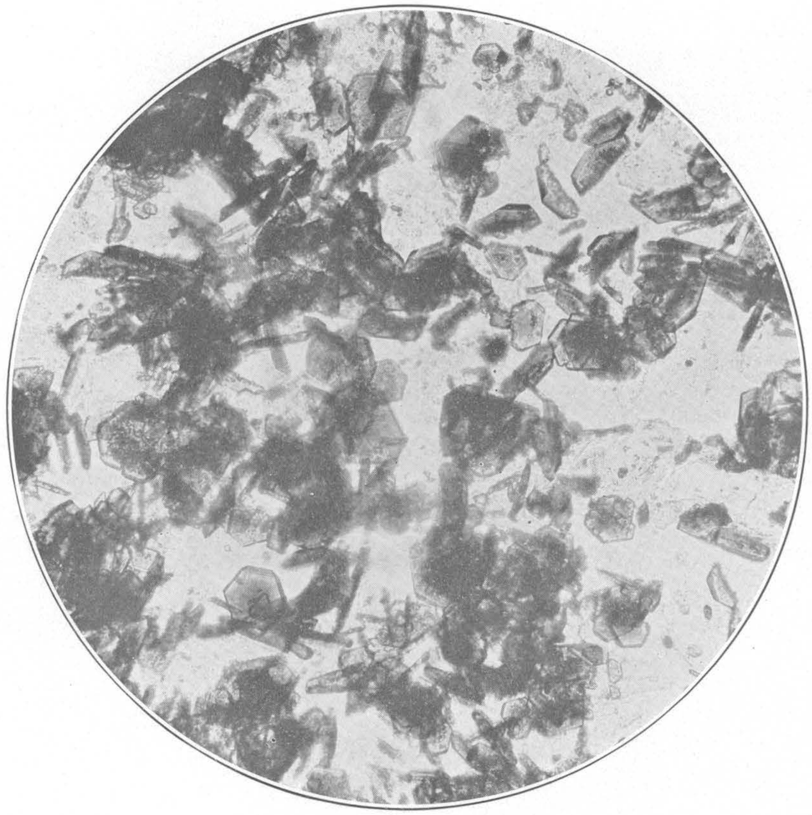
B. JAROSITIC CHERT, 100-FOOT LEVEL, KIRBY MINE

The differences in color are due to the different content of jarosite, the pure white containing very little and the black being more than half jarosite. Angular fragments of white chert suspended in black jarositic chert. Natural size.



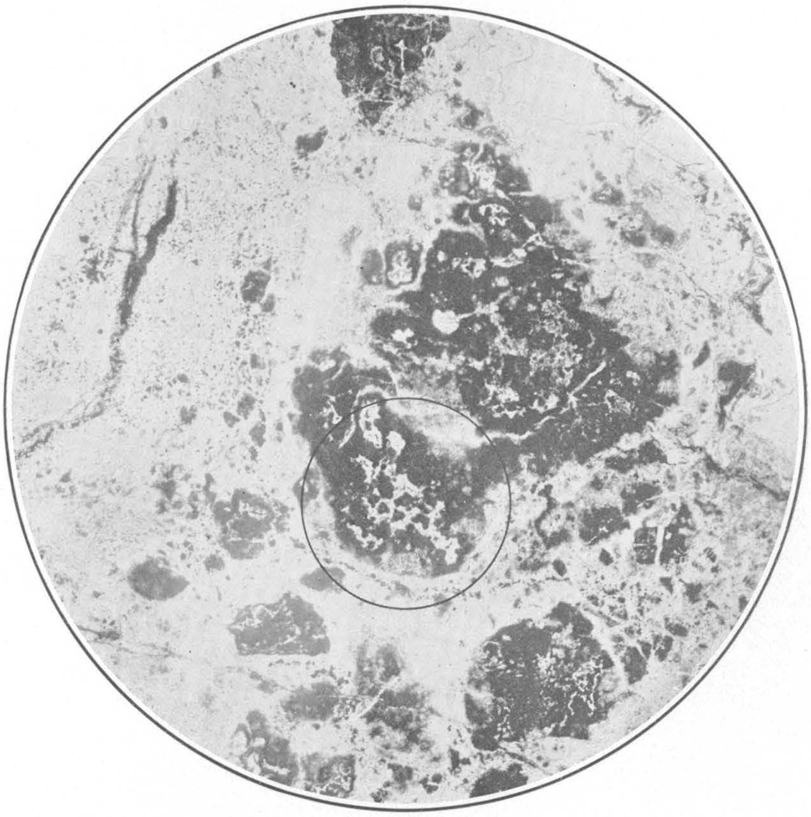
A. THIN SECTION OF JAROSITIC CHERT, 100-FOOT LEVEL, KIRBY MINE

The area inclosed in the circle is that shown in *B*. The dark areas are closely packed crystals o jarosite, and the light angular grains are clear quartz. Enlarged 28 diameters.



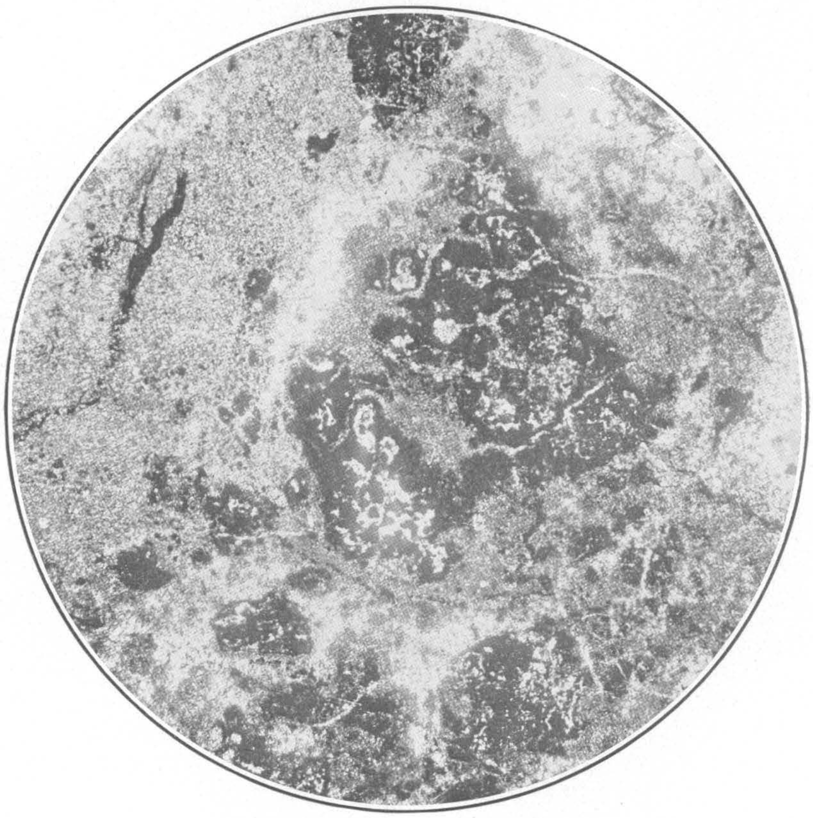
B. PORTION OF THIN SECTION SHOWN IN *A* ENLARGED

The hexagonal plates are plumbic jarosite embedded in fine-grained chert. Enlarged 210 diameters.



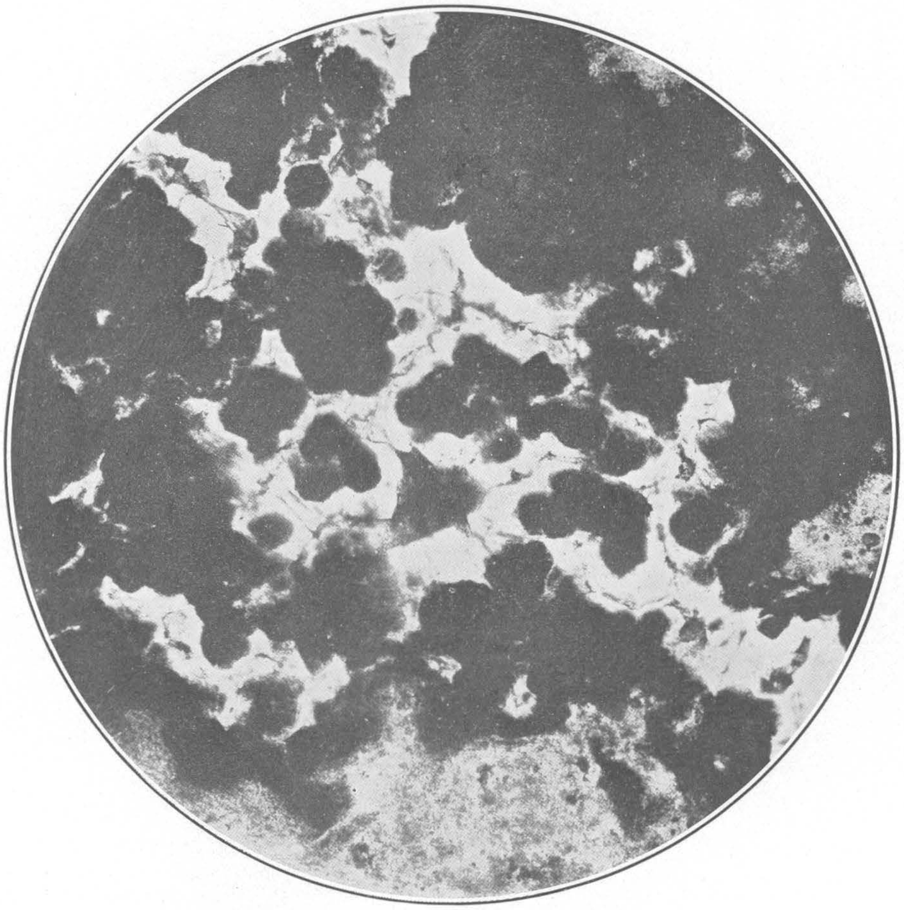
A. THIN SECTION OF JAROSITIC CHERT, SWEEPSTAKE CLAIM

The dark masses are very fine grained jarosite embedded in chert; the clear areas are granular quartz. Compare with Plate 25, *A*. Most of the area inclosed in the circle is shown in Plate 27, *A*. Ordinary light, enlarged 28 diameters.



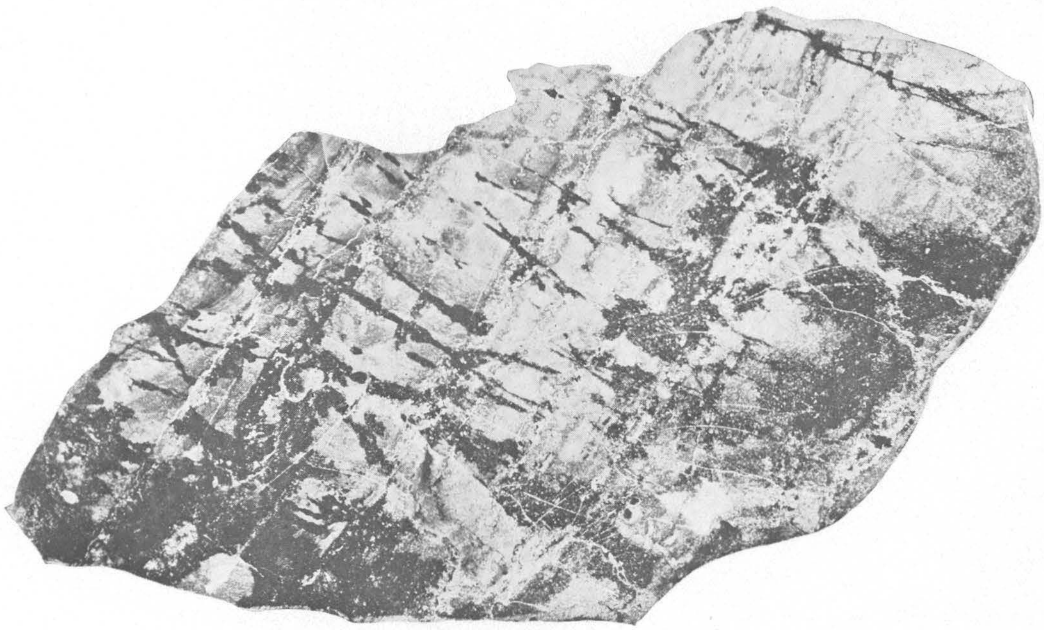
B. THIN SECTION OF JAROSITIC CHERT, SWEEPSTAKE CLAIM

Same section as that shown in *A* but with crossed nicols. Enlarged 28 diameters.



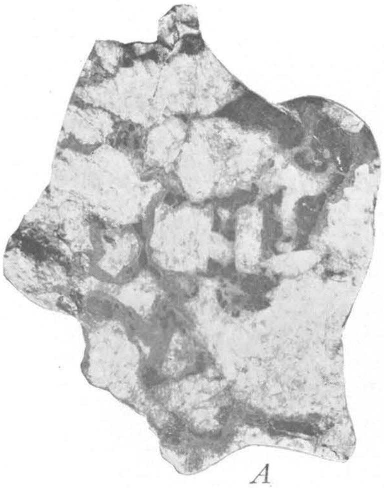
A. THIN SECTION OF JAROSITIC CHERT, SWEEPSTAKE CLAIM

The white areas are quartz; the black areas are minutely granular jarosite; and the shaded areas are chert containing disseminated jarosite. Portion of thin section shown in Plate 26, *A*. Enlarged 210 diameters.

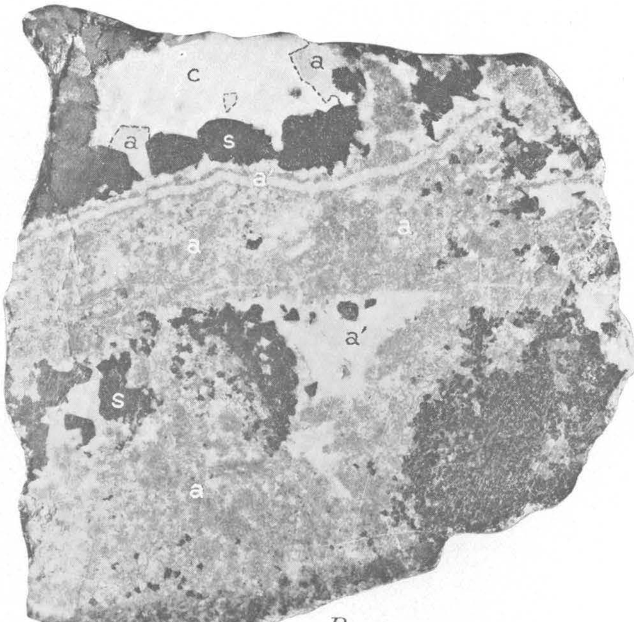


B. HETEROGENITE REPLACING DOLOMITE, COLUMBIA MINE

Polished surface of specimen from the footwall of the Columbia mine in the west shaft. The groundmass is dolomitized limestone of the Sultan formation partly replaced by heterogenite, hydrous cobalt oxide (black). Such material contains 3 to 5 per cent of cobalt. Three-fourths natural size.



A



B

C

D

A. LOW-GRADE COPPER ORE, AZURITE MINE

Angular dolomite breccia cemented by chalcopyrite, only a trace of which remains, the rest having been altered to limonite. The fragments are impregnated with malachite. One-half natural size.

B. UNWEATHERED ZINC ORE, THIRD LEVEL, EAST STOPE, POTOSI MINE

Sphalerite (s) deposited partly in dolomite (a) by replacement and partly in druses around fragments of dolomite. Some secondary dolomite (a′) and calcite (c) also deposited in the druses. Natural size.

C. DOLOMITE (a) PARTLY REPLACED BY HYDROZINCITE, 800-FOOT LEVEL NORTH, SOUTH SIDE OF DIKE, YELLOW PINE MINE

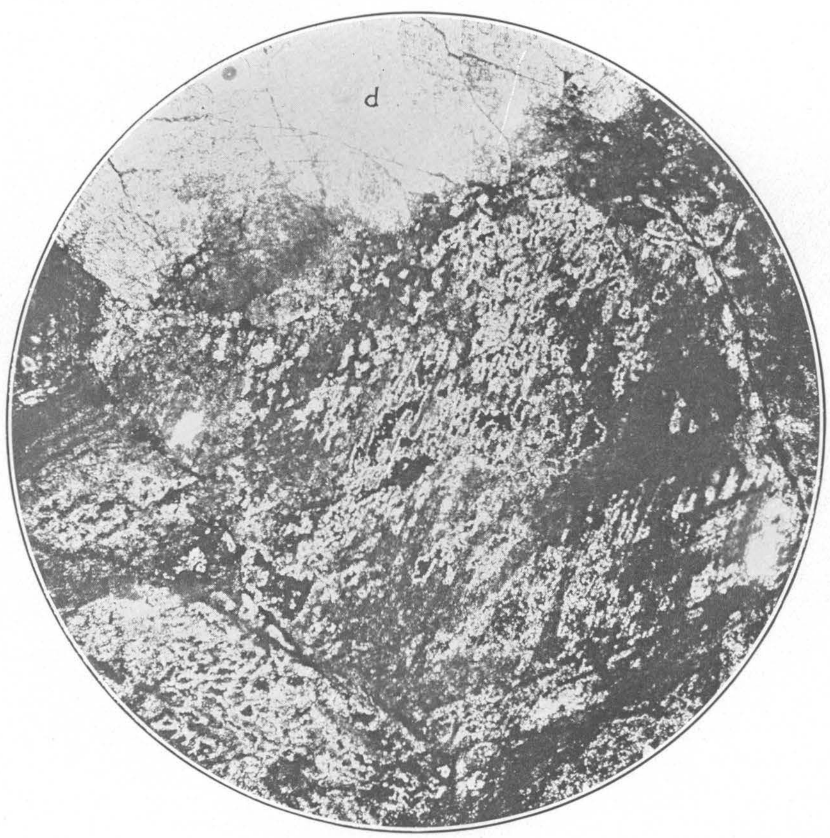
The hydrozincite shows several shades of brown, owing to its variable content of iron oxide. The white mineral is hydrozincite deposited in cavities, free of iron oxide. Natural size.

D. HYDROZINCITE ORE FROM A WATERCOURSE, 900-FOOT LEVEL NORTH, YELLOW PINE MINE

The darker veinlike masses are smithsonite, which was once deposited around angular fragments of dolomite in a fault. Later the dolomite was dissolved or replaced by hydrozincite, and feathery crystals of calamine cover the cavities. One-half natural size.

A. SPECIMEN OF HIGH-GRADE HYDROZINCITE ORE FROM A PILLAR 30 FEET HIGH, 700-FOOT LEVEL NORTH, YELLOW PINE MINE

The rude outline of a fragment of dolomite (d), now replaced by hydrozincite, remains in the lower left corner. Several small masses of unaltered galena (PbS) remain in partly terminated crystals. Natural size.



B. THIN SECTION OF ZINC ORE, ARROWHEAD PROSPECT, NORTH OF THE BLUE JAY MINE

Shows replacement of dolomite (d) by hydrozincite. The rhombic cleavage of the dolomite is retained in the hydrozincite. Enlarged 24 diameters.

orange vanadate that is probably descloizite ((Pb,Zn) $(VO_4)_2(Pb,Zn)(OH)_2$).

Psittacinite.—A yellowish vanadate at the Highline mine proved to be psittacinite ($(Cu,Pb)_3(VO_4)_2(Cu,Pb)(OH)_2$).

SULPHATES

Anglesite.—Inasmuch as anglesite ($PbSO_4$) appears to be the first stage of weathering of galena, it is doubtless as widespread in the district as that mineral. It is not abundant, however, and only rarely crystallized. A resident of the district possesses a very perfect pseudomorph of cerusite after anglesite, 1 inch in diameter, said to have been found in the Prairie Flower mine. Commonly it is massive and vitreous with a greasy luster, and the color is dark gray.

Brochantite.—Brochantite ($CuSO_4.3Cu(OH)_2$) was reported by Knopf [8] from the Boss mine.

Barite.—Barite ($BaSO_4$) has been observed at but three localities in the district. Near the southeast corner of sec. 8, T. 24 S., R. 58 E., a prospect pit 15 feet deep has been sunk on a vein of nearly pure barite, 12 to 18 inches wide, which lies parallel with the bedding of the inclosing limestone. The color is gray, and the structure is plumose. A little calcite is disseminated through it, and it appears to have replaced the limestone. In the south drift of the Argentena mine veins of coarsely crystalline white barite replace the Yellowpine limestone. The mineral is also present in a vein largely made up of pyrite near the Keystone dump.

Linarite.—Uncommonly large and perfect crystals of linarite ($(Pb,Cu)SO_4.(Pb,Cu)(OH)_2$ were found in one place on the north 900-foot level of the Yellow Pine mine. The largest crystal was tabular prismatic and about 4 inches long. The mineral is uncommon, but sporadic patches were noted at the Root mine and elsewhere. The crystals are almost uniformly covered with a layer of caledonite, a similar basic sulphate of copper, which represents a surficial alteration. This change involves a loss of the sulphuric anhydride and a larger loss of the copper present in the linarite.

Small quantities of linarite have been observed in a number of lead-mining districts of the Western States. Commonly a little caledonite is associated with the linarite.[9]

Gypsum.—Perfect crystals of gypsum ($CaSO_4.2H_2O$) an inch or more long are abundant on the surface of Mesquite Dry Lake. The mineral was noted in only a few mines and is very uncommon. Beds of gypsum occur in the red shaly sandstone at the top of the Supai formation and between the two limestone members of the Kaibab limestone.

Jarosite group.—Minerals of the jarosite group are common in the district and show a wide range of associations. Their presence is readily determined by simple chemical tests or examination under the microscope. On the other hand, the confident discrimination between the several species requires either exhaustive microscopic tests or chemical analyses, and only a few of these have been made. The minerals seem to be uncommonly stable, both on the surface and throughout the present limit of mine explorations; near the Lavina mine natrojarosite is common on the surface. Here and there, as in the Kirby, John, and Tam o' Shanter mines, the local relations indicate that jarosite has decomposed near the surface to form turgite and limonite.

Except plumbojarosite, which locally is compact and massive, all the minerals of the jarosite group commonly form aggregates of very perfect crystals whose range in size is from 0.01 to 0.10 millimeter, although some are as large as 1.0 millimeter. Not uncommonly a specimen that weighs a pound or more and appears earthy to the unaided eye is made up entirely of perfect crystals that range from 0.01 to 0.05 millimeter in diameter.

Alunite ($K_2O.3Al_2O_3.4SO_3.6H_2O$) is common in the Kirby mine but was not found elsewhere. Lenses of pure-white earthy material in the chert of that mine proved to be made up entirely of minute perfect rhombohedrons of alunite. In the zone 100 to 200 feet below the surface, the shale near the top of the Goodsprings dolomite is sporadically replaced by chalky alunite.

Natrojarosite ($Na_2O.3Fe_2O_3.4SO_4.6H_2O$) is probably the commonest variety in the district, although isomorphous mixtures with jarosite and other members of the group have been shown to be present. It is the most abundant sulphate in the Boss mine, where it forms yellow earthy lenses and masses of irregular shape. It is abundant in the Copperside mine, both as earthy masses and as minute crystals suspended in a matrix of calcite.

Jarosite ($K_2O.3Fe_2O_3.4SO_3.6H_2O$) is abundant at the Kirby and John mines, where it shows stages of alteration to plumbojarosite. (See pls. 24–26.) In order to throw light on this problem specimens of three varieties were submitted to W. T. Schaller, of the United States Geological Survey, for optical examination and chemical analysis. His report is summarized below. The optical determinations were made by E. S. Larsen. All the specimens were collected from the 100-foot level south in the Kirby mine, and it is clear from the local relations that the yellow material, A, is produced by the alteration of the brown material, C.

Specimen C is brown in color, well crystallized, and, to judge from the optical examination, is probably homogeneous. Its index is slightly higher than that of jarosite (1.82) but not as high as that of plumbojarosite (1.87); it is estimated to be about

[8] Knopf, Adolph, op. cit., p. 10.

[9] Rogers, A. F., Mineralogical notes No. 2: Am. Jour. Sci., 4th ser., vol. 12, pp 42–48, 1901. Anonymous, Notes on Canadian minerals: Toronto Univ. Studies, ser. 12, pp. 69–72, 1921. Shannon, E. V., The minerals of Idaho: U. S. Nat. Mus. Bull. 131, pp. 455–458, 1926; Linarite and leadhillite from Idaho: Am. Mineralogist. vol. 4, pp. 93–94, 1919.

1.83–1.84. This material is probably a fairly uniform isomorphous mixture of jarosite and plumbojarosite, nearer to jarosite. This suggestion is verified by chemical determinations, as shown below. The analyses are only approximate.

Analysis of brown mineral, C

	Analysis with 1 per cent of insoluble material deducted	Calculated composition: 20 per cent of plumbojarosite, 80 per cent of jarosite
Lead oxide	3. 9	3. 9
Potassium oxide	7. 8	7. 5
Sulphur trioxide	30. 1	31. 2

No phosphate is present. It is significant that, in contrast to specimen A, this material seems to be optically homogeneous.

No quantitative determinations were made on specimen B, as the material is too scanty and not well individualized. It seems to be the same as specimen C, as it contains much potash.

Specimen A is a yellowish powder and, as determined by the optical examination, a mixture. There is some jarosite (1.82) some plumbojarosite (much greater than 1.82 and higher than sample C), and probably a good deal of some intermediate isomorphous member of the group. Many of the crystals are zoned, the composition of the central part being near jarosite and that of the border close to plumbojarosite. The material is apparently jarosite changing to plumbojarosite. The sample contains a small quantity of some other lead mineral.

Partial analysis of yellow mineral, A

[Insoluble material deducted]

PbO	12. 5
K_2O	5. 1
SO_3	28. 1
P_2O_5	1. 5

This analysis can be interpreted as showing a mixture, mechanically as well as isomorphously, of 54 per cent of jarosite, 38 per cent of plumbojarosite, and 7 per cent of a theoretical iron-plumbogummite ($2PbO.3Fe_2O_3.2P_2O_5.7H_2O$). A slight excess of lead is left unaccounted for by such an interpretation. The analysis also can be interpreted, by referring the P_2O_5 present to corkite ($2PbO.3Fe_2O_3.2SO_3.P_2O_5.6H_2O$), as showing 47 per cent of jarosite, 39 per cent of plumbojarosite, and 14 per cent of corkite.

Without being able to settle definitely the several questions involved, the following suggestions are tentatively advanced:

Specimen C is a plumbiferous jarosite—that is, essentially a jarosite with about one-fifth of the potash replaced by lead. No P_2O_5 is present.

Specimen B is probably the same as specimen C.

Specimen A is a mixture of jarosite, plumbojarosite, a plumbiferous jarosite like C, and some other lead mineral probably of this group. Where the phosphoric acid belongs is not known. It may replace the SO_3 in the jarosite, or it may be present as corkite or as some other mineral of this group. The isomorphous replacement of potassium by lead seems to yield a mixture of several members of the jarosite group and to introduce some P_2O_5 by replacing SO_3. Possibly longer-continued reaction might result in the complete removal of the potash and might produce a single mineral species instead of a mixture.

Plumbojarosite ($PbO.3Fe_2O_3.4SO_3.6H_2O$) is common in the Yellow Pine mine, where it forms compact earthy brown masses and is locally abundant enough to ship as an ore of lead. It is probably widespread in the district. The greenish bismuth-bearing variety of the Boss mine, which contained platinum and palladium (pp. 114–118), has not been found elsewhere. According to W. T. Schaller, of the United States Geological Survey, a recalculation of the analysis quoted by Knopf indicates that the platinum, palladium, and gold present may be present as isomorphous mixtures in the bismuth-bearing plumbojarosite. The potash-bearing plumbojarosite of the Kirby mine is discussed above.

Beaverite [10] ($CuO.PbO.Fe_2O_3.2SO_3.4H_2O$) was collected in two localities—the Copperside mine and a prospect southeast of the center of sec. 25, T. 24 S., R. 59 E.

The name "vegasite" was given by Knopf [11] to a yellow ocherous mineral from the Rosella prospect, the analysis of which indicated the formula $PbO_3.Fe_2O_3.3SO_3.6H_2O$. A reexamination of the original material by W. T. Schaller, of the United States Geological Survey, shows the presence of 2.53 per cent of P_2O_5, not recorded in the earlier analysis but undoubtedly included with alumina. If, as appears probable, this phosphoric anhydride is present as a ferric plumbogummite, the remaining constituents are present in the same proportions as in plumbojarosite. A further careful determination of the optical character of the mineral indicates that it is negative, rather than positive as determined by Knopf. It is concluded, therefore, that the material is plumbojarosite.

MOLYBDATE

Wulfenite.—Wulfenite ($PbMoO_4$) was noted in a number of mines. It commonly forms the typical square tabular crystals of orange to wax-brown color. On the 200-foot level of the Milford mine, good specimens showing many needle-shaped pyramidal crystals were found. Like the vanadates, it is generally in drusy cavities and is one of the latest minerals to be formed. At the Mobile mine crystals of wulfenite are covered with minute perfect crystals of calamine.

HYDROCARBONS

Along the southern border of the ore shoot explored by the Azurite tunnel there were lenses of black material in the breccia zone that contained the ore. This material yields a heavy distillate and bituminous odor when heated in a closed tube but probably does not contain more than 10 per cent of volatile matter. Polished sections show numerous rounded lustrous black grains of bitumen in a matrix of black dolomite that doubtless contains minute disseminated grains of a hydrocarbon. Some of the black grains contain minute grains of chalcocite.

[10] Schaller, W. T., Mineralogical notes, series 2: U. S. Geol. Survey Bull. 509, pp. 77–79, 1912. Butler, B. S., Occurrence of complex and little-known sulphates and sulpharsenates as ore minerals in Utah: Econ. Geology, vol. 8, pp. 316–318, 1912.

[11] Knopf, Adolph, Plumbojarosite and other basic lead-ferric sulphates from the Yellow Pine district, Nevada: Washington Acad. Sci. Jour., vol. 5, pp. 501–503, 1915.

The black lens at the base of the Bird Spring formation in the E. ½ sec. 5, T. 24 S., R. 58 E., contains a disseminated hydrocarbon (analysis 19, p. 62).

In both of these places the locally concentrated bitumen has probably been derived from deeper limestones during the process of alteration to dolomite. Many tests have shown that most of the limestones of the region, especially those near the base of the Bird Spring formation, are bituminous and yield a fetid odor when broken. The process of dolomitization eliminated the bitumen, and doubtless it has migrated to higher or near-by beds.

EFFLORESCENCES IN MINES

The walls of several of the mine workings are coated with white efflorescences that have a mild, salty taste. These efflorescences were conspicuously abundant in the workings of the Anchor, Azurite, Boss, Lavina, Lincoln, and Potosi mines. In some places the efflorescence formed a crust uniformly distributed over the surface; elsewhere it formed myriads of minute hairs as much as an inch long. In only one mine, the Lavina, did such material occur below known sulphides other than galena, from which sulphur in the form of sulphates might be derived.

As such efflorescences have clearly formed since the workings were made, 10 to 20 years ago, and as there has been little oxidation of sulphides in the ore deposits above the lowest levels since that time, samples were collected for analysis in the hope that they would throw light on the chemical character of the solutions that have recently passed through the rocks. The samples from the Boss and Lincoln mines were collected from crosscuts more than 100 feet away from the ore zones. These samples have been tested by J. G. Fairchild, of the United States Geological Survey, whose report is presented below:

Results of qualitative tests of five samples of salty efflorescences collected from walls of mine workings in the Goodsprings district

[Water extract of sample]

Mine sample	Bases		Acids
	Major	Minor	
Lincoln	Na, Mg	K, Ca, traces	Cl, SO_4.
Boss	Na, Mg	K, trace	Cl, SO_4.
Azurite	Na, Mg	K, Ca, traces	SO_4 only.
Lavina [a]	Mg	K, Ca, Mn, Na	SO_4 only.
Potosi	Na, Mg		SO_4 only.

[a] The sample from the Lavina mine shows some Mn, possibly 1 per cent. The principal salt in all specimens appears to be $MgSO_4$.

The analyses show that the principal constituent of each sample is magnesium sulphate, probably epsomite, but sodium sulphate and calcium sulphate are common. It is interesting that chlorides are appreciable in the samples from the Boss and Lincoln mines, which lie close to the valley wash, whereas the other mines lie well within the range.

It would require a comprehensive review of the composition of the rocks of the region, as well as the local ground waters and the salty efflorescences of the dry valleys, to reach a confident conclusion as to the source of the efflorescences in the mines, but a brief survey leads the writer to the tentative conclusion that the chlorides and a part of the sulphates represent the salts that have been blown from the dry valleys to the near-by hills and then carried downward through the rocks by rain water. In other words, the chemical character of the ground waters in the hills is due in part to the character of the rocks through which the waters pass, and in part to the salty efflorescences in the near-by valleys.

GOLD DEPOSITS

During the progress of this investigation unweathered gold-bearing material was seen in but one locality—the Red Cloud mine. Here small quantities of gold are intimately associated with disseminated pyrite in sericitized porphyry. It is possible, as locally reported, that most if not all of the porphyry dikes or sills of the region, where they have been altered and slightly impregnated with pyrite, contain gold. The work on the Red Cloud dike seems to show that the weathered parts of such rocks are appreciably richer in gold than the part which is unweathered. The material that has yielded most of the gold of the region, however, is highly stained by hydrous oxide of iron and lies along fractures or faults, either on the contacts of the dikes or near by in the dolomite country rock or porphyry. If the iron-stained breccia on the Keystone overthrust, reported to carry gold locally, is excepted, all the gold-bearing fractures lie in or within 1,000 feet of outcropping dikes or sills of porphyry. The nature and relations of the limonite in some places indicate that the source was largely pyrite and that the limonite has not migrated far from the place where that pyrite was deposited. This can not be said of the gold, although no direct evidence of migration of gold during weathering has been obtained. The coarse wires and grains of gold reported in the Keystone mine may have been deposited originally in this form or have been formed during recent weathering. The fineness of the gold, together with the presence of manganese oxides in many parts of the mine, indicates that some enrichment has taken place, but the extent is not clear [12] and the presence of carbonate rocks near by should have prevented widespread enrichment.[13] As bearing upon the question of enrichment, it should be noted that, except on the deeper levels of the Red Cloud

[12] Emmons, W. H., The enrichment of ore deposits: U. S. Geol. Survey Bull. 625, pp. 305-314, 1917.

[13] Idem, p. 315.

mine, all the gold-bearing deposits are almost completely oxidized to the depths of present work.

An unusual feature of all the gold deposits is the absence of veins or other masses of coarse white quartz, which forms the gangue of many gold-bearing veins. The origin of the iron-bearing chert associated with the gold in some parts of the Keystone mine is obscure. As it resembles that which contains cinnabar in the Red Cloud mine, it may have been formed during weathering. The pulverulent quartz reported from lenses in the Keystone mine was not seen in place.

A little copper is present at most of the places where gold ore has been mined. This as well as other elements indicates an intimate relation between the gold and copper deposits. Probably the primary copper mineral was chalcopyrite.

In the structural history of the region the gold deposits clearly were formed after the intrusion of the porphyry, which they locally impregnate, as well as after faults of the thrust epoch, at least as late as the Keystone overthrust and the Ironside fault.

SILVER DEPOSITS

The Lavina mine and several prospects south of Crystal Pass are the only workings on deposits that yielded high assays for silver, but none have shipped ore. Proustite, tennantite, and pyrite in white quartz are the characteristic minerals at the Lavina, but only cerargyrite and some vanadates of lead were found at the other prospects. It is worth while to recognize the presence of the group because it appears to be intermediate between the copper-bearing gold deposits and those which largely contain copper, with little gold and silver. The silver deposits occur in or adjacent to granite porphyry dikes.

The silver content of the lead and zinc ores differs from place to place throughout the district but is uniformly lower than in most of the other producing areas in the region west of the Rocky Mountains.

The following table summarizes the range in silver content per ton of metallic lead in the ore of several mines, a considerable part of whose output is lead ore.

Silver content of lead ore, based on smelter receipts

Mine	Character	Silver per ton of lead (ounces)
Potosi	Low grade, crude, oxidized	15– 20
Yellow Pine	Average, concentrate, oxidized	60–100
Ruth	Low grade, crude, oxidized	40– 50
Kirby	do	15– 30
Bonanza	Average, crude, oxidized	20– 30
Singer	do	5– 10
Sultan	High grade, concentrate, oxidized	20– 40
Mountain Top	High grade, crude, unoxidized	6
Bullion	do	7– 12
Bullion	Average, concentrate, oxidized	15– 25
Anchor	High grade, crude, unoxidized	7– 10
Anchor	Average, concentrate, oxidized	15– 20
Milford	High grade, crude, oxidized	3– 5
Milford, No. 2	High grade, crude, unoxidized	2– 3

A review of these assays, as well as others not presented, indicates (1) that the lead ore from deposits near the principal intrusive masses of porphyry is higher in silver than that from remote deposits; (2) that oxidized material is uniformly richer, generally two or three times richer, in silver than unoxidized material, thus indicating an enrichment of silver during weathering; and (3) that concentration processes, wet or dry, applied to the oxidized ores, yield a concentrate richer in silver than untreated material containing the same percentage of lead.

The silver content of oxidized zinc minerals is uniformly lower than that of the lead minerals, commonly one-half to one-third, but smelters do not pay for it, as it is rarely recovered.

Inasmuch as no mine in the district has shipped material completely unaffected by oxidation and therefore by possible enrichment, the range in grade of the unaltered minerals must be inferred. There seems to be no doubt, however, that, as indicated above, the sulphide minerals contain less silver than those from most of the other districts west of the Rocky Mountains. It is an interesting speculation whether this difference is related to the outstanding geologic features of the districts, especially the character of the wall-rock alteration.

Although smelter analyses of a number of shipments of copper ores are available, the information at hand concerning their mineral composition is not adequate to determine the range and association of silver in them. Doubtless, the product of several mines, such as the Columbia, contained appreciable sulphides of copper, but the amount is not known. The silver content of all the copper ores is low, but it is least in those where the copper has clearly migrated appreciably from the original position of the chalcopyrite source. The highest silver content is probably that of the few shipments from the Lincoln mine, which ran as high as 35 ounces to the ton. Most shipments contained less than 10 ounces of silver to the ton, commonly 2 to 5 ounces.

COPPER DEPOSITS

Measured by their production of copper, according to customary standards in the western United States, none of the deposits in this quadrangle are large, and the chance for discovering large or rich deposits here seems remote. On the other hand, the association of platinum and palladium with the copper minerals of several deposits is uncommon and, when considered in connection with the near-by deposits of gold as well as lead and zinc, raises some interesting questions concerning their genesis.

Mineralogy.—Probably malachite has been the most abundant copper mineral in the shipments from the mines, but chrysocolla and chalcocite have locally been abundant. In some of the deposits dolomite stained by malachite has probably made up most of the product. Where sulphide minerals have been encountered chalcocite has been the most abundant, and in most places, such as the Boss, Copperside, Azurite, and Columbia mines, it contains nuclei of chalcopyrite and bornite. The relations indicate clearly that chalcopyrite was the principal if not the only copper-bearing sulphide in most of the deposits before weathering. The presence of traces of copper arsenates in several places and of tennantite in the Lavina mine indicates that copper sulpharsenides were sparsely present in some of the unaltered deposits.

The relations of the original chalcopyrite to the country rock are clear in only a few places, such as the Azurite and Columbia mines. (See pl. 28, *A*.) Here the mineral seems to fill angular dolomite breccia without the admixture of any other minerals.

The alteration of chalcopyrite to bornite and chalcocite without increase in volume demands that copper be brought to the site of deposition rather than that iron be merely withdrawn. The small amount of chalcocite in the deposits is proof that such concentration of copper has taken place only locally. On the other hand, the distribution of the oxidized copper minerals shows that during weathering the copper has been relatively dispersed from the position occupied by the original sulphide. Where the copper sulphide was originally mixed with fine-grained quartz, as in the Boss, Oro Amigo, Doubleup, and Keystone deposits, both the copper and the iron have been completely dissolved and removed to outer inclosing shells, leaving only fine pulverulent quartz. (See fig. 24.) The malachite shell is sharply separated from the inner limonite shell but merges with the outer mass of dolomite. The uniformly meager silver content of the oxidized copper ores may indicate that the original sulphides contained little silver or that, like iron, the silver did not migrate so readily under weathering. Chrysocolla, copper pitch, and dioptase occur in small quantities and largely on open fractures. Their presence indicates a tendency of the carbonates of copper to dissolve slightly in surface solutions and to be precipitated near by with the silica in those solutions.

The lack of a general tendency toward downward migration of copper and its local dispersion are probably due to the scanty rainfall of the region and the chemical character of the inclosing carbonate rock. The distribution of the oxidized zinc minerals also indicates that a small part of the rainfall readily finds its way to major fissures and descends to the deep water table, but the greater part merely wets a large volume of rock and is slowly returned to the surface and evaporated. The mineral deposits, therefore, are alternately slightly wetted and dried and the soluble materials tend to migrate only locally outward toward the fracture through which the water entered.

Little is known concerning the mineral or minerals of the copper deposits that were the source of the platinum and palladium which are especially characteristic of the Boss deposit. There has been sufficient study of the platinum-bearing plumbojarosite to show that native platinum is present, although it lacks the metallic properties commonly characteristic of that metal. The spongy form of the platinum suggests that it was once combined with another more soluble element, such as sulphur or arsenic. As sperrylite (platinum arsenide, $PtAs_2$) is the only natural compound of platinum known, except certain alloys with similar metals, this may have been its source. There is a possibility that a part of the platinum, palladium, and gold are combined with iron oxide and sulphur trioxide as a complex plumbojarosite. (See p. 118.) In some parts of the Boss mine the associations of the masses of plumbojarosite indicate that they might have been concentrated from more disseminated material.

The fine-grained gray quartz of the Boss deposit, which contained octahedrite, is present on the Oro Amigo and Doubleup claims also. It is an uncommon material, and its probable origin can only be inferred from its content of octahedrite.

Structural relations.—The bodies of copper minerals that have been mined have diverse shapes and sizes, but most of them are roughly tabular and underlie persistent walls that cut across the local bedding of the rocks. Only two bodies—the one in the Columbia east shaft and the Blue Jay—lie roughly parallel to the local bedding. On the other hand, at 11 out of the 18 mines described the bodies trend parallel to a persistent fault zone or underlie local walls that trend from north to N. 75° E. These 11 include the Boss, Copperside, Highline, and others on the west side of the range. In only three—the Ninety-nine, Azurite, and Lincoln—do the fractures trend northwest. Most of the overthrusts and reverse faults of the region trend north to northwest, and several faults that trend northeast, such as the Ironside and Tam o' Shanter, are reverse faults of the flaw type, probably formed late in the thrust epoch. It is believed that these copper-bearing faults and fractures belong to the same group. By contrast with the fractures that carry lead and zinc minerals, those which contain copper minerals are more uniform in attitude and relations. The only significance that can be attached to this relation is that it is in harmony with the conclusion that some if not all of the early normal mineral-bearing faults represent a reversal of movement along preexisting thrust faults.

Stratigraphic relations.—Most of the copper deposits occur in Devonian or earlier rocks, although a few, such as the Ninety-nine and the Doubleup, occur as high in the section as the Bullion dolomite. Only in a few places, as in the Copper Chief, Alice, and Mobile mines do copper, lead, or zinc deposits occur near by at the same horizon. Most of the copper deposits lie near the belt of granite porphyry intrusions that occur above the Keystone overthrust.

Relations to igneous rocks.—As shown in Plate 30, all the copper deposits, except the Ninety-nine, Doubleup, and a small deposit west of Wilson Pass, lie in an arc-shaped belt roughly parallel to the Keystone fault and the belt of porphyry dikes that occur above it. Dikes of porphyry that do not crop out were also struck in the workings of the Boss Extension tunnel 1,000 feet north of the Boss mine and in the Columbia East shaft. The areal distribution of most of the copper deposits, even though they are few in number, may therefore indicate a genetic relation to the porphyry intrusions. There is a similar relation of the gold deposits to intrusions, but the copper deposits are a little farther away.

Occurrence of cobalt.—Although cobalt oxide is found in the wall-rock dolomite of nearly every copper deposit in the district and locally is abundant, as in the Columbia, there is nothing to indicate the primary mineral from which it was derived. The primary mineral may have been one of the common arsenides or sulphides, but obviously it was closely associated with a copper-bearing sulphide. The specimens from the Contact claim, even though showing none of the oxidized copper minerals near the pink cobalt-bearing carbonate, contain dark-brown grains that give good tests for both metals. Though these grains are largely iron oxide, probably they were originally sulphide or arsenide minerals that contained the cobalt as well as the copper.

The most abundant cobalt mineral is the hydrous oxide, heterogenite, and the stalactitic form which it assumes in many places indicates that, locally at least, it was deposited directly from solution in open spaces. In some places, however, the cobalt appears to have been deposited first as cobaltous carbonate in near-by dolomite and then later oxidized to the black oxide. (See pl. 27, *B*.) As the result of both processes of alteration, first to carbonate and later to oxide, the cobalt has migrated some distance from the place where it was first laid down. In some places this distance is assuredly more than 30 feet, and elsewhere it may be 50 feet or more.

Even though traces of cobalt are widespread, the total quantity in the district is not large. About 20 tons of selected material containing from 6 to 29.18 per cent of cobalt has been shipped. Probably 200 tons of material containing 2 per cent or more of cobalt could be readily recovered from existing explorations.

LEAD AND ZINC DEPOSITS

Although there are a few deposits in the district that have yielded zinc alone, such as the Monte Cristo, and a few that have yielded lead alone, such as the Ruth, Kirby, and Silver Gem, as a rule the two metals are intimately associated. As the differences in content of zinc and lead do not correspond with differences in form, stratigraphic position, or structural relations, deposits containing both metals will be treated together.

HYPOGENE MINERALS

Even though zinc sulphide was observed in but two deposits, the Potosi and the Milford, where it was clearly the source of the more abundant carbonates and silicate of zinc, there can be no doubt that it was the primary source of the zinc in all the deposits. On the other hand, galena was observed at almost every deposit that has yielded lead, and beyond doubt it was the principal primary lead mineral. There is a remote possibility that sulphides of lead containing arsenic or antimony were also present in a few deposits.

Evidence concerning the method of deposition of zinc sulphide in the containing carbonate rocks was obtained at only one mine, the Potosi. Here part of the sphalerite was deposited as coarse crystals in open spaces of a dolomite breccia prior to the complete filling of the remaining space by white dolomite and calcite, and another, probably smaller part was deposited in the dolomite fragments by replacing the carbonate rock. (See pl. 28, *B*.) Probably the replacement of dolomite by zinc sulphide has rarely extended more than a few inches from open fractures.

The method of deposition of galena resembles that of sphalerite. In a few places it has been deposited as well-crystallized masses in open spaces, but more widely it has replaced the dolomite walls. In many places the masses of galena are well-terminated crystals in the midst of coarsely crystalline gray dolomite. At the Anchor mine, where considerable galena has been deposited in open fractures that were later filled with white dolomite, the sulphide occurs largely on the upper rather than the lower surfaces of the fractures. (See fig. 50.)

Probably the only other sulphide mineral that was common in more than a few of the zinc and lead deposits was pyrite or possibly but doubtfully marcasite. Neither mineral has yet been seen in most of the mines, but the abundance of limonite, ferruginous chert, and minerals of the jarosite group indicates the earlier presence of a sulphide of iron. Stibnite was found only in one area in the Yellow Pine mine. The presence of mimetite and annabergite in several deposits indicates the earlier presence of an arsenical sulphide, possibly arsenopyrite or löllingite, and the arsenides of nickel or cobalt.

Apart from the dolomitized wall rock, the commonest gangue mineral associated with sulphides of lead and zinc was coarse white calcite, but coarse white dolomite is widely present, and both appear to have been deposited largely, if not wholly, after the sulphides. Coarse white calcite cements fault breccias in many places remote from ore deposits, where it appears to be much younger than the metal sulphides. A little silica was deposited with the sulphide of lead in many places, but it has not been recognized near sphalerite. This silica takes the form of clear granular quartz filling pores in the dolomite (p. 57) and of very fine grained iron-bearing chert near the galena. Numerous polished sections of galena-bearing dolomite from the Lookout and Mountain Top deposits show a border of fine silica around the crystals of galena. The association of silica with galena is also indicated by the presence of 5 to 15 per cent of insoluble matter in many shipments of high-grade lead ore. The lenses of granular quartz found in several copper deposits, such as the Boss and Doubleup, were not noted in any of the lead and zinc deposits.

Barite is abundant in several deposits and may be more widespread, but it is not intimately associated with the bodies of lead and zinc minerals. It replaces the wall-rock dolomite along persistent fractures.

From the foregoing statements it seems clear that the mineralogy of the unweathered deposits of lead and zinc was uncommonly simple. Under the influence of weathering, however, a wide variety of minerals was formed—carbonates, sulphates, silicates, phosphates, vanadates, and arsenates.

FORM OF ORE BODIES

If all details are considered the bodies of zinc and lead ore have complicated forms. This is not surprising when it is recalled that even though the bodies of sulphide minerals may have been simple they have been modified by migration and redeposition of zinc under the influence of the processes of weathering. In spite of these irregularities of detailed form, most of the ore bodies, as viewed broadly, are tabular. The most distinctly tabular bodies include those of the Anchor, Monte Cristo, Kirby, Milford, Ingomar, and Tam o' Shanter mines. The bodies of the Yellow Pine and Alice mines are tabular pipes, and the main shoot of the Sultan mine assumes this form, although its structural relations are distinctly different from those of the other two bodies. Two extensive ore bodies, however, the Potosi and the Bullion, have generally similar forms that are unlike anything else in the district. These bodies are limited upward and outward by distinct curved walls that appear to be parts of cones. In most of the smaller mines, even though exploration has revealed several detached bodies, each irregular in form, their outer limits are tabular.

In the following discussion of the structural relations of the ore bodies, it will be the purpose to review those structural features of the deposits that appear to have determined form and continuity.

STRUCTURAL RELATIONS

In this review attention will be directed to two groups of fractures, distinguished, on the basis of their apparent relation to the sulphide minerals, as premineral fractures and postmineral fractures. The data used in distinguishing these fractures include the presence of sulphides, dolomitization, degree of cementation, size, and regional relations. The following criteria have been used in their discrimination:

(*a*) The presence of unbroken crystals or grains of blende or galena in cemented dolomite breccia in a fracture is regarded as proof that it was formed before mineralization. Several such mineralized fractures have been found in the Yellow Pine and Milford mines.

(*b*) If a breccia zone is wholly dolomitized and the fracture appears to have been the source of the dolomitization of the near-by walls it is regarded as premineral. Similarly, if the near-by walls are undolomitized the fracture is regarded as probably postmineral.

(*c*) Most premineral breccias are firmly cemented by dolomite or white calcite; most postmineral breccias are not firmly cemented.

(*d*) If a breccia zone is clearly displaced by a fracture the breccia zone is appreciably older than the fracture, but obviously other criteria must be used to determine whether either or both are earlier or later than the sulphides of the area.

(*e*) In the absence of good local criteria similarity in regional setting of fractures indicates similar age. For example, the Kirby and Rose mines lie in fracture zones that trend at right angles with the local folds; other near-by parallel faults, without apparent mineralization, probably have the same age—that is, premineral.

(*f*) The thickest breccia zones of the region are found on thrust faults, such as the several parts of the Sultan thrust, and all are premineral. In general, thick breccia zones occur on premineral faults and thin zones on postmineral faults, but without confirming features this criterion must be used cautiously.

In a region that has been frequently disturbed one would expect to find places where there has been postmineral movement on premineral faults. This may have occurred on a few fractures, such as that which the Star mine explores, but such movements do not appear to be common in the mines of the district.

As determined by these criteria most premineral breccias and fractures have two outstanding relations to the local bedding—they either lie nearly parallel to the bedding in both strike and dip or cross the bedding with a large included angle. It should be noted, however, that the ore-bearing fractures of the Sultan and Hoodoo mines lie in thick zones of thrust-fault breccias, and the conical fractures of the Potosi and Bullion mines form another distinct group. Most of the ore bodies have a broadly tabular form, and in most of the mines it has been shown that this tabular form is determined largely by premineral breccia zones or fractures. Some mines, such as the Yellow Pine and Milford, show premineral fractures both parallel and oblique to the bedding and permit conclusions concerning their relative age. A few other mines, such as the Potosi, show two systems of premineral fractures without evidence as to their relative age. In most of the mines, however, only one premineral fracture or group of fractures is shown, although closer examination might reveal two. Obviously, in drawing comprehensive conclusions concerning the structural relations of the ore deposits, emphasis must be placed upon the good evidence of some deposits in contrast to the obscure features of many other deposits.

Most of the lead and zinc deposits are listed below according to the structural relations of the principal bodies. The lists therefore record the relation of the most productive premineral fractures or breccia zones of each mine.

Ore bodies nearly parallel to bedding	Ore bodies cut across bedding
Yellow Pine.	Dawn.
Prairie Flower.	Kirby.
Pilgrim.	Whale.
Contact.	Tiffin.
Middlesex.	Belle.
Alice.	Star.
Ruth.	Christmas (part).
Shenandoah.	Silver Gem.
Mobile.	Addison.
Bill Nye.	Ingomar.
Fredrickson.	Tam o' Shanter.
Argentena (part).	
Lookout.	
Mountain Top.	
Hoosier.	
Spelter.	
Singer.	
Puelz.	
Monte Cristo.	
Palace and Porter.	
Accident.	
Anchor.	
Valentine.	
Milford.	
Bonanza.	
Christmas (part).	

The existing workings of some of the deposits of the first group do not reveal the detailed structural relations. At a larger number, including the Yellow Pine, Prairie Flower, Alice, Anchor, and Milford, the principal ore shoots occur in zones of brecciated dolomite underlying persistent walls, and in some of these there are intersecting cross fractures that contain galena and are undoubtedly premineral, as in the Yellow Pine and Milford. At the Yellow Pine mine also it has been proved that the breccia zones which are nearly parallel to the local bedding are offset by and are therefore older than the cross fractures. For this group of ore deposits the conclusion is reached that such breccia zones are thrust faults, in large part local but possibly in part persistent both horizontally and downward. On the other hand, the second group of ore deposits bears a structural resemblance to the mineralized crosscutting fractures of the first group.

The outstanding structural relations of four ore deposits that have been omitted from the two groups have some resemblance to those of the first group. The Sultan and Hoodoo deposits tend to follow persistent walls that cut thick thrust-fault breccias oblique to their strike and dip. The conical breccia masses of the Potosi and Bullion deposits are cut by persistent fractures that have the appearance of being premineral, although positive criteria have not been obtained.

From this brief summary it appears that most of the deposits for which there are good structural data belong to two groups that seem to fit into a simple structural setting. The smaller number of deposits lie along fractures that approximate plane surfaces, and most of these have shown small yield. The larger number of deposits lie in generally thicker breccia masses where they are cut by younger fractures or faults, in part at least, however, premineral. This second group includes the most productive deposits in the district. The simplest and most reasonable explanation that reconciles the structural relations of most of the deposits assumes that thrust-fault breccias were formed rather early in the history of deformation and that for the most part these breccias were larger and more open than those that were formed later along more simple transverse fractures. Considered as channels for access of ore-bearing solutions, the later transverse fractures seem to have an advantage, for, as they are nearly vertical and cross the beds, they would tend to persist in depth. On the other hand, although major thrust faults have been shown to persist over great horizontal extent and probably persist in depth, they have flatter dip, and solutions rising along them would tend to take advantage of any fractures leading more directly to the surface. Minor thrust faults may be related to local folding and pass in depth to bedding-plane displacements or major thrust faults. It seems reasonable, therefore, to regard the thrust-fault breccias as highly favorable sites for deposition of ores and the transverse faults as more favorable channels for access of the ore-depositing solutions.

The bearing of this interpretation on the problems of exploitation of the deposits is discussed on page 102.

STRATIGRAPHIC RANGE

The stratigraphic distribution of those lead and zinc deposits that lie roughly parallel to the bedding of the inclosing rocks is shown in Figure 15. The range of the deposits recorded is about 1,500 feet, and the zone to which they are confined lies near the middle of about

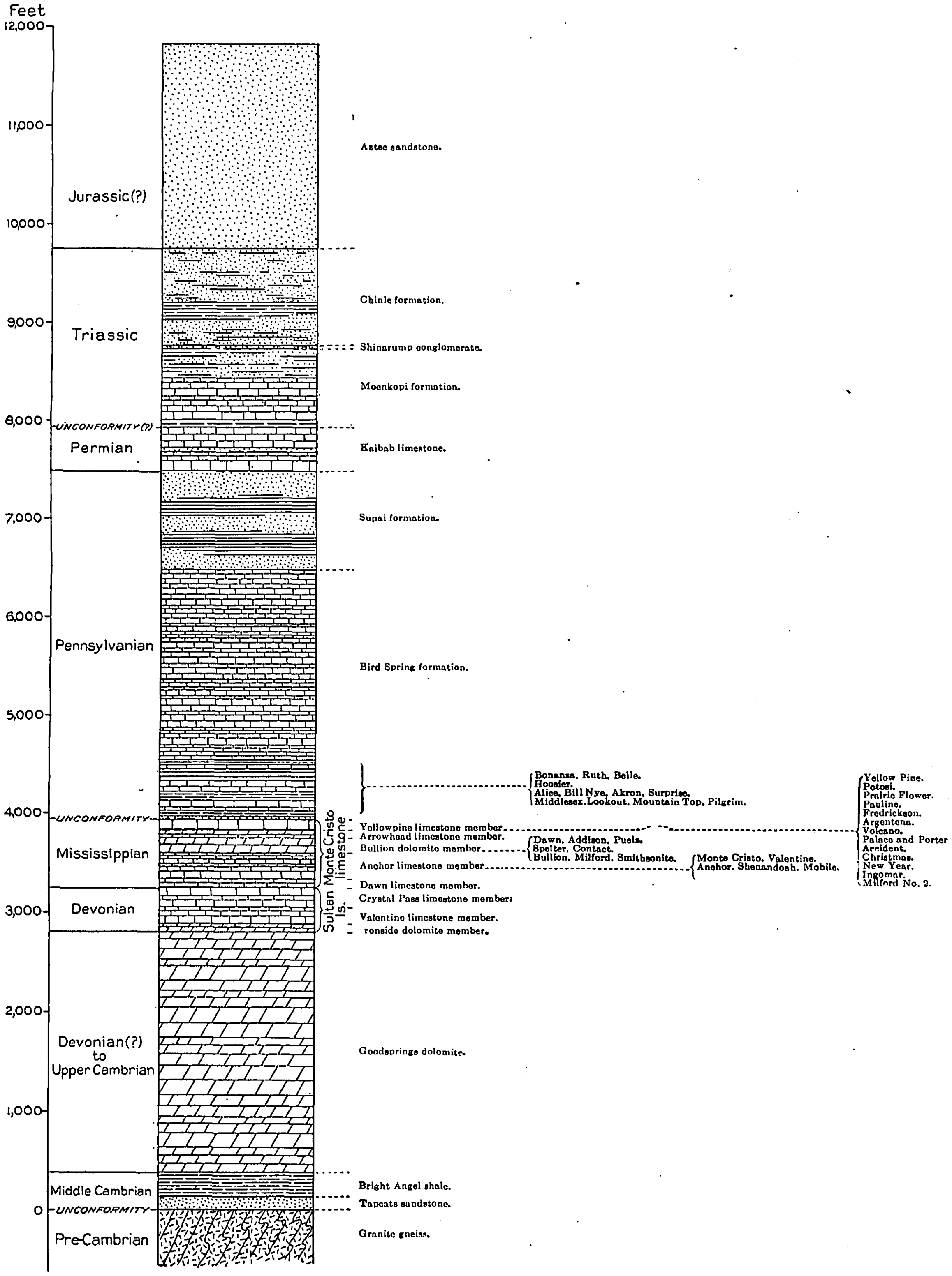


FIGURE 15.—Stratigraphic section of the Goodsprings district showing position of lead and zinc deposits

6,000 feet of limestone and dolomite. If all the deposits of lead, zinc, and copper were recorded here, regardless of structural association, the range would be only 4,000 feet, and 90 per cent of all these lie within a zone scarcely 1,000 feet thick. From another standpoint more than 95 per cent of all the lead and zinc ore of the district has come from a zone scarcely 600 feet thick. This relation shows clearly that there must be some feature or features of this zone that make it favorable for deposition of sulphides of lead and zinc. It has been pointed out already that deposition of sulphides appears to have been determined by structural elements rather than by chemical properties of the beds, as in some other districts.

The outstanding physical differences between the productive and unproductive parts of the stratigraphic section concern the character of the bedding. The 600 to 900 feet of beds that make up the lower Mississippian section are distinctly more massive, homogeneous, and lacking in bedding planes than those above and below. Locally the Devonian beds become massive, but the overlying Pennsylvanian beds, as well as the underlying pre-Devonian beds, are uniformly thin bedded. The overlying beds also contain numerous thin layers of sandstone and shale. In many places in the district it is apparent that the massive beds are competent and determine the general character of the folding, whereas the overlying thin beds are intricately folded to accommodate themselves to the simpler forms of the massive beds. It would therefore seem that the massive beds are more disposed to break and slip along the fractures than the overlying beds that would accommodate themselves to stress by folding and slipping along the bedding. However this may be, it is clear that the zone of lower Mississippian beds is the most favorable in the search for ore deposits.

SUPERGENE MINERALS

On account of the effects of weathering the details of form and mineralogy of most of the ore bodies that have been mined bear only slight resemblance to those of the bodies of lead and zinc sulphides that were deposited originally. Not only have new minerals been formed, but the metals have migrated appreciably before the new minerals were deposited. The new lead minerals do not appear to have been deposited far from the original sulphide source, probably rarely more than a foot or two. On the other hand, sufficient quantities of zinc to form minable ore bodies have migrated from 5 to 50 feet and in a few deposits as much as 150 feet. This migration has taken place in spite of the fact that the walls of the ore bodies are made up of carbonate rocks that should readily react with the common soluble forms of zinc.

Lead minerals.—Galena was observed at nearly every deposit in the district that has shipped lead-bearing material. It is not possible to state with confidence the proportion of lead that occurs as sulphide in the output of many deposits nor in the entire district. In some deposits, such as the Anchor, it has probably amounted to more than three-fourths of the total lead in the shipped product, but in others, especially the group that occurs in fractures which cut obliquely across the bedding, such as the Kirby and Tam o' Shanter, only traces of galena or none whatever was found. The galena of the latter group is rather uniformly more completely weathered to carbonate and to greater depth than that in the deposits that lie nearly parallel to the bedding. Doubtless such fractures offer a better opportunity for water to pass quickly downward to the level of permanent water.

The relations of galena, anglesite, and cerusite in this district closely resemble those in most other districts in the arid West and therefore do not warrant extended description. Only a little of the sulphate, anglesite, occurs as crystals in druses, under associations which indicate that it was deposited from solution after migration. Most of it forms a border around grains of galena or occupies completely the space once filled by galena. The simplest reaction by which galena oxidizes to the sulphate, $PbS+4O=PbSO_4$, indicates that if all of a given unit mass of galena weathered, the resulting anglesite would occupy about 50 per cent more space than the original galena; also that if anglesite replaces a crystal or unit mass of galena, without showing evidence of swelling, about one-third of the original lead present must have been carried away to open spaces near by. The relative abundance of anglesite and cerusite indicates that much more than one-third of the lead has migrated from the site of the original sulphide.

The carbonate of lead, cerusite, was not noted adjacent to the sulphide, and where the two are near by they are separated by a film of sulphate. The carbonate commonly forms distinct crystals, either separate or in druses, or occurs as the typical grid of penetrating crystals that meet at an angle of about 60°. It was not found replacing the carbonate wall rocks, like the hydrous carbonate of zinc, nor in open fault breccias remote from original sulphide bodies, like the carbonate of zinc. The hard masses of chert and cerusite from the prospects south of the Rose mine were probably formed in the same way as the jarositic cherts of the Kirby and other mines. (See p. 143.) The features and associations of the carbonate of lead, as contrasted with those of the sulphate, indicate that in most places the metal has migrated in solution as the bicarbonate a few feet before being deposited as the carbonate.

Among the other oxidized minerals of lead, the phosphate has assuredly formed locally by replacement of the carbonate, but elsewhere, as in the Pilgrim mine, the origin of rather large pockets is obscure. A part of the plumbojarosite of the Kirby mine has formed by the reaction of lead in solution with solid plumbic jarosite or even pure potassic jarosite, but elsewhere the mineral has been formed by the reaction between an iron sulphate in solution and solid cerusite. The several vanadates, although very stable at the present surface, appear to have been deposited from solutions many feet distant from the nearest other lead minerals underground, as in the Bill Nye mine. The molybdate and arsenate of lead likewise have similar relations.

At the Kirby mine it seems clear that in the zone of oxidation there has been appreciable enrichment of lead by the progressive decomposition and re-formation of plumbojarosite, but this has not been an important factor in the formation of lead-ore bodies elsewhere.

Zinc minerals.—Except in the two mines where zinc sulphide was observed, inferences concerning the migration of zinc are based on the assumption that the sulphide was originally associated closely with that of lead, as is common in otherwise similar districts.

The most abundant zinc mineral in almost every deposit examined in the district is hydrozincite, and it has probably been the most abundant in shipments to date. In this respect the district is unique in the western part of the United States. (See p. 98.) In most localities, except in a few of the largest deposits and in places where the hydrozincite lines drusy cavities, there is abundant good evidence that it has been formed by the replacement of dolomite; in some localities it may have replaced limestone. In the largest masses, such as occurred on the 700-foot level of the Yellow Pine mine, where there was a pillar of nearly pure hydrozincite from roof to floor of the stope, 30 feet high, replacement of the dolomite is so complete that only faint traces of dolomite may be found by close search. (See pl. 29, *A*.) The evidence of replacement is beautifully shown in some thin sections under the microscope. Thus, in a specimen from the Arrowhead prospect traces of the rhombic cleavage of the dolomite are well preserved in the fairly crystalline hydrozincite. (See pl. 29, *A*.) Elsewhere the evidence of replacement rests on the recognition of detached rounded masses of dolomite in the midst of pure hydrozincite (pl. 28, *C*) and on the deposition of grains of the zinc mineral along cleavage planes of dolomite where large masses of the minerals are in contact. In large bodies the process of replacement obliterates all traces of the dolomite, and the resulting hydrozincite is either minutely granular (0.005 to 0.01 millimeter in diameter) or delicately plumose.

In a few deposits, as in the Monte Cristo mine, smithsonite was abundant but not assuredly the most abundant mineral. Where observed by the writer it was either an insignificant part of the larger bodies of hydrozincite or occurred in smaller bodies along fracture zones beneath the principal deposits. Numerous bodies of the second group have been mined in the Yellow Pine mine, but most of them 50 to 150 feet below larger bodies of hydrozincite. In such places the smithsonite has a cellular structure, as if it had been deposited in masses of angular dolomite that had later been dissolved and carried away. (See pl. 28, *C*.) As galena was not observed closely associated with such bodies, and as there was no other evidence that the fracture was premineral and may have contained zinc sulphide, the conclusion is reached that the zinc in the bodies of smithsonite is that which has been dissolved above, where it existed as sulphide or hydrozincite, and redeposited lower down.

Calamine is not and probably has not been an abundant mineral, although small quantities are widespread. There is no evidence that it results from the replacement of any other zinc minerals, but the available evidence indicates that it either has been deposited in open spaces or, rather rarely, by replacing the carbonate wall rocks, as in the Whale mine, or the layers of chert which they contain, as in the Monte Cristo mine. In almost all deposits a few crystals of calamine are scattered over the surface of nearly every other oxidized mineral, whether carbonate, sulphate, phosphate, vanadate, or molybdate. Sporadic small crystals of quartz have a similar widespread distribution and indicate that the latest waters that have filtered through the deposits have been saturated with silica.

The general chemical features of the process of weathering, in so far as they concern zinc, may be briefly summarized. This examination does not indicate that much zinc sulphide is replaced in situ by oxidized zinc minerals, as may be noted with lead, so that only the process of deposition of migrating zinc in solution will be described. The reaction by which zinc sulphide oxidizes to zinc sulphate is well known and need not be reviewed. Some experimental work shows that the rate of oxidation of zinc sulphide is increased where sulphates of iron are present,[14] but to judge from the small quantity of iron oxides in the oxidized zones of most of the lead and zinc deposits in the Goodsprings district, these salts have not greatly aided solution of zinc here. Much has been written concerning the chemistry of the solution and deposition of zinc minerals, but some of it has doubtful value because it is based on speculation unsupported by experiment. The experiments by Wang [15] have a definite bearing upon conditions in the Goodsprings district and are confirmed by the mineralogy of the district. Wang performed many experiments, but only those that bear on conditions here will be mentioned. He treated a solution of zinc sulphate with a solution

[14] Emmons, W. H., The enrichment of ore deposits: U. S. Geol. Survey Bull. 625, p. 373, 1917.

[15] Wang, Y. T., Formation of the oxidized ores of zinc from the sulphide: Am. Inst. Min. and Met. Eng. Trans., vol. 52, pp. 657-710, 1915.

of normal carbonate of sodium and found that a basic carbonate of zinc, $ZnCO_3.2Zn(OH)_2$, was precipitated—a reaction indicated by the following equation:

$$2Na_2CO_3 + 4H_2O + 3ZnSO_4 \rightarrow 3Na_2SO_4 + 2H_2CO_3 + ZnCO_3.2Zn(OH)_2.$$

By contrast, a solution of zinc sulphate, mixed with a solution of bicarbonate of soda, yielded a precipitate of normal zinc carbonate, and the following reaction was indicated:

$$ZnSO_4 + 2NaHCO_3 \rightarrow ZnCO_3 + Na_2SO_4 + H_2O + CO_2$$

The first experiment seems to explain why hydrozincite is the principal zinc mineral of the district, and the second the reason why smithsonite is largely confined to open fractures below the larger bodies of hydrozincite. In order to understand these relations it is necessary to bear in mind the low rainfall of the region and the uncommonly deep water table. Obviously the principal carbonates and bicarbonates available for reaction with zinc sulphate would be those of calcium and magnesium rather than sodium or potassium, and the relative proportion of carbonate to bicarbonate in solution is determined by the amount of carbon dioxide in solution. If calcium carbonate and bicarbonate were used instead of salts of sodium, the reaction would be expressed as follows:

$$3CaCO_3 + 4H_2O + 3ZnSO_4 \rightarrow 3CaSO_4 + 2H_2CO_3 + ZnCO_3 + 2Zn(OH)_2$$

and

$$CaH(CO_3)_2 + ZnSO_4 \rightarrow ZnCO_3 + CaSO_4 + HO + CO_2$$

The possible sources of the carbon dioxide appear to be three only—that dissolved from the air in rain water, that contributed by decaying vegetation in the soil, and that produced by the reaction of zinc sulphate and the carbonates or bicarbonates in solution. Only the first two would be available in the upper parts of the ore bodies, whereas the third source would tend to yield more as solutions passed downward in the ore zones. That the first two sources of carbon dioxide are not as abundant in a dry region as in a moist region is indicated by relative absence in this region of caves in the limestones and dolomites. In a region with 5 to 10 inches of rainfall, where the soil is deficient in organic matter, the waters are doubtless sufficiently low in carbon dioxide to permit the basic carbonate of zinc to form in the upper parts of ore bodies, but the carbon dioxide in solution in the surface waters tends to increase with depth, so that in the lower parts or below the ore bodies there is sufficient bicarbonate of calcium or magnesium to produce the normal carbonate of zinc.

If these conclusions are correct, a review of the literature on zinc deposits should indicate a progressive increase in the relative quantity of hydrozincite as compared with smithsonite from the moist eastern regions to the arid western districts.

Hydrozincite is sparingly present in the zinc deposits of Pennsylvania [16] and Kentucky [17] but is very rare among the other districts in the Eastern States [18] and the Mississippi Valley.[19] The mineral appears to be very uncommon in those districts in the Rocky Mountains that have been sources of zinc,[20] but it is more common in deposits in the ranges of the arid West. [21]

From this brief review it appears that although there are local exceptions in several districts, the formation of hydrozincite tends to be favored by an arid climate, other factors being similar.

Silica and iron minerals.—Although the minerals that contain iron and silica do not appear to react on each other or to combine chemically under conditions of weathering, they are considered together because they are commonly closely associated in this district. The properties and general distribution of the different forms of silica noted in these deposits are presented on pages 82–83. At this place the mode of origin will be discussed.

When all the data concerning the varieties of silica and iron-bearing minerals are reviewed, the following conclusions may be drawn:

1. In some lead and zinc deposits and copper deposits, notably the Kirby, Tam o' Shanter, John, Oro Amigo, and Ironside, there is a concentration of silica, largely of the cherty variety, in a zone that extends from the surface to as much as 200 feet below it. In the deeper explorations there is little or no silica, and that present is largely of the hypogene varieties.

2. Within the zone just described brown ferruginous chert and more or less limonite occur at or near the surface, but these minerals are underlain generally by cream-colored chert that contains more or less jarosite or plumbic jarosite. (See pls. 24–26.) Clearly the ferruginous chert and limonite are stable under surface

[16] Miller, B. L., Lead and zinc ores of Pennsylvania: Pennsylvania Geol. Survey, 4th ser., Bull. M5, p. 61, 1924.

[17] Ulrich, E. O., and Smith, W. S. T., The lead, zinc, and fluorspar deposits of western Kentucky: U. S. Geol. Survey Prof. Paper 36, pp. 122–123, 177, 1905.

[18] Watson, T. L., Lead and zinc deposits of Virginia: Virginia Geol. Survey Bull. 1, pp. 44–45, 1905. Secrist, M. H., Zinc deposits of east Tennessee: Tennessee Dept. Education, Div. Geology, Bull. 31, p. 27, 1924.

[19] Bain, H. F., Zinc and lead deposits of the upper Mississippi Valley: U. S. Geol. Survey Bull. 294, p. 50, 1906. Buckley, E. R., The geology of the Granby area: Missouri Bur. Geology and Mines, 2d ser., vol. 4, pp. 44, 56, 1906.

[20] Loughlin, G. F., The oxidized zinc ores of Leadville, Colo.: U. S. Geol. Survey Bull. 681, p. 18, 1918. Crawford, R. D., and Gibson, Russell, Geology and ore deposits of the Red Cliff district, Colorado: Colorado Geol. Survey Bull. 30, p. 51, 1925. (Hydrozincite is not mentioned in U. S. Geological Survey reports on the Coeur d'Alene, Park City, and Bingham districts.)

[21] Lindgren, Waldemar, and Loughlin, G. F., Geology and ore deposits of the Tintic mining district, Utah: U. S. Geol. Survey Prof. Paper 107, p. 149, 1919. Butler, B. S., Loughlin, G. F., and Heikes, V. C., The ore deposits of Utah: U. S. Geol. Survey Prof. Paper 111, p. 111, 1920

conditions, and that which is exposed by erosion is weathered by disintegration rather than solution.

3. Where the two varieties of chert are in contact the local relations indicate that the brown ferruginous chert is formed from the lighter jarositic chert. Locally, as in the Kirby mine, the lighter chert also decomposes to a white powder; a part of the silica is dissolved and is probably reprecipitated at a lower horizon (p. 144).

4. The most common jarosite is probably a potassium-bearing natrojarosite. If exposed at the surface by erosion it is surprisingly stable, but underground it may be decomposed to iron oxide, which remains in place, and to the alkalies and sulphate radicle, which go into solution and migrate downward.

5. Lead-bearing jarosite and plumbojarosite are probably stable on the surface but like the other jarosites are liable to decomposition underground. In such places the lead is probably reprecipitated at a lower horizon as plumbojarosite or cerusite.

In the light of these conclusions it is hard to avoid the additional conclusion that an appreciable part of the cherty silica in the shallow zones of many of the ore deposits represents material that has been progressively dissolved near the surface and reprecipitated at a lower zone. The remainder of the silica, that which becomes fixed as ferruginous chert near the surface, is disintegrated at the surface and dispersed by erosion.

Most of the deposits characterized by chert occur in shaly zones in the stratigraphic section. In one mine, the Kirby, the original source of silica seems to be that set free where sulphuric acid attacks shale and forms alunite. In other places the source of the silica is obscure.

In the realm of ore deposits and lithology, good examples of the widespread solution of silica or decomposition of silicates near the surface are not uncommon. Satisfactory experimental work, which indicates some of the chemical conditions under which solution of silica takes place, has also been done. Places where large masses are precipitated near the surface, however, are rare. Recent experimental work by Lovering [22] has shown the degree to which several salts, common in surface waters, affect the solubility of several forms of silica and silicate minerals. This work showed that among the common carbonates, sulphates, and chlorides magnesium bicarbonate most effectively dissolves the finer varieties of silica, such as jasper, chalcedony, and opal.

With regard to the deposition of silica, experiments by the same author led to the conclusion that

> The factors governing the precipitation of silica, * * * while not clearly understood, are probably related to the change in the solutions from acid to alkaline, or to the mixing of two solutions, one rich in electrolytes and the other containing a relatively large amount of silica.

[22] Lovering, T. S., The leaching of iron protores: Econ. Geology, vol. 18, pp. 523-541, 1923.

In this region it seems that both the solution and deposition of silica may have been accomplished by a single solution, changing in character as it passed downward. Relatively pure rain water falling on the surface would probably quickly become nearly saturated with carbonates of lime and magnesia and therefore would become an active solvent of silica. As the water filtered downward through an ore deposit that contained first sulphates, like the jarosites, and lower down sulphides, the sulphate content of the water would rise. With this rise in sulphate content the silica would tend to be deposited, and with greater depth the water would lose most of the silica and become a sulphate or mixed sulphate-carbonate water. No analyses of mine waters from the mountains of the region are available, but numerous waters from wells in the alluvial valleys are of this type.[23] Their silica content largely ranges from 10 to 40 parts per million and is rather high for cold waters, even with so high a content of dissolved salts, 250 to 1,500 parts per million.

The general conclusion is reached that in this arid region silica tends to be progressively concentrated in a shallow surface zone. The minerals of the jarosite group are uncommonly stable on the surface but tend to be decomposed in a shallow zone near the surface. The work in this region indicates that the jarosites are more widespread in this province than existing records indicate. Somewhat similar materials that occur under similar circumstances in western Australia have been described by Simpson.[24]

RELATION OF THE ORE DEPOSITS TO INTRUSIVE ROCKS

The areal or rather, spatial distribution of ore deposits, particularly considered in relation to bodies of intrusive igneous rocks, known or inferred, commonly suggests and aids in interpretations of their genesis. During recent years the idea has grown that the metalliferous deposits of districts characterized by bodies of intrusive igneous rocks tend to be disposed in zones around a center, either on the existing surface or lying at some distance below it. Many believe that these centers lie in and are somehow related to the bodies of igneous rock.[25] Investigation tends to show, however, that in studying this problem attention must be directed to large areas, such as those embraced in entire mining districts or even larger regions, in order to avoid undue emphasis of local features. In order to portray these relations in the Goodsprings district Plate 30 has been prepared.

It has been pointed out on page 76 that most of the ore deposits of this district occur in an area about

[23] Waring, G. A., Ground water in Pahrump, Mesquite, and Ivanpah Valleys, Nev. and Calif.: U. S. Geol. Survey Water-Supply Paper 450, pp. 80-81. 1920.

[24] Simpson, E. S., Secondary sulphates and chert in the Nullagine series; Roy. Soc. Western Australia Jour. and Proc., vol. 9, pt. 2, pp. 45-63, 1923.

[25] Spurr, J. E., A theory of ore deposition: Econ. Geology, vol. 2, pp. 781-795, 1907; Theory of ore deposition: Econ. Geology, vol. 7, pp. 485-492, 1912. Emmons, W. H., Primary downward changes in ore deposits: Am. Inst. Min. and Met. Eng. Trans., vol. 70, pp. 964-992, 1924; Relations of metalliferous lode systems to igneous intrusives: Idem, vol. 74, pp. 29-70, 1926.

10 miles in diameter, the center of which lies 4 miles southwest of Goodsprings. A few deposits lie north of this area, a few lie northwest of it, and a few lie south of it, but except for a single prospected deposit in the Bird Spring Range, none are known east of it for many miles. The deposits that have been examined within the quadrangle seem to conform in a broad way to a zonal distribution around the intrusive centers localized on the major thrust faults.

First, as viewed broadly, there are more ore deposits in the belt overlying the Keystone thrust fault east of the transverse Ironside fault than in all the rest of the district. Within this belt lies a group of intrusive masses of granite porphyry, beginning with the Keystone dike on the west and extending eastward to the Lincoln mine. The porphyry sill in the Boss Extension mine, which doubtless rises along the Ironside fault, is one of this group. A second group of intrusive masses, smaller in number but larger in areal extent, includes the Yellow Pine sill and the Lavina dike. No intrusive porphyry masses are known in the Spring Mountains north of the Yellow Pine sill, near the Snowstorm mine, for 40 miles or more, or south of the Lincoln mine for 20 miles. As noted earlier in this report, the thrust faults have undoubtedly determined the general distribution of the intrusive masses. These bodies of intrusive rock have the same structural relations as an enormous body of quartz monzonite that crops out over an area of several hundred square miles 20 to 40 miles south of the Goodsprings district.

Next, as viewed in detail, there is a distinct tendency toward zonal arrangement of the ore deposits in several parts of the district. The most productive gold deposits—the Keystone and Red Cloud—are wholly in or adjacent to bodies of intrusive porphyry, and minor prospects, such as the Chaquita, are within 1,000 feet of outcropping intrusive masses. The deposits which have yielded high assays for silver but which have not been productive—the Lavina and Crystal Pass—also lie in or adjacent to porphyry dikes. The iron-stained fault gouge of the Keystone thrust is widely reported to yield fair assays for gold.

In the belt of rocks overlying the Keystone thrust fault copper deposits tend to lie stratigraphically and topographically below near-by lead and zinc deposits. Thus the Boss, Highline, Copperside, Rose, Columbia, and Lincoln, as well as numerous smaller deposits, lie largely in Devonian or older rocks near the bases of escarpments, whereas numerous zinc and lead deposits lie in younger rocks on or near the crests of the escarpments. An exception to this tendency is found in the Kirby lead deposit, which lies within the belt of rocks favored by copper deposits. The Alice, Yellow Pine, Prairie Flower, and Pilgrim zinc-lead deposits lie in higher beds than the near-by Copper Glance and Snowstorm copper deposits. In the southern part of the district the deposits that are higher both in altitude and in stratigraphic position tend to contain more lead than zinc. Porphyry masses were encountered in the Columbia and Boss Extension mines, although the copper deposits were near these masses rather than in them. Recently Emmons,[26] in reviewing the relations of metalliferous deposits to intrusive rocks, included a brief summary of the deposits of the Yellow Pine district as described by Hill and concluded that "the deposits are not clearly separated into zones, and there is evidence of some overlapping of copper deposits." In the writer's opinion the ore deposits are separable into several groups, in at least two of which there is a distinct tendency toward a zonal arrangement of the deposits, and especially in the part of the district that contains most of the deposits.

The causes that account for the failure of the Kirby and some other deposits that lie outside the central part of the district to conform to a simple zonal arrangement can only be conjectured. Only zinc and lead deposits are known in the southwestern part of the district, and among these only a slight tendency toward zonal arrangement may be noted. The causes of the local distribution of the zinc and lead deposits are probably to be sought among their structural and stratigraphic relations. It seems fairly probable, however, that buried bodies of intrusive rock underlie small areas in the southern part of the district.

The relations described conform with the general distribution of gold, copper, zinc, and lead deposits as set forth by Spurr.

The question may well be raised as to what features have controlled the localization of many sporadic outlying deposits, notably the Potosi zinc and Ninety-nine and Doubleup copper deposits and others in the southern part of the district, most of which are 4 to 7 miles from the nearest surface outcrop of porphyry. A brief examination of the Potosi deposit by Bain,[27] in advance of a comprehensive knowledge of the areal geology of the district, yielded the impression that the deposit had no relation to intrusive igneous rocks, such as most observers have concluded to exist for the zinc and lead deposits of the Mississippi Valley. In the light of the present knowledge of the central part of the Goodsprings district this conclusion was premature, but now, as then, in attempting to deduce confident conclusions, one is hampered here, as in many other places, by lack of knowledge concerning unexposed, possibly slightly buried bodies of igneous rock.

RELATION OF THE ORE DEPOSITS TO ROCK ALTERATION

In the section on rock alteration (pp. 55–67) the existence of widespread dolomitization and meager

[26] Emmons, W. H., Relations of metalliferous lode systems to igneous intrusives: Am. Inst. Min. and Met. Eng. Trans., vol. 74, p. 38, 1926.

[27] Bain, H. F., A Nevada zinc deposit: U. S. Geol. Survey Bull. 285, pp. 16-166, 1906.

silicification of limestone is discussed fully, and possible sources of magnesia are suggested. In many parts of the district the ore deposits seem to coincide closely with areas of dolomitized limestone, but in other parts, largely in the northern half of the quadrangle, where there is widespread dolomitization, no ore deposits are known. Even after allowance is made for the possible existence of undiscovered ore deposits, the conclusion seems to be suggested that, although practically all the known zinc, lead, and copper deposits occur in dolomitized limestone, all areas of altered limestone do not necessarily include ore deposits. With the wider knowledge gained through the study of a much larger area, that of the Ivanpah quadrangle, which includes about 3,800 square miles, this impression is confirmed. For example, the ridge north of Sloan shows a good cross section of 800 feet of beds that include Devonian and lower Mississippian formations, and the exposure is improved by a quarry, which extends for 1,000 feet along the south slope. The beds of the section are normally limestone, but here all are altered to dolomite except a lens in the middle of the quarry, which coincides with the Crystal Pass limestone. In fact, the purpose of the quarry is to mine the lens of limestone, which is overlain and underlain by dolomite. However, no lead or zinc minerals are known near by nor for a distance of 14 miles. The conclusion is reached therefore that there is general but not precise coincidence of ore deposits and dolomitization.

When the two processes are considered in the light of their chronologic succession in the region, there seems again to be general but not close coincidence. Not only are the sulphide minerals of many localities deposited in angular dolomite breccia, but some shoots of sulphide minerals lie along well-defined walls in porous dolomite breccia, notably in the Sultan and Hoodoo mines. There seems to be no doubt that such breccias were altered to dolomite before they were crushed and the sulphide minerals deposited and therefore that dolomitization began before the deposition of sulphides, even though it continued during that deposition.

In a recent review of the evidence from a number of districts in which lead and zinc occur in dolomitized limestone,[28] the writer reached the conclusion that the conditions in the Goodsprings district were similar to those encountered in many other districts in the United States as well as Europe. In general the process of alteration has preceded the deposition of sulphide minerals, and although most ore deposits in each district are enveloped in an aureole of dolomitized limestone some deposits are found in unaltered rock. It therefore seems that although the magnesia was brought to fractured areas earlier than the sulphides of the metals, the channels of access were essentially the same.

Dolomitization of limestone adjacent to lead and zinc deposits has been noted in the following districts in the United States: Aspen [29] and Red Cliff,[30] Colo.; Tintic, Utah; [31] Cerro Gordo, Calif.; [32] the Mississippi Valley; [33] and Tennessee.[34]

In Europe dolomitization of limestone near lead and zinc deposits has been observed in many localities but notably in the Weardale district, England; [35] the Welkenraedt-Vieille Montagne district, Belgium; [36] the Iglesias district, Sardinia; [37] and Upper Silesia, Germany and Poland.[38] The process of alteration has occurred in many other European districts where it has not been closely studied.

SUMMARY OF GENESIS OF ORE DEPOSITS

The following elements enter into the hypothesis that is offered to explain the genesis of the ore deposits of this district: (1) Source of the metals and elements that have produced rock alteration; (2) method of transfer; (3) method of deposition; (4) places of deposition; (5) effects of weathering; (6) postmineral faulting.

1. This investigation does not yield evidence of the ultimate source of the metals now found in the ore deposits. That source might have been deep-seated reservoirs of magma, the shallow bodies of intrusive rock that are now highly altered, or some deeply buried sedimentary rocks. It seems clear that the concentrations of the metals now found in the ore deposits depend in some way upon the intrusions of igneous rock, but whether these intrusions were the source, or whether they were derived from a common deeper magmatic source or were gathered from many rocks and deposited by the water circulation set up by the intrusion is not revealed. The silica, iron, and magnesia found in the altered wall rocks may have been derived from one or all of these sources, but after reviewing the geologic features of a number of districts that contain the same metals and show the same rock

[28] Hewett, D. F., Dolomitization and ore deposition: Econ. Geology, vol. 23, pp. 821-863, 1928.

[29] Spurr, J. E., Geology of the Aspen mining district, Colorado: U. S. Geol. Survey Mon. 31, pp. 206-216, 1898.

[30] Crawford, R. D., and Gibson, Russell, Geology and ore deposits of the Red Cliff district, Colorado: Colorado Geol. Survey Bull. 30, pp. 55-56, 1925.

[31] Lindgren, Waldemar, and Loughlin, G. F., Geology and ore deposits of the Tintic mining district, Utah: U. S. Geol. Survey Prof. Paper 107, pp. 159, 184, 1919.

[32] Knopf, Adolph, Geologic reconnaissance of the Inyo Range, Calif.: U. S. Geol. Survey Prof. Paper 110, p. 114, 1918.

[33] Bain, H. F., Van Hise, C. R., and Adams, G. D., Preliminary report on the lead and zinc deposits of the Ozark region: U. S. Geol. Survey Twenty-second Ann. Rept., pt. 2, pp. 119, 203-212, 1901. Bain, H. F., Zinc and lead deposits of the upper Mississippi Valley: U. S. Geol. Survey Bull. 294, p. 30, 1906. Siebenthal, C. E., Origin of the zinc and lead deposits of the Joplin region: U. S. Geol. Survey Bull. 606, pp. 187-192, 1915.

[34] Secrist, M. H., Zinc deposits of east Tennessee: Tennessee Dept. Education, Div. Geology, Bull. 31, p. 165, 1924.

[35] Carruthers, R. S., Lead and zinc ores of Durham, Yorkshire, and Derbyshire: Geol. Survey Great Britain Mem., vol. 24, p. 11, 1923.

[36] Timmerhause, C., Les gîtes métallifères de la région de Moresnet, Liège, p. 21, 1905.

[37] De Launay, L., Gîtes minéraux et métallifères, vol. 3, p. 221, 1913.

[38] Handbuch des oberschlesischen Industrie-Bezirks: Oberschl. berg- u. hüttenm. Verein Festschrift, Band 2, pp. 42-52, 1913. Liedl, K., Die oberschlesische Zink Erzlagerstätten: Oberschl. berg- u hüttenm. Verein Zeitschr., Jahrg. 66, pp. 762-776, 1927.

alterations, the writer concludes that an important source, if not the most important, lay in the shallow bodies of intrusive rocks, some of which now crop out in the district.

2. No features of the metallic sulphide minerals prove clearly whether they were transported in water solution or otherwise. On the other hand, the major as well as many minor features of the wall-rock alterations seem to demand a degree of mobility, especially of magnesia, that could be attained only by aqueous solutions. The intimate though not invariable association of sulphides and dolomitization points to a similar method of transfer.

3. The magnesia seems to have been brought to an upper zone in the crust by circulation along fractures, but a large part of the actual process of replacement of limestone seems to have been accomplished by diffusion. The metallic sulphides rose along similar major channels but appreciably later than the magnesia and were deposited in part by replacement of the carbonate wall rock and in part by precipitation in open spaces.

4. The places of deposition of the metallic sulphides were determined in a broad way by the distribution of bodies of intrusive granite porphyry and locally by the structure. The principal channels by which the metals were brought to their sites of deposition were steeply dipping crosscutting fractures. Some of the bodies of sulphides were deposited in these fractures, but the largest bodies were formed in bedded breccias along flat thrust faults near their intersection with crosscutting fractures.

5. Among the zinc minerals, which have been the principal product of the district thus far, hydrozincite is the most abundant, but considerable smithsonite and a little calamine have been produced by some mines. These minerals represent zinc once deposited as sphalerite, oxidized to the sulphate, and reprecipitated near by but at lower levels under the influence of weathering. The original lead sulphide is largely unaffected by weathering, but the shallow zones of many mines yield some carbonate and sulphate of lead. Under weathering numerous vanadates of zinc, lead, and copper have been formed. Only traces of copper sulphide minerals are exposed in the mine workings, as most of them have been weathered to form the carbonates and silicates. Minerals of the jarosite group—hydrous sulphates of iron with the alkalies and other metals—are common.

6. Many deposits show displacements along fractures that have been formed since the metallic sulphides were deposited. There is little if any record of movement along these fractures since the oxidized minerals were formed, and it seems that most of the weathering has taken place since the formation of the fractures.

SUGGESTIONS TO GUIDE THE SEARCH FOR ORE DEPOSITS

The search for ore deposits assumes several forms—the search for undiscovered districts, the search for undiscovered deposits in productive districts, the search for the continuations of explored deposits. Different kinds of geologic data are used for each of these undertakings. This inquiry is obviously concerned only with the second and third forms of search. The following suggestions are based largely on the information derived from existing explorations in the district.

As a result of studies in this and a few other generally similar districts, it seems clear that areas of dolomitized limestone offer much more promise for ore bodies than areas of unaltered limestone. In fact, it can be said that prospecting for ore in the unaltered limestone of this district is almost certain to fail. Further, if in exploring outward from known ore bodies, the country rock is found to change from dolomite to limestone, work can safely be abandoned. Exceptions to this rule can be cited—for example, one of the shoots in the Milford mine—but broadly they can be ignored.

In the light of the somewhat imperfectly displayed tendency toward a zonal distribution of the metalliferous deposits, it seems that the territory stratigraphically and topographically higher than known copper deposits is worthy of careful examination for zinc and lead deposits.

The major thrust faults seem to have determined the local distribution of intrusive rocks, the centers of intrusion control the general distribution of ore deposits, and most of the ore deposits occur in bedded breccias along thrust faults; nevertheless the major thrust faults do not contain many ore deposits. Minor bedded breccia zones that show considerable dolomitization deserve much more attention.

In general, areas that show much fracturing as well as dolomitization are more promising than areas of unbroken rocks. There are more ore deposits in the much fractured belt extending 2 miles south from Deadmans Canyon (fig. 6) than in any equivalent area elsewhere in the district, although the largest mines are elsewhere. In the light of this conclusion Ruth Mountain, west of the Lavina mine, deserves more exploration that it has received. More locally, the search for and exploitation of the ore deposits of the district are largely structural problems; they demand the observation and record of the attitude of the beds and of all fractures and breccia zones and the relations of the different minerals to them. No simple rules can be formulated that can be rigidly applied to every locality in the district with unfailing success. The district requires and deserves much closer study of the structural setting of each deposit than it has received, and, in a general way, production will proceed in an orderly and regular manner only when such study is given.

For most of the ore deposits there are at least two essential structural features—a channel of access for the metal-bearing solutions and a site of deposition. In a few deposits a third structural feature appears in the form of postmineral fractures, along which movement has displaced the bodies prior to weathering. In places the channels of access may be small and inconspicuous, so that they are found only after close search, but elsewhere they are large enough to warrant mining. The criteria for their recognition are given on page 93. The sites of deposition are commonly the zones of dolomite breccia which lie nearly parallel to the bedding. They are much more conspicuous than the channels of access, but the ore minerals are sporadically distributed in them. It has frequently happened in the district that with exploitation ore has been exhausted from a bedded breccia zone, and the operator is forced to do exploratory work in search of new bodies. Generally he has chosen to do this by pursuing the breccia zone laterally or in depth, not uniformly with success. It is suggested that in such situations, if the breccia zone is relatively high in the favored part of the stratigraphic section (see p. 95), the operator should consider the wisdom of sinking deeper on recognized crosscutting premineral fractures in the hope of finding ore where they intersect lower breccia zones. Such superposed parallel breccia zones have been found only in several places in the Yellow Pine and Anchor mines, but the fact that they exist justifies their consideration.

The migration and redeposition of zinc under the influence of weathering create some problems in exploitation that are not widely understood in the district. Such secondary minerals as smithsonite and calamine represent zinc that has migrated downward from the original source. Where bodies of such minerals fail in depth, it is generally unwise to explore deeper; it would be better to explore upward unless the bodies in that direction have already been exhausted. The presence of some galena in the oxidized zinc minerals is the only trustworthy evidence that they occupy their original position or lie in a premineral fracture or breccia that can be explored with confidence.

DETAILED DESCRIPTION OF THE MINES

GOLD MINES

RED CLOUD MINE

Location and history.—The Red Cloud mine (No. 10, pl. 30) is near the road to Wilson Pass, about 4 miles northwest of Goodsprings. The deposit was located by J. C. Armstrong in January, 1902. A little work was done between that year and 1904, but most of the present work was done between July, 1905, and September, 1907. Early in 1906 a small cyanide plant was installed and operated almost continuously until September, 1907.

Most of the workings explore a granite porphyry dike about 65 feet wide that trends N. 40° W. and may be traced about 1,500 feet by outcrops and prospects. The adjacent rocks are smoky-gray dolomitized limestones of the Bird Spring formation, perhaps 500 to 800 feet above the base. These and higher beds were probably limestone originally, but they are now dolomitized over an irregular area that extends westward beyond Wilson Pass. The dolomitized beds overlie the Potosi thrust fault, which lies under the wash east of the mine. Near the mine these beds trend rather uniformly N. 30° E. and dip 30° SW., so that the dike cuts across them obliquely in strike and dip. The only evidence of contact action on these rocks is a slight bleaching. As exposed underground they are finely crushed near the dike and recemented by calcium carbonate. The dike itself is completely altered near the mine, the orthoclase crystals being converted to a minutely felted mass of sericite, and the groundmass is altered as well as impregnated with minute grains of pyrite. Even below the depth of weathering it is sparsely cavernous through the removal of part of the rock by solution.

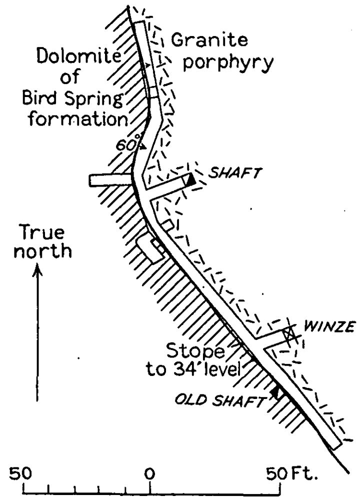


FIGURE 16.—Geologic map of 87-foot level, Red Cloud mine

There are several shafts at the southeast end of the dike, but the deepest and the one from which the production of the mine was made lies north of the central part. This shaft is vertical to a depth of 116 feet and is inclined at 65° thence to the bottom, 300 feet below the collar. There are levels at 34, 87, 136, 190, and 300 feet. Only the workings on and above the 87-foot level were examined, for below that level there was serious caving of the shaft. (See fig. 16.)

According to Mr. Armstrong, the principal sources of ore were three shoots. One lay above the 34-foot level and southeast of the old shaft; another extended from the 34-foot level to the 87-foot level, northwest of the old shaft; and a third extended from the 87-foot level diagonally downward toward the 116-foot level in the new shaft. Only the second of these shoots could be examined. It covered an area about 25 by 50 feet, and the width ranged from 4 to 10 feet. The stope followed the southwest or footwall contact of the dike with the dolomite, and both materials seem to have been mined. The contact is marked by sporadic lenses of dark-brownish chert, which the microscope shows to be microgranular and to contain sparsely distributed grains of a brown oxide of iron that was probably formed during weathering.

As exposed by crosscuts on the 87-foot level, a part of the pyritized porphyry is oxidized, and another part, generally a central core, is unoxidized. All the ore that yields the highest assays for gold, as well as that which has been stoped, is oxidized, whereas the unoxidized part is of lower grade and generally contains only $1 to $3 worth of gold to the ton. It is reported that there was much less oxidized porphyry on the 300-foot level than above, and almost the entire dike was unweathered.

According to Mr. Armstrong, it was the aim in operating the cyanide plant to supply ore that was valued at $9 to $12 a ton, and this range was maintained during a part of the period of operation. The only accurate records available cover the period from February to July, 1906, and are presented in the following table:

Records of operation of cyanide plant, Red Cloud mine, 1906

Month	Ore treated (tons)	Value of gold per ton of ore			Value of gold produced
		Crude ore	Tailing	Recovered	
February	171	$5. 78	$1. 66	$4. 12	$704
March	390	5. 88	1. 12	4. 76	1, 856
April	221	5. 34	1. 91	3. 43	756
May	363	4. 92	1. 67	3. 25	1, 180
June	406	6. 78	2. 27	4. 51	1, 831
July	256	5. 61	1. 07	4. 53	1, 160
	1, 807				7, 489
Average per ton					4. 14

Free gold has never been seen in Red Cloud ore. The opinion prevails that it must have been very fine, and this is confirmed by the good extraction obtained at the cyanide plant—65 to 90 per cent of the gold from material crushed to pass rolls set 1 inch apart. The fineness of the bullion from the cyanide plant ranged from 0.700 to 0.880, but the silver content was low.

Other than the iron oxides and silica in the oxidized ore, the only mineral observed was cinnabar. This mineral was found here and there in sufficient quantity to form an appreciable part of the cyanide precipitate. In the specimens collected by the writer it occurred as small round grains in the ferruginous chert, probably formed during the process of weathering.

There is no record of the total production; probably it did not exceed $20,000.

CHAQUITA MINE

On the Chaquita claim (No. 21, pl. 30), 3,000 feet west of the Keystone, nearly 1,000 feet of work has been done. Here the dark-gray dolomites near the middle of the Goodsprings formation strike west and dip about 5° S. Most of the work has been done at two tunnels and a shaft near the top of a low knoll. These openings explore some siliceous limonite lenses that lie parallel to the bedding of the dolomite. The lowest tunnel, 310 feet long, was driven under these workings but cut no vein. Although good assays for gold are reported, no ore has been milled.

There are a number of other tunnels and shallow shafts within 2,500 feet northwest and southeast of the Keystone mine, most of which explore either porphyry dikes or their contacts with the dolomite beds of the Goodsprings formation. The total length of these workings must be 3,000 or 4,000 feet, but as little authoritative information could be obtained concerning them, and as they yield no significant geologic data, they will not be described.

KEYSTONE MINE

Location.—The Keystone mine (No. 22, pl. 30) is the most productive of the group near the head of Keystone Wash, on the west slope of the Spring Mountains. Although scarcely 5 miles due west of Goodsprings, the mine is 12 miles distant by the road over Wilson Pass. The workings lie near the base of a prominent ridge and are readily accessible by the road up Keystone Wash. (See pl. 31, *A*.)

Although the Keystone claim was first located in 1882 by Joseph Yount and others, no work was done before 1888, when it was relocated, with the adjoining Honduras claim, by Jonas Taylor. In 1892, after a little work had been done, rich ore was struck, and a shipment of 10 tons to Pueblo yielded $7,160.[39] In June, 1892, S. T. Godbe, of Salt Lake City, purchased an interest for $20,000 and active exploration was begun. A 10-stamp mill was built at Sandy, 6 miles southwest, in 1893, and it is reported [40] that this mill was operated continuously through that year and yielded $30,000 a month. During a part of this period the ore treated averaged $92.20 in gold to the ton. In June, 1895, the company was in financial difficulties, and a receiver was appointed. The mine was operated intermittently thereafter until 1897, when it was closed down.[41] During this early period of work four tunnels were driven and the old shaft from tunnel 3 was sunk to a depth of 530 feet. Operations were conducted at great disadvantage, as the nearest source of supplies was Manvel (later Barnwell), 80 miles distant.

In May, 1902, the Nevada-Keystone Mining Co. was formed to take over the property, and the mine was operated for two and one-half years. During this period the new inclined shaft was sunk to a point 820 feet below tunnel 3, or 1,000 feet below the outcrop, and the deposit was explored to nearly the present

[39] Eng. and Min. Jour., vol. 54, pp. 447, 591, 615, 1892.
[40] Idem., vol. 57, p. 183, 1894.
[41] Idem., vol. 59, pp. 567, 613, 1895; vol. 64, p. 77, 1897.

state of development. (See figs. 17, 18.) For six months during 1905 it was operated under lease by M. R. W. Rathborne. Little work has been done at the mine since that time, although the tailing dumps near Sandy have been reworked in a small cyanide plant from time to time. In 1922 most of the underground workings except the old shaft were accessible.

Production.—The record of production for the Keystone mine prior to 1902 is not accessible, but the present company estimates it at $380,000. All the ore that was treated during this period came from the northern shoot—that explored from tunnels 1, 2, and 3—and the old inclined shaft. The production since 1902 is presented in the accompanying table, compiled from the records submitted annually by the owners to the Geological Survey, supplemented for several years by records of lessees' work. During 1902 and 1903 most of the ore milled came from the extension of the old shoot below the 200-foot level, but since 1903 most of the ore came from the southern shoot, as indicated on Figure 18. Apparently the total production was valued at about $600,000.

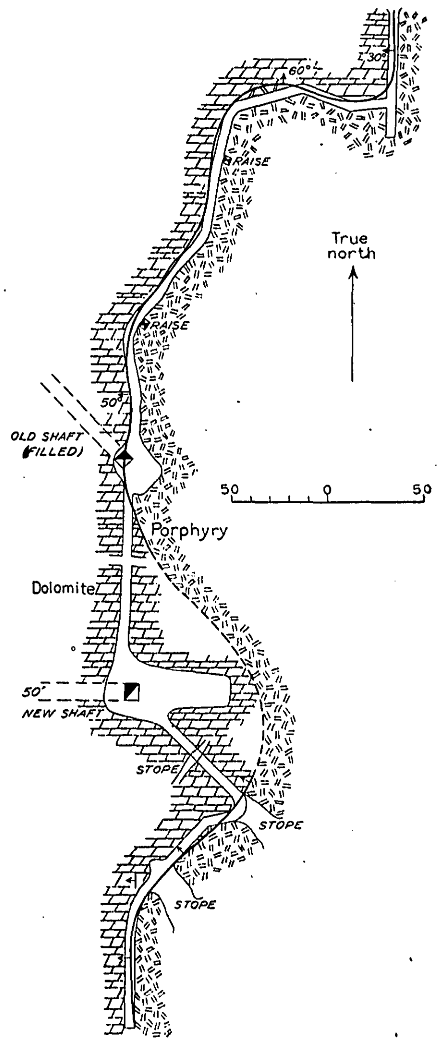


FIGURE 17.—Geologic map of tunnel 3, Keystone mine

It is estimated that the production of the Barefoot mine, now a part of the Keystone group, is about $50,000.

Production of Keystone mine, 1902–1920

Year	Crude ore milled (tons)	Gold (ounces)	Silver (ounces)	Total value
1902	2, 078	2, 137. 14		$44, 175
1903	2, 034	2, 583. 04	235	53, 618
1904	1, 929	2, 316. 10	146	53, 576
1905	640	725. 62	41	15, 024
1906	400	406. 35	149	8, 501
1907	350	364. 46	23	7, 533
1908	[a]2, 000	372. 73	198	7, 809
1909	[a]4, 000	[b]490		[b]10, 000
1911	(?)	[b]200		[b] 4,090
1919	[a]925	161	24	3, 354
1920	[a]475	141	23	2, 946

[a] Old tailing. [b] Approximate.

Local geology.—In this region the dark dolomite beds of the Goodsprings formation form a broad anticline, the highest part of which lies in the small amphitheater west of the Keystone mine. From this area the beds dip southward only 5° to 10° near by but attain 50° on the high ridge south of the mine. Half a mile west of the mine the beds form a broad arc, open eastward, and dip 10° to 35° W. and SW. On the northeast the anticline is abruptly cut off by the Keystone thrust, along which the dolomites, 2,500 feet below the top of the Goodsprings formation, rest against Pennsylvanian limestones, 1,000 feet or more above the base of the Bird Spring formation. The thrust, well shown by outcrops, trends N. 45° W. and dips about 45° SW.

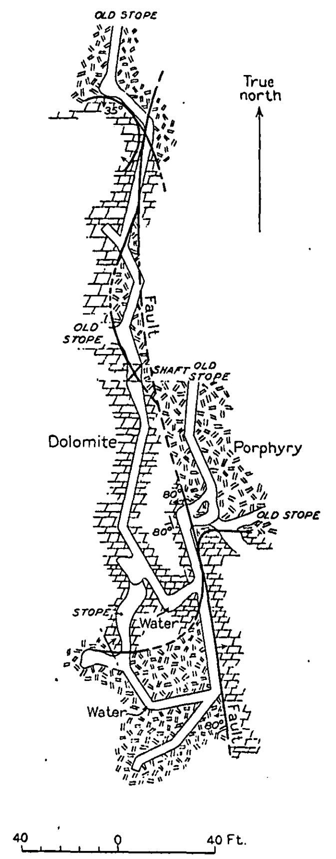


FIGURE 18.—Geologic map of 100-foot level, Keystone mine

Near the Keystone mine there are at least three intrusive masses of granite porphyry. The largest and most complex in form is that explored by the mine. It appears to abut on the north against the Keystone thrust and to extend southward as a branching dike 200 to 400 feet wide. In a number of places it cuts across the surrounding dolomite beds. Both contacts, as well as the dike itself, have been explored by many tunnels and shallow shafts. Another mass south of the Keystone mine, locally explored by the Barefoot and Golden Chariot mines, is clearly a sill several hundred feet thick, but it may connect with the Keystone dike in depth. Two thousand feet east of the Keystone another dike has been explored by prospects. It is scarcely 100 feet thick and trends southeast, parallel to the Keystone thrust, but appears to dip more steeply locally. Another smaller dike of irregular form lies 3,500 feet west of the Keystone mine, just east of the Chaquita mine; it may be a faulted portion of the west end of the Keystone dike. In several places, both in the Keystone mine and elsewhere, there are angular blocks of dolomite, as much as 3 feet in diameter, wholly inclosed in the porphyry. None of these blocks show the common evidence of contact metamorphism.

It appears to be characteristic of these dikes, as of most of the others in the district, that they produce no visible alteration in the adjacent and near-by carbonate rocks, either in the form of bleaching or by the development of new minerals. Wherever the porphyry is explored by prospects or mines the texture and mineral content appear to be the same, but locally it shows an advanced state of alteration. In most places, although the rock may break into angular blocks, these largely disintegrate to rounded masses or fine débris after brief exposure on the surface. In the Keystone mine these blocks are bounded by joints, but they show sheared surfaces. Masses near the contact with dolomite are generally most decomposed, and the feldspars are replaced by a reddish soaplike mineral, possibly halloysite. Old records report that the porphyry was locally impregnated with pyrite, probably like the Red Cloud dike, but this was not noted, although a new shaft sunk in 1916 near the north edge of the Keystone dump struck veins of pyrite and barite in the porphyry.

No faults that are conspicuous on the surface were noted near the Keystone, but there are many small faults underground. Some of these are undoubtedly postintrusive and premineral, but others are probably postmineral.

The deposit.—The Keystone mine explored several shoots of gold ore, of which the two most productive lay along the contact of the porphyry dike and the inclosing dolomite. In several places gold-bearing material was mined from veins wholly in the porphyry; in other places from veins wholly in the dolomite; and in still others from veins in faults that disturb both rocks.

The porphyry dike trends nearly north and dips 30° W. It is broken by faults of several varieties, however. and in some places it is not clear whether the irregularities of form are original or are due to faulting. The accessible workings above the 300-foot level largely explore shoots on the upper contact of the dike with the dolomite (fig. 17), but from the 300-foot level downward most of the work is on the lower contact of the dike. As a result of the necessarily brief examination made by the writer, the impression was obtained that some of the shoots on the upper contact, worked above the 300-foot level, have not been explored below that level. Most of the stopes range from 2 to 3 feet wide, but wider stopes are not uncommon, and some as much as 8 feet wide are reported.

A vein wholly in dolomite lies 50 feet south of the new shaft on the No. 3 tunnel level and has been stoped over a width of 2 to 3 feet for a length of 20 feet. On the 300-foot level south of the shaft, ore has been stoped over an area 20 by 30 feet which is limited by a conspicuous footwall that trends N. 20° W. and dips 25° NE. This wall appears to be a fault that separates porphyry above from dolomite below, and the stoped material was wholly porphyry. In its attitude and structural relations it is unlike most other stopes in the mine. On the 300-foot level north ore was stoped from the lower contact of the porphyry, and it was terminated southward by a fault that trends northwest and dips northeast.

An interesting structural feature is found on the 100-foot level, where the relations indicate that faults of the thrust group which probably carried some ore have been formed after the intrusion of the porphyry. (See fig. 18.) South of the shaft the exposures indicate clearly that the porphyry dike is cut obliquely and dragged along a fault that trends northward, the east side moving north and probably upward with respect to the west side. Although the exposures on the north side of the shaft are good, the relations might be explained in several ways but are not inconsistent with the explanation offered.

At points in the shaft 20 and 25 feet above the 540-foot level there are two faults. The first trends N. 10° W., dips 50° NE., and cuts off a 2-foot sill of porphyry; the second trends N. 20° W., dips 35° NE., and drops dolomite above against dolomite below. To judge by their attitude and relations they may belong to the late normal group and be postmineral; they are assuredly postintrusive.

The principal evidence of mineralization in the stoped areas is abundant limonite, both as cubes, which indicate its derivation from pyrite, and impregnating decomposed porphyry. Manganese oxide, generally wad, is present at many places. In some places dark chert forms thin veins on the limiting surfaces of porphyry, as well as in the dolomite near by, but it is not abundant, and the common varieties of vein quartz were not observed at any place. Old records indicate that here and there in the upper levels lenses of pulverulent quartz were found inclosed in shells of limonite and copper carbonates, such as are characteristic of the ore shoots at the Boss mine (fig. 24), but none were seen by the writer. Chrysocolla was noted on the 300-foot level north, where ore was stoped from the lower contact of the dike.

According to old records, as well as the testimony of miners interviewed by the writer, the gold in the Keystone mine was characteristically associated with a greenish talcose mineral, probably one of the clays. This mineral and clay heavily stained with limonite were the guides in stoping, although some high assays were obtained from dark chert. Specimens of the clay allowed to disintegrate in the mouth yielded either a mass of wire gold or irregular grains and threads of gold. The composition of the bars of bullion recovered from the amalgam in the mills indicates that the range in fineness of the gold was rather constant at 0.920 to 0.930, and that it was therefore uncommonly pure. The bullion from the cyanide plant was not so pure, the fineness ranging from 0.820 to 0.900 if base metal is ignored.

The average grade of the ore is shown in the table of monthly records of mill operation. During the period from May, 1902, to October, 1904, the value of the gold in the crude ore charged to the mill ranged from $22 to $36 a ton.

The record of assays from the mine as far down as the 540-foot level, kept by the superintendent, Carl Anderson, shows many in which the value of the gold ranged from $30 to $100 a ton, where the width of sampling ranged from 2 to 4 feet. Some samples across 6 to 12 inches of vein showed from $100 to $300 a ton. According to Anderson's reports, the ore shoots were most productive where the vein was flatter than the average, and he emphasizes the fact that the productive area between the 100 and 200 foot levels was found where the dip was only 18° instead of 40° to 50°, as above and below it.

A question of considerable interest, with respect to the genesis of the deposit and its future exploitation, is concerned with the quantity of gold in the porphyry dike. Through the early work it was recognized that the rock contained appreciable quantities of gold, and it is locally claimed that most, if not all, of the dikes of the region contain more than the traces of gold common in such rocks. Numerous assays by the superintendent from 1902 to 1904 indicated the value of the gold in decomposed porphyry a few feet from the richer vein stuff to be $1 to $4 a ton. Later mill tests were made on three lots of 53 (from the 740-foot level), 55, and 75 tons. The bullion recovery on these tests was valued at $5.09, $4.95, and $4 a ton, respectively. In 1914 the dumps were extensively sampled by a prospective purchaser. Thirty-two 2-ton samples were collected, broken, and quartered for assay. The average of the 32 samples was 0.073 ounce of gold to the ton, or if one sample containing 0.41 ounce to the ton is omitted, the average of the remaining 31 samples was 0.06 ounce.

These results are too discordant to permit an assured conclusion concerning the probable average content of gold in the dike but leave no doubt that it is higher than the average in such rocks.

CLEMENTINA MINE

The Clementina mine (No. 23, pl. 30) lies about 3,000 feet southeast of the Keystone. The claim was one of several located early in 1892, when it became apparent that there was high-grade gold ore in the Keystone mine. The workings include a shaft 75 feet deep and a tunnel 110 feet long, with a shaft 75 feet deep near the entrance. In this area the dark dolomites about 2,000 feet below the top of the Goodsprings formation strike northwest and dip 5° to 10° SW. The principal source of the gold produced is a shear zone that trends N. 50° W. and dips steeply southwest, along which there were lenses and irregular masses of gold-bearing ferruginous chert, slightly stained with malachite and chrysocolla. This deposit is credited with having shipped 13 tons of material to the smelter which yielded a total of 10 ounces of gold, 8 ounces of silver, and 522 pounds of copper.

GOLDEN CHARIOT CLAIM

The Golden Chariot claim (No. 24, pl. 30) lies half a mile west of the Keystone mine. The principal exploration is a tunnel that trends generally southeast for about 200 feet. The workings explore several iron-stained shear zones that trend northwest and dip northeast and are wholly in a sill of granite porphyry. There are two small stopes above the tunnel level, one of which extends to the surface. Several hundred tons of material from the stopes has been milled at the Keystone mill, and the value of the gold recovered is variously reported at $20 to $40 a ton. In 1916 Harvey Hardy, of Goodsprings, shipped about 13 tons of copper-bearing ore from this claim that yielded the following returns from the smelter: Gold, 0.105 ounce to the ton; silver, 0.45 ounce to the ton; copper, 14.65 per cent; iron, 18 per cent; insoluble, 33.80 per cent. According to Hardy, assays of similar material have shown the presence of platinum, in one sample as much as half an ounce to the ton.

SILVER MINES AND PROSPECTS

LAVINA MINE

There are a number of shallow shafts and tunnels near the head of the wash 2½ miles west of Goodsprings, but most of the work has been done on the Lavina claim (No. 16, pl. 30). Although no ore has been shipped, the explorations are interesting because an uncommon group of minerals was struck and the workings reveal the extent and relations of one of the granite porphyry intrusions.

The claim was located in 1903, and the workings accessible at present, including a tunnel and an inclined shaft, were driven before 1906. About that time a new shaft was sunk vertically to a depth of 130 feet and then at 60° to 175 feet, and several drifts were run, but none of this later work is accessible. No work has been done since 1907. The western or upper limit of the dike is in contact with crushed Devonian limestone, which marks the base of the block of upper Paleozoic beds that is thrust upon red shale of the Moenkopi formation. North of the Lavina shaft the dike ends squarely against these red shales, and the eastern lower surface of the dike rests on the same beds, the surface of contact dipping steeply west. None of the rocks in contact with this part of the dike show any noticeable alteration. On the other hand, the V-shaped block of shaly limestone of the Moenkopi formation that lies between forks of the dike farther south is completely altered to a mixture of garnet and quartz (p. 56). Apparently the dike is intruded along the Contact thrust but has forced tongues into the underlying block. By contrast the Keystone dike abuts against the Keystone thrust below but forms irregular tongues upward into the overlying block.

The workings on the Lavina claim explored several narrow sulphide-bearing quartz veins in the porphyry intrusives. In places bunches of sulphides lay along shear zones. The sulphide minerals noted include pyrite, arsenical gray copper (tennantite?) and ruby silver (proustite?). According to reports made by engineers in 1907, samples of the sulphide-bearing quartz veins showed as much as 0.40 ounce of gold and 12 ounces of silver to the ton and 3 per cent of copper, but the porphyry, which showed only disseminated pyrite, contained less than 0.04 ounce of gold and 1 ounce of silver to the ton and appears to be of lower grade than similar material from the Keystone and Red Cloud dikes. Sulphide minerals occur within 50 feet of the surface, but locally iron stains persist to the lowest accessible level. Water stands in a winze below the 90-foot level about 140 feet vertically below the surface.

CRYSTAL PASS PROSPECTS

South of Crystal Pass, which is 2½ miles south of Goodsprings, a dike of granite porphyry crops out for 750 feet. On weathering it yields locally myriads of nearly perfect crystals of orthoclase half an inch to 2 inches long. Other dikes crop out farther southeast and south. In the vicinity of these dikes in the SW. ¼ sec. 1, T. 25 S., R. 58 E., there are a number of prospects, some of which explore veins carrying silver and others explore for gold or lead.

The greatest amount of exploration has been done where a 60-foot inclined shaft follows a poorly defined lens composed of magnetite, hematite, and siderite down the dip of the inclosing dolomites. A sill of granite porphyry underlies this lens and is in turn underlain by another similar lens. It is reported that these lenses were explored for their content of gold, but the quantity could not be determined.

At another prospect in the E. ½ sec. 2, T. 25 S., R. 58 E., which explores the contact of a dike of granite, the silicified dolomite breccia contains sporadic crystals of anglesite, cerargyrite, and a yellow silver haloid, probably iodyrite.

COPPER MINES

NINETY-NINE MINE

The Ninety-nine Mining Co. owns a group of 14 claims on the northeast side of the high ridge that extends eastward from Potosi Mountain. (See pl. 31, *B*.) A. J. Robbins first located the deposit in 1894 but abandoned it; the present Ninety-nine claim (No. 2, pl. 30), was located by C. M. Over in 1899, and most of the remaining claims in 1907. It is reported that the property was sold to J. B. Jenson for $30,000 in 1904, and he incorporated the present company. It has not been operated since 1919.

The following table of production, taken from the records of the Geological Survey, is very likely incomplete. Probably the total output exceeds 2,000 tons.

Production of Ninety-nine mine, 1903–1918

Year	Crude ore (tons)	Gold (ounces)	Silver (ounces)	Copper (pounds)	Lead (pounds)
1903	18		119	11, 800	
1906	111		305	23, 300	
1907	48		467	9, 890	
1908	112	1. 60	351	36, 212	
1910	199		851	80, 757	
1911	386	2. 79	2, 104	131, 215	
1912	251	. 41	717	72, 063	
1913	51		94	20, 258	
1915	146		341	38, 092	
1916	155	11. 51	155	46, 500	
1917	111	. 74	366	39, 042	
1918	51		131		16, 143

The workings include a tunnel and drifts, in all about 280 feet, which connect with a shaft reported to be 400 feet deep, from which there are four levels. These workings explore a breccia zone that cuts the Bullion dolomite. In the tunnel (fig. 19) the Arrowhead shaly limestone trends northwest and dips northeast. The footwall material is probably Bullion dolomite. The extensive Ninety-nine fault lies a short distance northeast of the shaft.

The property was idle in January, 1922, and only the tunnel level could be examined. The following statement was prepared by Hill [42] after his inspection in 1912:

> The beds are cut by a fault zone which strikes N. 65° to 70° W. It dips 87° N. to a depth of 150 feet but flattens to 65° at the 200-foot level and to 45° at the 250-foot level. At the 300-foot level the dip increases to 75° and striae on the footwall pitch 15° E. This fault zone is filled with 2 to 4 feet of crushed limestone, in places partly cemented by calcite. The fragments are all under 1 inch in size, and the great majority less than half an inch. Above the 250-foot level this filling is more or less iron-stained and contains pockets and

[42] Hill, J. M., The Yellow Pine mining district, Clark County, Nev.: U. S. Geol. Survey Bull. 540, p. 45, 1913.

stringers of copper carbonates and oxide constituting the ore. On the 250-foot level, from 30 to 70 feet east of the shaft, there is an open stope 4 to 6 feet wide which extends to the 200-foot level and from which a considerable body of ore was taken. In some of this ore there are small remnants of chalcocite, now largely altered to cuprite and malachite. At the 200-foot level the limestone for 8 feet north of the fault contains some limonite, which fades out into unaltered limestone at a distance of 10 feet. At one place near the east end of this level there is a flat stope where the ore is apparently conformable to the bedding of the limestone. At the 400-foot level the fault zone is still strong but shows no mineralization.

All the ore from this mine was taken from the surface to a depth of 260 feet, where it played out, from stopes running not over 80 feet east of the shaft. The ore is sorted at the mine, and of 25 cars shipped in the fall of 1912 none ran below 20 per cent of copper, and most of it averaged 24 to 25 per cent.

According to A. Munzebrook, who was superintendent in 1907, the ore bodies were lenses of ferruginous chert with associated malachite and chrysocolla, which lay in the dolomite breccia parallel to the strike of the limiting walls but were flatter in dip. The largest lens

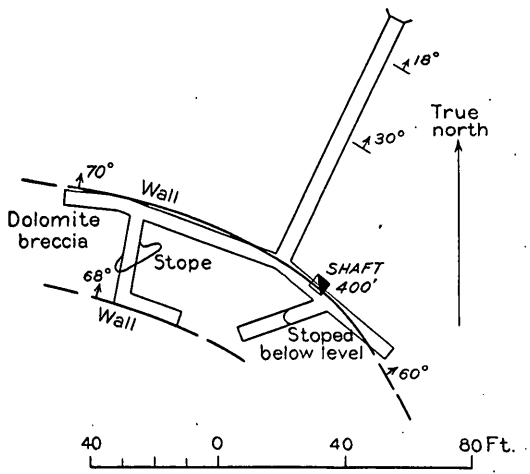


FIGURE 19.—Geologic map of tunnel level, Ninety-nine mine

had a stope length of 50 feet, a pitch length of 40 feet, and a thickness of 5 feet. The ore consisted largely of oxidized copper minerals to the greatest depths penetrated, but here and there pockets that yielded as much as 3 tons of high-grade chalcocite were found. No cobalt minerals were recognized on the claims by the writer.

About 1,000 feet east of the Ninety-nine shaft a 10-foot pit is sunk along a bedding-plane fracture zone in the upper Monte Cristo dolomitized limestones. It trends N. 20° W. and dips 10° E., and along it there are crusts of cuprodescloizite and manganese oxides. About 500 pounds of material that would contain 8 per cent of vanadic oxide was sorted from the rock removed from this pit.

DOUBLEUP MINE

The Doubleup mine workings (No. 3, pl. 30) are situated on both sides of the high ridge in the SE. ¼ sec. 17 and the SW. ¼ sec. 16, T. 23 S., R. 58 E. The property was located about 1886 by Joseph Yount, but most of the present work was done by the Copper Peak Mining Co., of Salt Lake City, between 1914 and 1919. The workings include one tunnel 150 feet long on the northeast side of the ridge, from which most of the ore has been shipped, and five tunnels on the southwest side of the ridge, which aggregate about 700 feet, but the longest, next to the lowest, contains 310 feet of drifts and crosscuts. The five tunnels are distributed through a vertical distance of 250 feet.

According to local report, the gross value of the ore shipped from the mine is about $40,000, which would indicate about 1,000 tons of 20 to 30 per cent copper ore. The extent of the stope indicates that this estimate is high; probably the tonnage lies between 500 and 750 tons. The latest shipment (1918), of 10 tons, contained 18.2 per cent of copper, 11.5 per cent of iron, 5.3 per cent of insoluble matter, and 0.95 ounce of silver to the ton.

The workings of the Doubleup mine are in dolomitized Yellowpine limestone at the top of the Monte Cristo formation, which here trends N. 57° W. and dips 30° SW. Specimens from the underground exposures are coarsely crystalline and so hard that they resemble a highly altered rock. The examination of thin sections and polished surfaces shows that they contain veinlets and poorly defined areas of quartz, which in part replaces the dolomite and in part fills drusy cavities in the dolomite. By contrast, the beds several hundred feet east and west of the deposit are composed of normal bluish-gray limestone. The ravine west of the mine workings coincides with a fault that trends N. 30° E. and dips 30° NW., and along it the west side has dropped 100 feet. It is well shown near the Doubleup camp.

The five tunnels on the southwest side of the ridge explore a broad fracture zone that trends N. 70° to 80° E. and dips 30° to 40° SE. and therefore is unlike the fault a short distance west. The tunnel on the northeast side of the ridge probably explores the same zone. In the fracture zone there are lenses of dark fine-grained quartz much like that characteristic of the Boss deposit, which contains needles of octahedrite. The quartz is generally compact and free from stains of iron and copper, but on the border it merges with a porous limonitic zone, outside of which there are layers of copper carbonate minerals. Here and there the near-by dolomite is stained green. The largest bodies are 20 to 35 feet long, 10 to 20 feet wide, and 4 to 5 feet thick, and although they are entirely removed, only the outer shell of copper minerals was shipped. In contrast with the conditions at many other copper deposits in the district, good walls are uncommon in this zone and the lenses are not parallel but disposed in many different positions.

No cobalt minerals were recognized in material from any of the workings.

Production of Doubleup mine, 1900–1918

Year	Crude ore (tons)	Gold (ounces)	Silver (ounces)	Copper (pounds)	Lead (pounds)	Zinc (pounds)
1900	28					
1915	27	-------	-------	--------	-------	16, 065
1916	236	35. 40	590	59, 000	-------	-------
1917	17	-------	13	4, 632	-------	-------
1918	73	-------	38	11, 485	3, 118	18, 657

BLUE JAY MINE

The principal workings on the Blue Jay claim (No. 7, pl. 30), which lies 4 miles northwest of Goodsprings, are two inclined shafts that attain a maximum depth of 35 feet. In this area the country rock, Bullion dolomite, is much crushed, doubtless by the Contact overthrust, which lies not far below the surface, probably about 200 feet. The shafts explored two lenses of copper-bearing ore, and although little could be seen in place underground there was on the dump several tons of material that contained copper and cobalt minerals. Apparently the copper, as well as the cobalt minerals, lay along fractures that trend N. 30° W. and dip 55° NE., roughly parallel to the bedding.

The deposit is interesting because it has yielded unusual mineral specimens. At one place some drusy cavities yielded excellent crystals of malachite, pseudomorphous after azurite, as much as an inch long. In 1921 cobalt minerals were recognized on the dump, and A. Woodard, of Las Vegas, mined the cobalt-bearing material recorded below. In the material on the dump heterogenite was common, in part replacing the dolomite wall rock and in part forming slender stalactites, on some of which quartz has been deposited. Some specimens show a pale-pink dolomite that cements gray dolomite. Blowpipe tests show that the pink dolomite contains an appreciable trace of cobalt.

Production of Blue Jay mine, 1912–1926

Year	Crude ore (tons)	Gold (ounce)	Silver (ounces)	Copper (pounds)	Lead (pounds)	Zinc (pounds)
1912	4	-------	16	1, 245	-------	-------
1916	9	-------	3	1, 140	-------	2, 550
1917	12	0. 97	78	600	6, 686	-------
1918	3	-------	5	290	-------	-------
1926	3	-------	23	--------	3, 087	-------

In 1922 the dump yielded 1,223 pounds of material that contained 6.37 per cent of cobalt.

SNOWSTORM MINE

The Snowstorm group of claims (No. 8, pl. 30) covers the south end of a prominent ridge 4½ miles northwest of the town. The principal workings include a shaft 100 feet deep on the crest of the ridge and smaller shafts and open cuts within an area 500 feet in diameter. All these explorations are in the Bullion dolomite. The most productive exploration is an open cut on the east side of the ridge, which follows a breccia zone parallel to the bedding. From this open cut 76 tons of low-grade ore was shipped. According to Mr. Feaster, the owner, the material was similar to that exposed in the open cut—dolomite breccia cemented by malachite. The total output from the claims is 93 tons of copper ore, most of which contained from 5 to 12 per cent of copper; one lot of 6 tons contained 18 per cent of copper.

At the south end of the ridge a shallow pit has exposed a vein of clear gray barite 12 to 18 inches thick, which lies parallel to the bedding of the inclosing rock.

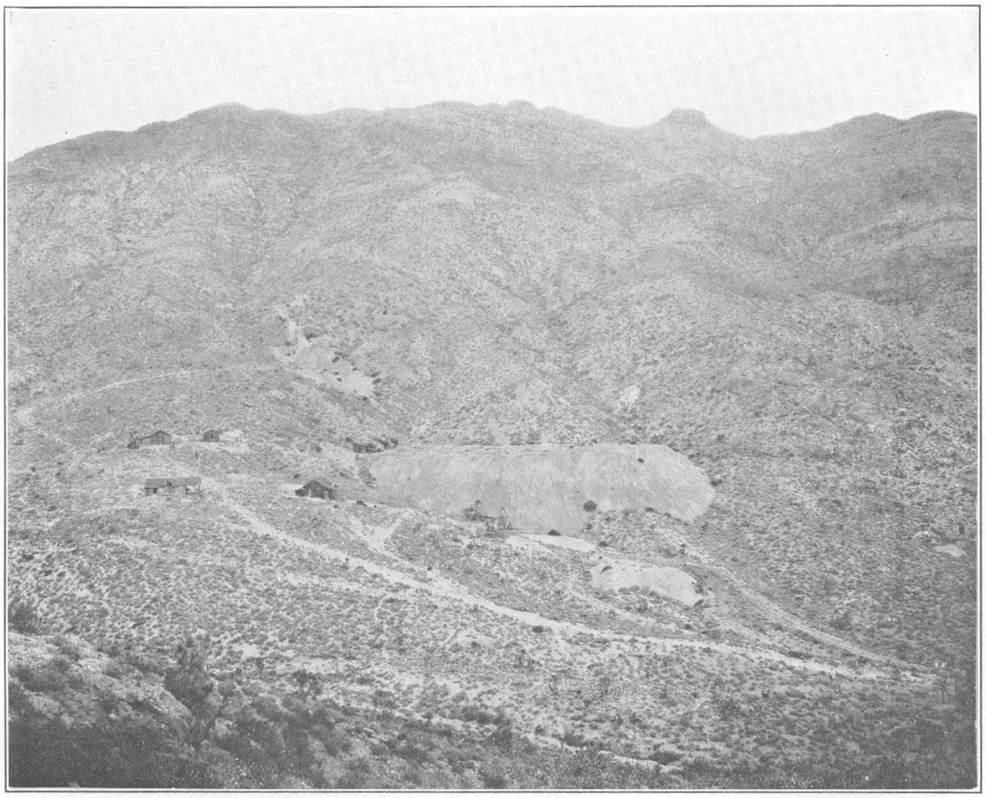
GREEN COPPER MINE

The Green Copper claim (No. 13, pl. 30) lies in the NE. ¼ sec. 20, T. 24 S., R. 58 E., south of the Yellow Pine Mining Co.'s railway. The principal exploration is a tunnel about 125 feet long that explores a shear zone in the upper part of the dolomitized Anchor limestone. There is also a winze inclined 52° and 35 feet deep to a short drift. The shear zone is probably associated with the northeast extension of the Alice fault. According to Allen Campbell, son of the original owner, the mine has yielded two carloads or about 75 tons of copper ore that probably contained 15 to 20 per cent of copper.

There is little copper-bearing material left in the mine, but the source of the production was undoubtedly two small stopes above the level and an open cut at the entrance of the tunnel. These stopes underlie well-defined walls that trend generally eastward and dip south. Apparently copper carbonates and silicates were associated with lenses of iron-stained chert which are conspicuous on the surface. Several lenses of chert were apparently associated with the walls, but others that are unmined have no close relation to the walls. The chert is sporadic and does not persist downward to the lower level. Here, as at the Oro Amigo and Kirby mines, the walls are neither regular nor persistent. They appear to be the minor fractures that limit lenses in a wide shear zone.

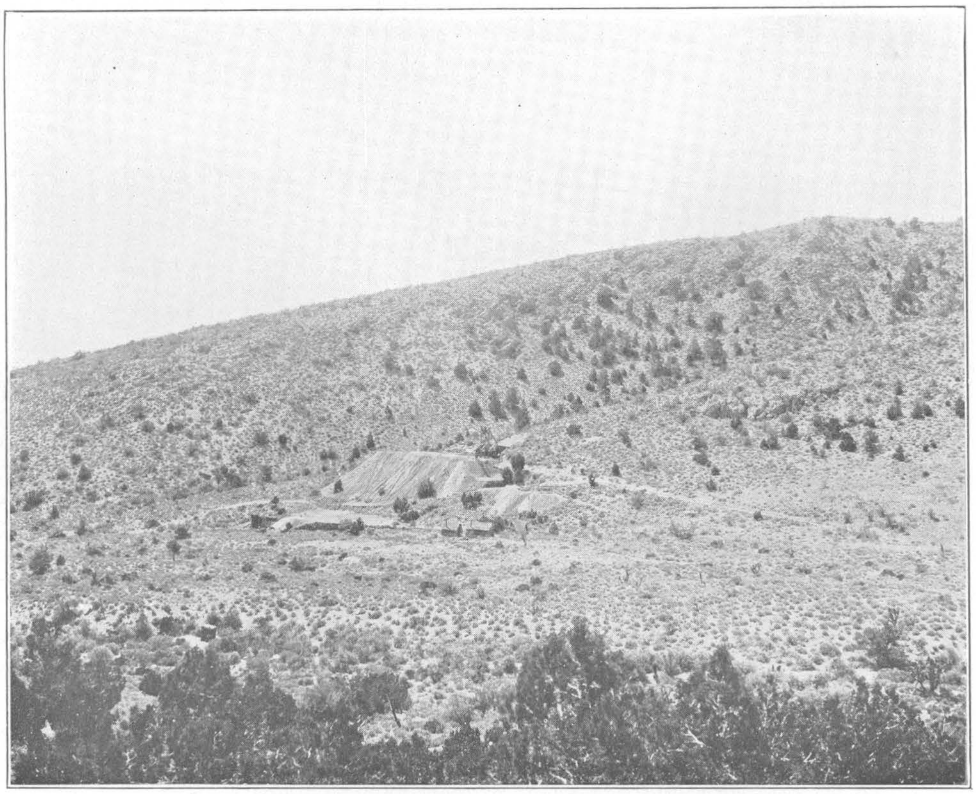
COPPER GLANCE MINE

The Copper Glance claim adjoins the Green Copper on the west. The principal exploration is a trench that extends northward and intersects a stope along a vertical shear zone trending north of east. The stope extends along the zone for 45 feet and to a maximum depth of 75 feet below the outcrop; the width ranges from 1 to 6 feet. The ends and sides of the stope show many veinlets of chrysocolla and malachite, and the product of the mine was probably in large part such



A. KEYSTONE MINE, NW. ¼ SEC. 30, T. 24 S., R. 58 E.

The slopes back of the mine are made up of thin-bedded dolomite of the Goodsprings formation.



B. NINETY-NINE MINE, W. ½ SEC. 15, T. 23 S., R. 58 E.

The ridge on the left is made up of limestones near the base of the Bird Spring formation which dip eastward (left). The Ninety-nine fault passes through the ravine in the center.

material sorted to contain more than 15 per cent of copper. The dolomite wall rock contains sporadic round grains of cobalt oxide. The lenses of ferruginous chert that are characteristic of most of the copper deposits are not present here.

The record of production has not been obtained; probably it did not exceed 50 tons of low-grade copper ore.

COSMOPOLITAN CLAIM

The Cosmopolitan claim (No. 18, pl. 30) is on the south side of Lavina Wash, in the SE. ¼ sec. 29, T. 24 S., R. 58 E. The principal work is a vertical shaft about 100 feet deep that was sunk along a shear zone that trends N. 15° E. and dips 85° SE. It is now inaccessible, but from what may be seen from the surface and on the dump, the shear zone was silicified and contained some copper minerals. Within 300 feet to the southeast there are four small shafts and tunnels, from which small quantities of copper-bearing material were mined. The zone explored by the deepest shaft appears to be the fault along which the eastern block of the Keystone thrust is dropped several hundred feet

BELLE OR MAYBELLE CLAIM

The Belle claim (No. 19, pl. 30; locally known as the Maybelle) lies on the divide between Lavina Wash and a ravine that drains southwest to Mesquite Valley, in the south-central part of sec. 29, T. 24 S., R. 58 E. The workings include a shaft more than 100 feet deep, now inaccessible, and several tunnels and shallower shafts. These workings explore a silicified shear zone that strikes N. 60° W. and dips 80° NW.; the country rock is the Bird Spring formation. The dump material shows considerable manganese oxide and small quantities of chrysocolla and a yellow vanadate.

The local rock exposures indicate that the shear zone lies in a block of dolomitized Bird Spring limestone that overlies the Contact thrust and is limited on the south by the Keystone thrust and on the west and east by later normal faults. If extended 100 feet farther, the deepest shaft would pass into beds under the Contact thrust, probably the lower part of the Moenkopi formation.

Although copper-bearing material has probably been shipped, no record of the quantity has been obtained.

ORO AMIGO MINE

The Oro Amigo-Platino Mining Co. owns a group of four claims (No. 20, pl. 30) that cover some low hills south of the mouth of Keystone Wash, in the E. ½ sec. 23, T. 24 S., R. 57 E. Three claims were located in June, 1905, and the fourth in 1917. There was some exploration from an upper tunnel in the early days, but most of the work, including the lower tunnel, 600 feet long, was done after the incorporation of the company in 1916. The only production is a single car of copper ore, shipped in 1917. The shipment weighed 18 tons and contained copper, 17.17 per cent; iron, 12.20 per cent; insoluble matter, 28.50 per cent; gold, 0.15 ounce to the ton; and silver, 0.5 ounce to the ton. According to Knopf,[43] H. K. Riddall made assays on material from this deposit that contained as much as 0.51 ounce of gold and 0.11 ounce of platinum to the ton.

The workings explore a zone of fractures in the dolomitized Valentine limestone, which here trends generally northeast, although most of the fractures underground trend N. 70° W. and dip 40° SW. The

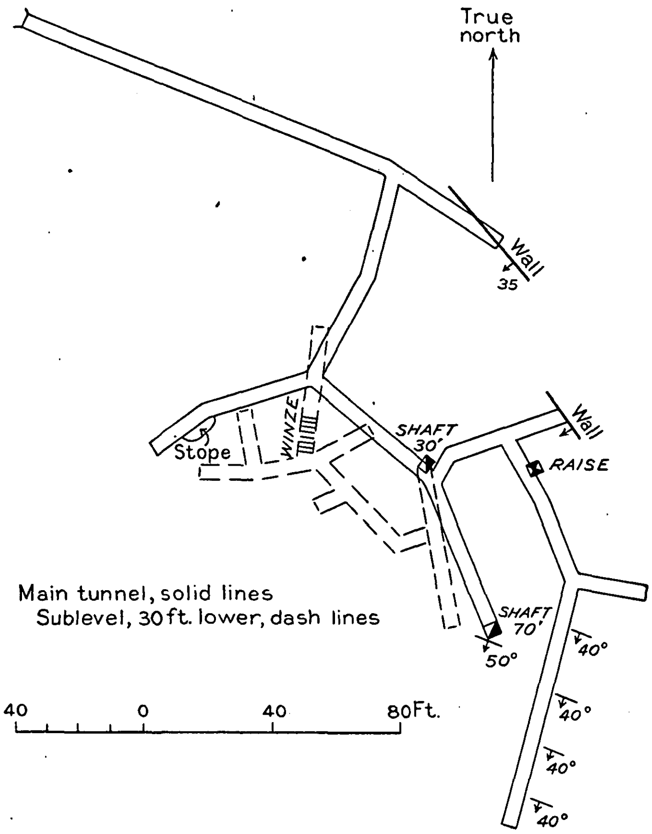


FIGURE 20.—Sketch map of main tunnel, Oro Amigo mine

fracture zone is most conspicuous in the upper tunnel, where it trends nearly east and is made up of a group of minor nonpersistent walls of divergent strike and dip. The ore that was shipped represented copper-bearing material that occurred on the borders of lenses of ferruginous chert. These lenses generally overlie the minor fractures. Although the main tunnel (fig. 20) explores the same zone 50 feet lower, the fractures are much less conspicuous and contain less chert and only sporadic traces of copper. One stope is 10 by 10 feet and 4 feet wide. On the sublevel, 30 feet lower than the main tunnel, there are only traces of copper.

The ore minerals include the oxidized copper minerals—malachite, azurite, copper pitch, and chryso-

[43] Knopf, Adolph, op. cit., p. 12.

colla. Traces of the black oxide of cobalt are present in much of the material adjacent to the lenses of chert, and some specimens show the pinkish cobalt-bearing dolomite. Here, as at the Copperside mine, the copper minerals form a thin layer around the borders of the lenses of ferruginous chert. In the zone explored from the surface to a maximum depth of 100 feet there is an impressive decrease in the quantity of chert as well as copper minerals.

HIGHLINE MINE

The property of the Red Streak Mining Co. includes two claims—the Red Streak and Highline (No. 25,

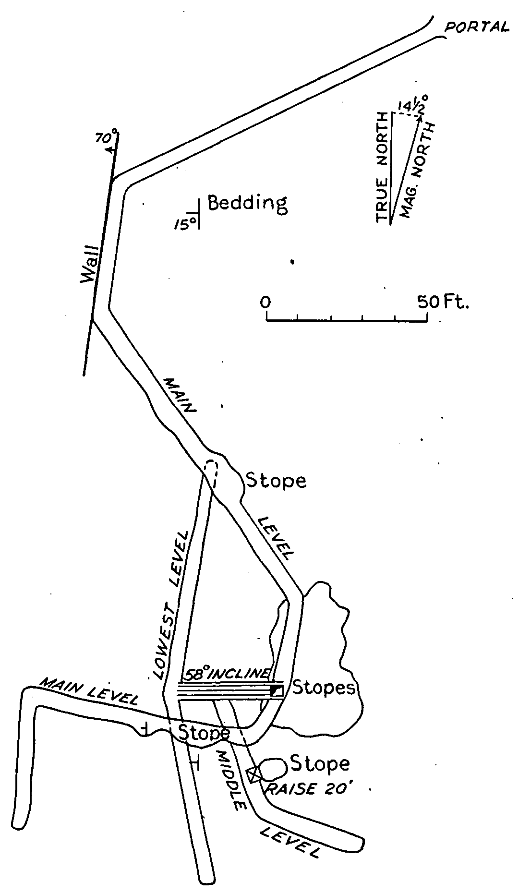


FIGURE 21.—Sketch map of Highline mine

pl. 30)—that lie high on the north side of the prominent ridge in the E. ½ sec. 26, T. 24 S., R. 57 E. The Copperside adjoins the east side of the Red Streak claim.

On the Red Streak claim there are two tunnels whose total length is less than 300 feet. The workings that have been the source of all the shipments lie 1,000 feet to the west, on the Highline claim, and amount to about 750 linear feet. (See fig. 21.) These tunnels explore beds that lie about 200 feet above the base of the Sultan limestone. The bedding trends nearly north and dips 15° W.

The principal stope extends along the level for 50 feet and from a point 35 feet above the level to a point 20 feet below. It explores a shear zone 3 to 5 feet wide that trends north, parallel to the bedding, but dips 60° W. and therefore cuts across the bedding of the dolomite in depth. The zone is explored to a lower level by a shaft 65 feet deep at an inclination of 58°, but there is no stoping at this depth.

The total production from these claims, 477 tons of copper ore, had a gross value at the smelter of $54,687 and a net value after deducting freight and charges of $50,337. The average copper content, about 35 per cent, is the highest in the district. The silver content ranged from 0.35 to 1.1 ounces to the ton and the gold from 0.04 to 0.085 ounce to the ton. Insoluble material averaged about 11 per cent and the iron content about 12 per cent. During 1921 Frank Williams mined and sorted from the dump two lots of cobalt ore that showed the following returns: Lot 1, weight 4,820 pounds, cobalt 6.35 per cent; lot 2, weight 1,200 pounds, cobalt 12.45 per cent.

The ore that can now be seen underground and on the dump is almost completely oxidized, and positive conclusions concerning the original minerals and their associations can not be stated. A little chalcocite can be found here and there, but it is the only sulphide observed. The most abundant material is a mixture of chrysocolla, tenorite, malachite, and cobalt oxide in a gangue of ferruginous chalcedony. Fractures are commonly coated with chrysocolla, upon which crystals of dioptase are distributed. The dolomite in and near the shear zone locally contains black mottlings of cobalt oxide. Probably the original ore was dolomite breccia slightly silicified, with veins and lenses of chalcopyrite and a cobalt sulphide. The present workings indicate that the shoots are sporadically distributed in the shear zone. The tonnage shipped indicates that an unusually large part of the shoot contained copper ore of good grade.

Production of Highline mine, 1917–1920

Year	Crude ore (tons)	Gold (ounces)	Silver (ounces)	Copper (pounds)
1917	382	27.00	219	246,324
1918	61	15.14	43	30,629
1919	21	.84	23	8,120
1920	13	.80	8	5,538

COPPERSIDE MINE

The Copperside claim (No. 26, pl. 30) lies on the north side of a high ridge in the E. ½ sec. 26, T. 24 N., R. 57 E. It is owned by F. Renaux and O. F. Schwartz, of Goodsprings. The principal work is a tunnel about 250 feet long from which there are several shafts and winzes to a level 30 feet lower and about 100 feet long. (See fig. 22.) The total production is 621 tons of copper ore whose gross value at the smelter was about $55,000 and whose net value was about $46,000.

According to the smelting receipts, the copper content of the shipments ranged from 13.8 to 36.5 per cent, with the average about 24 per cent. Iron ranged from 7.7 to 16.5 per cent, insoluble matter from 4.3 to 19.4 per cent, gold from nothing to 0.18 ounce to the ton, and silver from 0.10 to 1.20 ounces to the ton.

The mine workings lie about 200 feet above the base of the Sultan limestone and the beds trend nearly due north and dip 15° W. Two distinct shoots of ore have been the source of the production, and both underlie well-defined hanging walls. The inner or western shoot underlies a well-defined wall that trends N. 20° E. and dips 40° W.; the outer or eastern shoot underlies a wall that trends N. 30° W. and dips 45° SW. The inner shoot has been stoped over an irregular area about 40 by 50 feet and to a maximum height of 15 feet. The outer shoot has been stoped over an

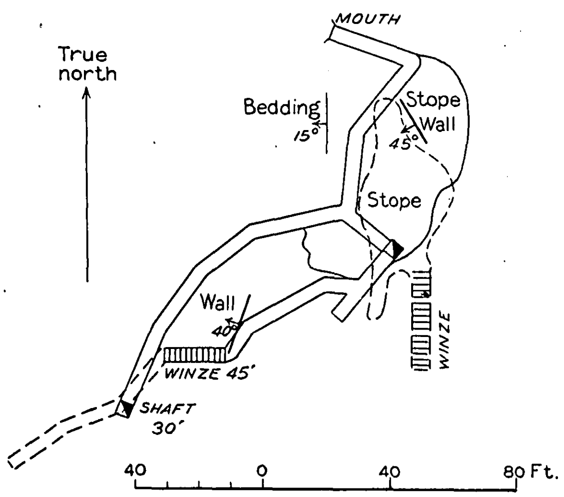


FIGURE 22.—Geologic map of Copperside mine

area 30 by 40 feet and to a height of 10 feet. In the shoots the ore formed lenses that lay generally parallel to the bedding—that is, flatter than the hanging walls. At present the lenses are made up largely of oxidized minerals, but some contain central masses of chalcopyrite, bornite, and chalcocite, in which the last two minerals have been derived from the first by weathering. One lens remaining in place is 10 to 15 feet wide, 1 to 3 feet thick, and of indefinite length. It contains a central core that is largely jarosite and brownish ferruginous chert. This core is surrounded by a border of limonite, and this in turn by an outer zone that contains copper carbonate and silicate minerals. It seems clear that in this locality jarosite is first formed as one of the oxidation products of chalcopyrite and that as weathering progresses the jarosite itself is decomposed to hydrous oxide of iron. The silica is largely chert, but crevices are coated with crystals of quartz, one of the latest minerals to form. Probably the silica is wholly supergene.

In this mine, as in the Azurite mine near by, the two shoots are not on the same fracture zone but on roughly parallel zones.

Production of Copperside mine, 1917–1920

Year	Crude ore (tons)	Gold (ounces)	Silver (ounces)	Copper (pounds)
1917	159		63	91, 140
1918	254	2. 54	142	125, 900
1919	158	. 03	4	66, 560
1920	50	. 17	21	20, 424

SWEEPSTAKE PROSPECT

The Sweepstake claim is near the center of sec. 25, T. 24 S., R. 57 E., on the north side of the divide between drainage going northwest toward the Oro Amigo mine and southwest toward the Mobile mine and Sandy. Although no shipments of ore have been made, the deposit is interesting because it presents unusual and interesting relations of silica and several sulphate minerals. A tunnel that extends southwest 30 feet and then southeast 20 feet explores two lenses of silicified limestone that are about 10 feet long and 2 feet wide. Smaller lenses are explored by trenches for a distance of 300 feet, and there is a conspicuous outcrop of brown ferruginous chert. The silicified material contains traces of several oxidized lead and copper minerals, but more interest is attached to the sulphate minerals—jarosite, plumbojarosite, and beaverite.

The waste material on the dumps presents a wide range of colors, from white through dull olive-green and yellow to brown and red. By close examination it is found that the white material consists of clean chert of minutely granular texture. The transition from white to yellow and olive-green is abrupt in some places and gradual elsewhere. Similarly, the red areas merge with the yellow in some places and abruptly in others. Such tests as have been made indicate that the dull olive-green areas are intimate mixtures of chert and jarosite that are not resolved into grains by the highest power of the microscope. The yellow areas are probably plumbic jarosite or plumbojarosite resulting from the addition of lead to the jarosite. In the midst of olive-green and yellow areas there are coarsely crystalline patches of quartz, in which occur a few crystals of the sulphate minerals. (See pl. 26.) The inference seems clear that silica and the sulphate minerals were first deposited in intimate mixture and that later they segregated as coarsely crystalline grains and crystals. The red material is hydrous oxide of iron derived from jarosite or plumbojarosite. All these materials are interpreted as the products of weathering.

IRONSIDE MINE

The Ironside group (No. 27, pl. 30) lies in the W. ½ sec. 26, T. 24 S., R. 57 E., in the low ridges north of Shenandoah Gulch. The Ironside claim was first located in 1892 but has been abandoned and relocated under a different name four times since. Most of the present workings were made during 1916 and 1917. According to local report no ore has been shipped from the property.

The workings explore a fracture zone near the base of the dolomitized Valentine limestone, which here trends north and is nearly vertical. The beds form the east side of a sharp anticline that ends southward against the Ironside fault. The fault is shown by a zone of crushed dolomite 100 feet or more broad, which trends N. 45° E. and dips 60° NW. Some of the fractures in the Ironside mine are parallel to the walls of the fault and evidently were formed at the same time.

The workings include a tunnel 110 feet long, at the end of which there is an inclined shaft. There are three levels, 50, 80, and 135 feet below the tunnel, but none is more than 60 feet long. At the head of the shaft there is an irregular raise to the surface. These explorations follow a shear zone at least 5 feet wide that trends generally N. 40° E. and dips 60° NW. Within this zone there are numerous local walls that strike N. 20° to 60° E. and dip 40° to 70° NW. These walls limit lenses of cellular ferruginous chert as much as 5 feet thick. On the outer borders of these there are layers of malachite and azurite from 1 to 3 inches thick that probably constituted the material sought. Among the several similar deposits in this region the chert is much less abundant on the lower levels than on that of the tunnel. Although a close search was made, no jarosite or cobalt oxide was found.

BOSS MINE

History.—The history of the Boss mine (No. 28, pl. 30) is separable into two periods. The first begins with the discovery of the lode and location of the Boss claim by Joseph Yount on January 1, 1886, and covers the 28 years during which it was intermittently worked as a source of copper and gold. During this period the three upper and lowest tunnels were run. About 1898 an option was given to Emory Hershing, who, on the basis of this and an option on the Columbia mine, erected a mill to treat the ore near the town of Goodsprings. The mill was sold in 1902 to the Yellow Pine Mining Co., and it formed the nucleus of the mill used by that company until it burned in 1924. According to S. E. Yount, about 200 tons of copper ore was mined at the Boss mine from 1898 to 1900. The second period of the mine's history begins with the discovery of platinum in the ore by H. K. Riddall about March 1, 1914, and the coincident formation of the Boss Gold Mining Co. After a little exploration an option on the mine was given in September, 1914, to W. C. Price and associates, of Los Angeles, for $200,000, of which $50,000 was paid in cash. They organized the Platinum Gold Mining Co. and carried out extensive development but shipped no ore. When they failed to complete the purchase, the mine reverted to the owners in October, 1915, and they mined all of the ore in sight. Except for two brief periods of exploration and current assessment work, there has been no mining on the property since 1919.

At the time of the writer's examination in 1922 all the workings were accessible, but the stopes from which most of the ore had come were filled with waste. In the preparation of this report the writer has conferred with S. E. Yount, O. J. Fisk, and Frank Crampton, manager during 1915, and has had access to a comprehensive suite of specimens collected by Mr. Crampton, as well as assay maps showing the source and composition of about 600 samples.

Production.—The production of the Boss mine, assembled from reports submitted annually by the owners to the United States Geological Survey, is presented below. If to the 3,051 tons recorded here is added the estimated production prior to 1900, the total is about 3,500 tons, and the gross value of the output is about $210,000.

Production of Boss mine, 1914–1920

Year	Crude ore (tons)	Gold (ounces)	Silver (ounces)	Platinum (ounces)	Palladium (ounces)	Copper (pounds)	Lead (pounds)
1914	61	386.49	322	----	----	13,194	33
1915	163	38.27	409	(?)	(?)	36,986	720
1916	746	373.00	1,119	181.6	----	149,200	----
1917	1,099	438.25	2,506	138.0	355.0	199,421	----
1918	735	170.58	1,755	42.1	35.7	129,972	----
1919	204	359.22	858	34.3	203.3	26,048	----
1920	43	6.00	45	----	----	13,278	----

Smelter analyses of shipments from Boss mine, 1916–1919

[The record is almost complete for the period covered]

1916

Dry weight (pounds)	Gold (ounces per ton)	Silver (ounces per ton)	Platinum (ounces per ton)	Palladium (ounces per ton)	Copper (per cent)	Iron (per cent)	Insoluble (per cent)
Copper ore:							
51,972	0.72	2.70	0.93	----	11.38	4.50	46.0
65,800	.21	1.90	5.25	----	11.75	13.50	34.2
54,304	.15	1.80	.15	----	7.72	3.30	50.8
72,030	.17	1.65	----	----	7.88	4.20	57.4
62,810	.105	2.20	----	----	7.00	3.40	69.8
80,000	.105	2.60	.07	----	6.64	4.00	67.8
69,188	.115	1.85	.07	----	6.44	5.10	60.0
70,618	.17	1.75	.21	----	8.92	7.80	49.4
78,740	.12	1.75	.09	----	7.12	5.80	60.6
62,088	.15	1.30	.09	----	18.50	6.50	43.80
63,800	.08	1.50	----	----	13.22	4.00	60.50
Platinum ore:							
79,918	.44	.0	.36	0.895	11.37	----	----
68,932	.62	2.4	.31	.87	10.85	----	----
78,751	.58	3.0	.30	1.07	12.05	----	----
65,658	.70	1.75	.42	.985	13.40	----	----
77,950	.48	.0	.65	1.32	11.97	----	----
69,166	.81	.80	.77	1.67	10.585	----	----
69,394	.82	.80	.68	1.675	13.24	----	----

Smelter analyses of shipments from Boss mine, 1916–1919—Con.

Dry weight (pounds)	Gold (ounces per ton)	Silver (ounces per ton)	Platinum (ounces per ton)	Palladium (ounces per ton)	Copper (per cent)	Iron (per cent)	Insoluble (per cent)
1917							
Copper ore:							
60,606	0.04	1.45	0.01		8.95	3.40	69.80
60,572	.04	1.80	.05		8.40	3.90	67.40
57,182	.08	1.70	.05		21.35	5.80	43.80
58,544	.09	1.65	.07		11.35	4.50	38.60
68,128	.03	1.95	.03		8.20	2.60	48.90
61,370	.03	2.40	.03		9.40	3.20	58.0
77,384	.05	2.40	.09		8.05	4.20	56.8
68,258	.06	2.40	.04		7.74	7.00	47.2
73,060	.06	2.00	.06		7.50	4.50	62.2
67,110	.06	1.90	.06		9.13	4.50	60.6
69,684	.06	2.60	.11		8.93	7.80	45.9
72,816	.09	2.60	.16		6.95	5.60	60.0
73,880	.11	3.30	.03		7.96	7.20	58.9
69,154	.12	2.45	.09		6.25	6.30	57.0
71,378	.12	1.85	.07		7.12	6.30	53.3
69,974	.11	2.25	.08		11.38	6.20	47.8
69,736	.21	2.20	.12		15.47	9.00	42.2
75,766	.10	1.75	.04		10.02	9.90	47.0
81,358	.20	2.30	.16		10.10	13.60	38.8
Platinum ore:							
369	30.44		1.05	6.70			
58,826	.55	3.54	.27	1.17	15.98		
78,116	.54	2.67	.28	1.14	13.92		
2,300	4.40	7.20	1.08	4.56			
40,070	1.47	3.60	.40	1.57	2.64		
75,892	.41	1.43	.09	.37	7.16		
70,740	.40	1.86	.12	.44	8.56		
76,946	.70	2.47	.36	1.05	7.57		
84,936	.74	2.35	.30	1.28	14.10		
43,228	1.12	2.90	.26	1.10	6.17		
51,820	1.05	2.30	.21	.90	8.02		
67,300	.74	2.20	.24	.60	7.75		
78,160	1.04	2.85	.30	1.20	7.90		
1918							
Copper ore:							
76,760	0.21	2.45	0.09		10.75	11.70	41.2
80,912	.11	1.70	.08		12.95	8.60	39.0
83,556	.11	2.10	.06		10.03	6.30	53.4
77,964	.05	2.00	.10		9.55	6.00	39.3
82,024	.07	1.75	.06		8.85	7.00	43.60
78,138	.05	1.60	.05		6.83	3.40	41.0
84,104	.05	1.60	.06		7.32	3.40	37.0
89,494	.09	3.10	.04		10.15	10.70	40.0
81,908	.08	3.70	.06		10.65		
89,608	.09	2.75	.05		9.72	8.70	46.80
78,834	.10	2.50	.06		9.39	7.80	50.0
74,490	.08	2.75	.04		8.43	9.20	47.0
80,920	.05	2.10			8.10	9.80	43.10
77,432	.04	2.20	.02		9.05	3.70	38.40
75,620	.18	2.00	.07		9.58	4.10	46.10
Platinum ore:							
92,520	.93	2.35	0.05	0.35	5.49		
88,348	1.49	4.00	.12	.40	3.65		
421	9.72	7.80	1.44	9.05			
1919							
Copper ore:							
77,722	0.11	1.85			9.45	6.30	
78,136	.09	2.30			10.84	6.80	
87,456	.10	4.05			13.05	6.30	
96,388	.23	2.30			10.22	12.10	
Platinum ore:							
96,491	3.25	6.10	0.25	1.64	.74		
74,155	2.54	5.25	.35	1.62	1.02		
54,558	3.34	4.00	.34	2.35	1.31		

Total for the period, approximately 2,617 tons.

Geology.—The Boss ore body lay along a minor fault zone that separates coarse gray dolomitized limestone near the base of the Monte Cristo formation on the southeast from thinner-bedded light and dark gray dolomites that probably are a part of the Valentine member of the Sultan limestone on the northwest. (See pl. 33, *A*.) This fault zone appears to merge northward with the Ironside fault, one that makes a right angle with the Keystone thrust but is undoubtedly related to it in age. The beds northwest of the Boss fault strike northeast and dip gently northwest, the dip increasing from 15° at the south end of the explored zone to 45° at the north end. The beds southeast of the fault trend northwest but dip 5° SW. The dip of the fault is not constant but averages 70° NW., and the relations indicate that the beds that make up the hanging wall have moved upward and northeastward with reference to those on the footwall. (See fig. 23.) There is thus a structural analogy with the Kirby, Rose, Highline, Copperside, and other near-by deposits. The underground workings reveal many faults, and the relations of most of them are obscure. Along the northeast part of the 200, 300, and 400 foot levels most of the faults appear

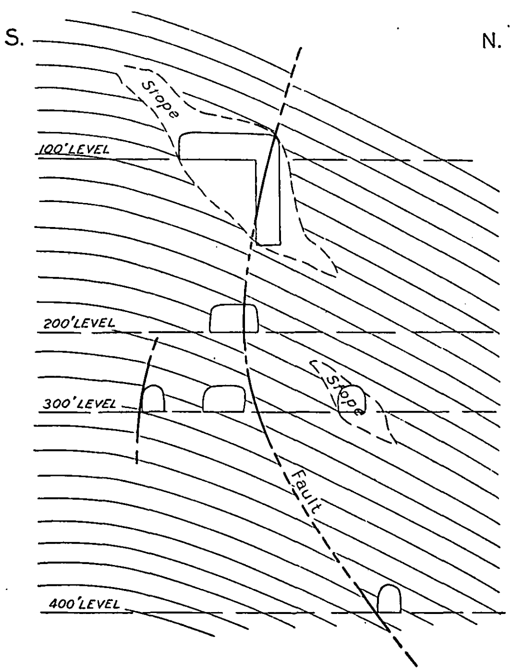


FIGURE 23.—Geologic cross section through Boss mine along line X-X, Plate 32

to form a simple major system, but in the near-by country rock well-defined walls are met whose relations to the major faults are obscure. Most of these walls trend northeast and dip steeply northwest. Striae are common on the walls of the faults and largely range from horizontal to 20° NE. Therefore they do not confirm the interpretation of the movement on the basis of the beds on the two walls. In addition to the northeastward-trending faults, to which the ore shoot appears to be related, two cross faults which limit a V-shaped block are shown on the 100 and 300 foot levels. (See pl. 32.) Several observers agree that the block which is limited by these faults was dropped several feet below near-by parts of the ore shoot. It may probably be regarded as postmineral and preoxidation.

No igneous rocks are known underground or on the surface near by. A sill of granite porphyry was encountered in the workings of the Boss Extension Mining Co. 1,500 feet to the northeast.

Ore deposit.[44]—All the ore shipped from the Boss mine was derived from a single rather simple continuous shoot, although other smaller bodies that yielded good assays were found and explored also. This shoot lay largely on the northwest or hanging-wall side of the main fault zone and formed a rudely elliptical pipe, which cropped out above the mouth of the 100-foot level and pitched about 10° NE. to the entrance of crosscut 209, where it terminated. (See pl. 32.) In few places it was more than 25 feet in diameter, and the length was about 200 feet. Smaller bodies that had the form of irregular lenses were encountered in crosscuts 307 and 313 and crosscut and winze 312, and although they had a general trend northeast, they cut across the bedding in strike and dip. Although a small lens of iron oxide was found in a winze below the 400-foot level, there is no record that any samples from this or the 500-foot level showed appreciable copper, gold, platinum, or palladium.

A review of the structural associations of the principal shoot, after making allowances for the poor exposures underground, indicates that its general position is determined by the intersection of the major fault with a favorable stratum. The average trend of the fault is N. 50° E., and the beds in the northeastern part of the workings strike N. 60° to 80° E. and dip 30° to 40° NW. A simple calculation will show that the intersection of these surfaces would pitch northeast at 7° to 19°, which may be compared with the pitch of 10° noted. On the other hand, explorations seem to show that there is no extension of the shoot directly down the dip of the fault.

Although the principal shoot is practically mined out and filled with waste, several persons who examined it repeatedly soon after it was explored state that the larger relations of the minerals were the same as those which may still be seen in the smaller shoots, such as are shown along crosscut 307. The most abundant material in most of the shoots, large and small, is quartz, which occurs largely in the form of a white powder but in part as a dark coherent cellular mass. (See fig. 24, zone 4.) The powder is made up of myriads of nearly perfect doubly terminated clear crystals, 0.1 to 0.2 millimeter in diameter. As shown in the table of analyses (p. 117), this material contains little gold or platinum. According to Knopf,[45] it contains a small percentage of minute crystals of octahedrite, the tetragonal form of titanium oxide. According to a private report by Ray C. Moore, a large body of this material overlay the lens of high-grade platinum ore below the first level. The dark cellular masses of quartz were apparently confined to the principal shoot, as none were found elsewhere. In thin section this quartz is made up of interlocking clear grains nearly equal in size; the range in diameter is 0.03 to 0.1 millimeter. The dark color of the quartz is due to a small percentage of minute grains rather uniformly dusted throughout the mass without regard to the border of the grains of quartz. Doubtless this is the material determined by Knopf to be octahedrite. Both the cavities in the quartz and the fracture surfaces are covered with minute quartz crystals, which were probably deposited during the process of weathering.

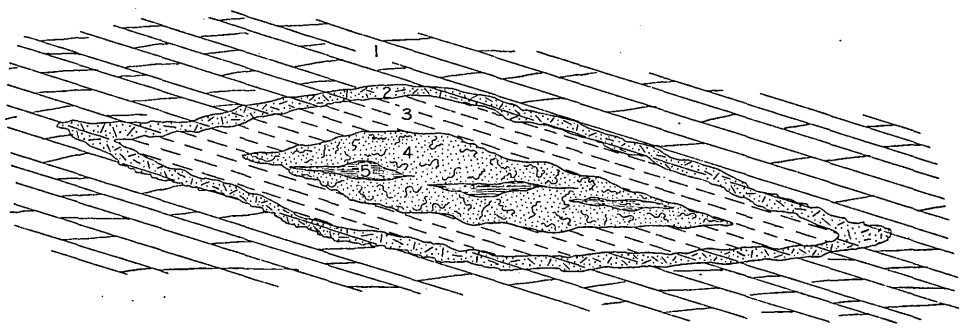


FIGURE 24.—Diagrammatic sketch showing typical relations of minerals at Boss mine. Proportions probably not correct. 1, Country rock of dolomitized limestone; 2, zone of dolomite impregnated with copper carbonate and silicate; 3, zone of limonite containing a little jarosite and malachite; 4, zone of quartz, partly dark and coherent, largely white crystalline powder; 5, lenses and irregular masses of platiniferous plumbojarosite

[44] Knopf, Adolph, A gold-platinum-palladium lode in southern Nevada: U. S. Geol. Survey Bull. 620, pp. 1-18, 1915.

[45] Knopf, Adolph, op. cit., p. 7.

Representative assays of different types of material from Boss mine

[Assays made by F. R. Crampton, 1915]

Material and source	Gold (ounces per ton)	Silver (ounces per ton)	Platinum and palladium (ounces per ton)	Copper (per cent)
Limestone, stained with iron and copper:				
4 samples, third level	Trace to 0.06		0 to 0.04	Trace to 1.3.
1 sample, second level	0.10		0. 08	
3 samples, first level	0.08 to 0.10		None	0.80 to 3.9.
Limonite:				
3 samples, third level	0.04 to 0.06		None to 0.04	Trace to 1.8.
2 samples, first level	0.10 to 0.27		Small	2.9 to 4.9.
Copper carbonate:				
1 sample, intermediate level	0.36		0.36	38.40.
1 sample, winze below 312 crosscut	0.20	3. 40	0.12	34.
3 samples, third level	0.10 to 0.40		Trace to 0.35	30 to 35.2.
Mixed siliceous limonite and copper carbonate: 1 sample, 204 crosscut, second level	0.80	4. 70	0.10	19.60.
Fine powdery white quartz:				
10 samples, third level	Trace to 0.05		Trace to 0.08	Trace.
1 sample, source unknown, about	0.70		0.80	None.
Black quartz, cavernous:				
1 sample, first level	12.12	4. 60	Pt, 4.18; Pd, 2.06	None.
1 sample, source unknown	8.52	11. 13	Pt, 7.24; Pd, 4.52	Trace.
Gray quartz powder with 10 to 20 per cent of plumbojarosite: 1 sample from ore shoot on intermediate level only.	2.92	9. 41	Pt, 1.38; Pd, 1.91	None.
Yellowish-gray quartz powder with 20 to 40 per cent of plumbojarosite: 1 sample from intermediate level	81.61	23. 14	Pt, 107.17; Pd, 137.28	None.

The material richest in gold, platinum and palladium was a greenish-yellow powder locally called "talc," which was 25 to 50 per cent bismuthic plumbojarosite in the form of myriads of perfect flat crystals 0.01 to 0.1 millimeter in diameter. The remainder was perfect quartz crystals similar in form and size to those which make up the quartz powder. Knopf [46] records an analysis of rather pure material made by R. C. Wells, of the United States Geological Survey, as follows:

Analysis of bismuthic plumbojarosite from the Boss mine

Fe_2O_3	32. 24	CO_2	0. 43
Al_2O_3	. 14	As_2O_5	. 09
SO_3	24. 08	P_2O_5	Trace.
PbO	16. 75	SiO_2	6. 90
H_2O-	. 02	TiO_2	. 37
H_2O+	8. 55	Au	. 79
CuO	1. 97	Pt	. 05
Bi_2O_3	6. 34	Pd	. 22
CaO	. 06	Ir	Trace.
MgO	. 14	Ag	Trace.
K_2O	. 22		
Na_2O	. 52		99. 88

Reduced to ounces a ton, the analysis shows gold to be present to the extent of 234 ounces, platinum 15 ounces, and palladium 64 ounces. Assays of similar material are reported to show as high as 575 ounces of gold, 230 ounces of platinum, and 30 ounces of palladium. The silica and titania shown by the analysis represent an admixture of quartz and octahedrite.

The gold and platinum metals can be partly separated from the plumbojarosite by panning, but long before a clean separation can be effected fine gold and especially platinum pass into the tailings, in spite of the utmost precaution. The gold is extraordinarily rough and spongy; delicate platy forms are common, and some is intergrown with quartz and plumbojarosite or is molded around minute quartz crystals. It is more or less blackish, and aggregates of the finer particles look like so much black sand. Treatment with hydrochloric acid and annealing, however, bring out the normal yellow color of gold. Some of the larger particles after being treated thus were analyzed by R. C. Wells, as follows:

Analysis of gold from the Boss mine

Gold	97. 8
Silver	2. 2
Platinum metals	Trace.
	100. 0

Qualitative tests on other gold particles always showed the absence of platinum metals, and the inference of Ledoux & Co. that the metals are present "apparently as alloys of gold and platinum metals" is therefore not borne out. The platinum and palladium occur in extremely small particles, which even at high magnification under a binocular microscope are indistinguishable from the dull blackish particles of gold; in all material examined by the writer chemical tests were necessary to establish the presence of the platinum and allied metals. By cleaning the precious metals in molten sodium carbonate, particles of gray metal (platinum and palladium, or an alloy of these) become distinguishable from yellow gold. The possibility was entertained that sperrylite might be present in the residue of the pannings from the plumbojarosite or elsewhere in the ores of the Boss mine, but no trace of this mineral, which, according to its discoverer, is characterized by a wonderfully brilliant luster, was found.

This material has been reexamined recently by W. T. Schaller, who reports that it may be regarded as a mixture of plumbojarosite, beaverite, bismutite, and quartz in the percentages 67.3, 17.2, 6.9, 6.9. The presence of beaverite has already been established by Knopf. The recognition of bismutite is based upon

[46] Knopf, Adolph, op. cit., p. 8.

the fact that dilute nitric acid causes effervescence, and the filtrate contains much bismuth. Plumbojarosite and beaverite are insoluble in dilute nitric acid. If, after deducting the beaverite, bismutite, quartz, and the noble metals, the molecular proportions of the remaining radicles are calculated, they are found to be (PbO, K_2O, Na_2O) : Fe_2O_3 : SO_3 : H_2O = 0.99 : 2.89 : 4.05 : 6.08. These may be expressed $1 \times 0.99 : 3 \times 0.95 : 4 \times 1.01 : 6 \times 1.01$ and are very close to the ratios of plumbojarosite, 1 : 3 : 3 : 6.

It is possible that part of the noble metals are present as components of a mineral of the jarositic group or else that the portions of them present in the metallic state have been derived from the decomposition of such a jarosite, isomorphous with plumbojarosite.

According to F. R. Crampton,[47] some of the masses of plumbojarosite were stratified as if laid down in water; others formed narrow veins in diverse attitudes. The inner mass of quartz was surrounded by a persistent but not uniform layer of coherent brown limonite, locally siliceous, which contained sporadic masses of yellow jarosite. (See fig. 24, zone 3.) This material contained small quantities of copper but little gold, platinum, and palladium. It was not sharply separable from the inner quartzose core nor the outer zone, which was largely dolomite impregnated with copper carbonate, although here and there chrysocolla filled fractures or covered druses. The copper-bearing minerals and impregnated dolomite contained only traces of gold and platinum.

Chrysocolla is a common mineral in the Boss workings. It forms mammillary crusts on veinlets and in open spaces and appears to have resulted from the addition of silica in solution to the previously existing copper minerals, generally malachite. Loosely coherent masses of the basic copper phosphate, libethenite, were found on the dump. Sulphide minerals were found at several places in the workings, but the total quantity was small, and the relations with the dark quartz are obscure. In the northeastern part of the intermediate level, not shown on Plate 32, angular masses of copper minerals were found in which chalcopyrite, bornite, and chalcocite formed nuclei in the oxidized minerals, malachite and cuprite.

Even though present exposures of the ore shoot are meager, it seems clear that the unoxidized shoot was a pipelike mass of cellular quartz impregnated with chalcopyrite and possibly pyrite and that these minerals contained uncommon amounts of gold, platinum, and palladium. The white quartz powder contains little of these metals, but the presence of octahedrite in it indicates that it was formed at higher temperatures than those which have prevailed since weathering began. The present distribution of iron and copper minerals in the shoots is doubtless due to migration during w athering. It is such as would be expected if the deposit were repeatedly wetted and dried and opportunity therefore offered for repeated solution and deposition of iron and copper salts. The nearly perfect segregation of copper minerals from the iron oxide zone indicates that in a zone permeated by carbonate waters copper is more soluble than iron.

[47] Personal communication.

From what is recorded concerning the distribution and grade of the platinum-bearing plumbojarosite it seems certain that both platinum and palladium have migrated locally from the position at which they were originally deposited. The meager content of platinum and palladium in the oxidized iron and copper minerals from all parts of the mine, however, indicates that those metals were much less soluble under the local conditions than iron and copper. Although no assays of unweathered sulphide minerals for platinum and palladium have been made, it seems certain that the platiniferous plumbojarosite contains more of these metals per ton of material and that enrichment has taken place during the weathering.

The explorations that have been made appear to show adequately that the ore shoot of the Boss mine does not persist directly down the dip of the fault zone. If the position of the shoot is determined, as the writer believes, by the intersection of the fault zone and a certain stratum in the hanging wall of the zone, any extension of the shoot should be sought northeast of the present workings, in the general direction of the pitch of the principal shoot.

PLATINA MINE

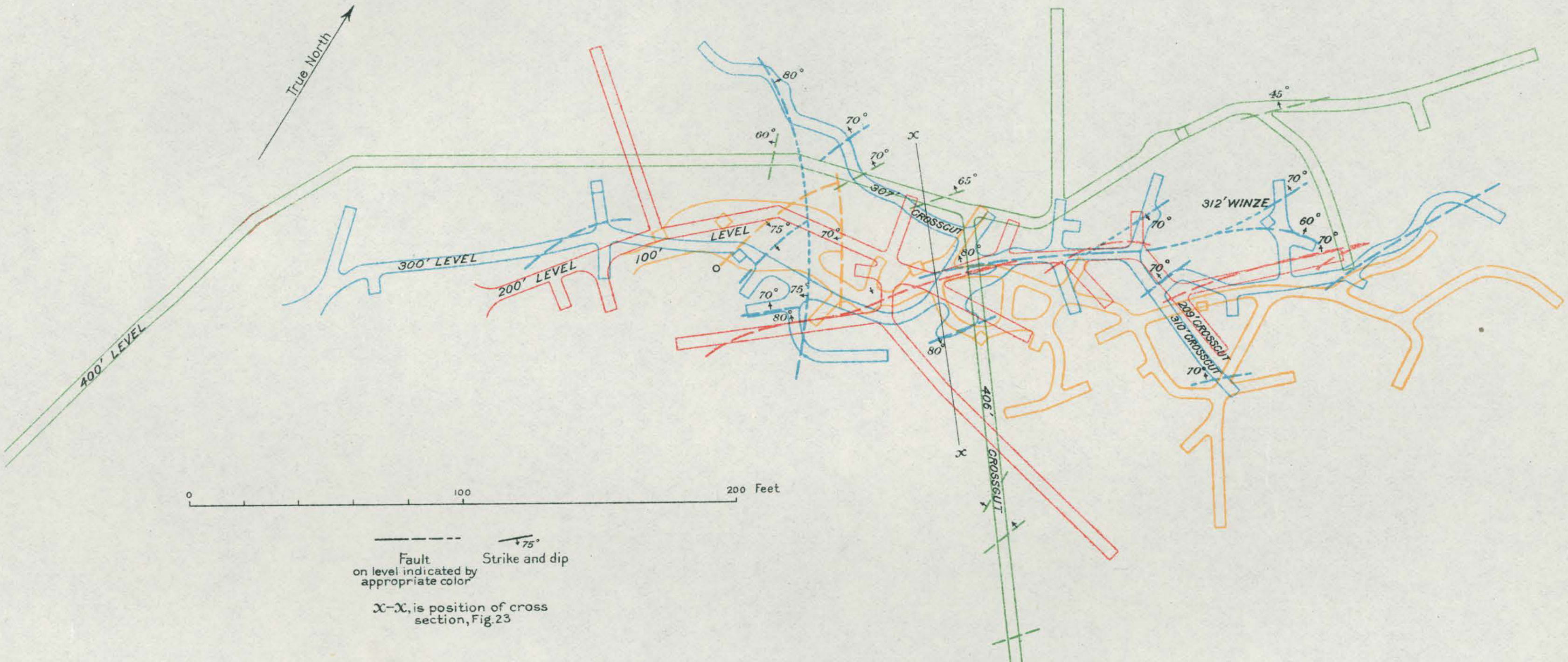
The Platina Mines Corporation owns two claims in the NE. ¼ sec. 34, T. 24 S., R. 57 E. (No. 29, pl. 30). The workings include two tunnels on the north side of a prominent spur south of the Boss mine and five short tunnels on the south side of the ridge. These workings explore beds of dolomitized Dawn limestone, which here trend northwest and dip 25° SW. It is locally reported that one car of copper ore was shipped from the property during the period of activity of the Boss mine, 1916–1918.

The lower tunnel with drifts is about 345 feet long but appears to have shown the presence of but little copper. In the upper tunnel, only 95 feet long, there is a stope about 15 by 35 feet, parallel to the bedding and 3 feet high. The material on the dump indicates that this stope yielded lenses of ferruginous chert around the border of which there were layers of malachite and chrysocolla. Some samples of material from this tunnel are said to have shown the presence of platinum, but this has not been confirmed.

Of the five tunnels south of the ridge the longest is about 100 feet and the dumps show little copper.

AZURITE MINE

The Azurite group of claims (No. 30, pl. 30) lies along the north slope of a high ridge that extends west



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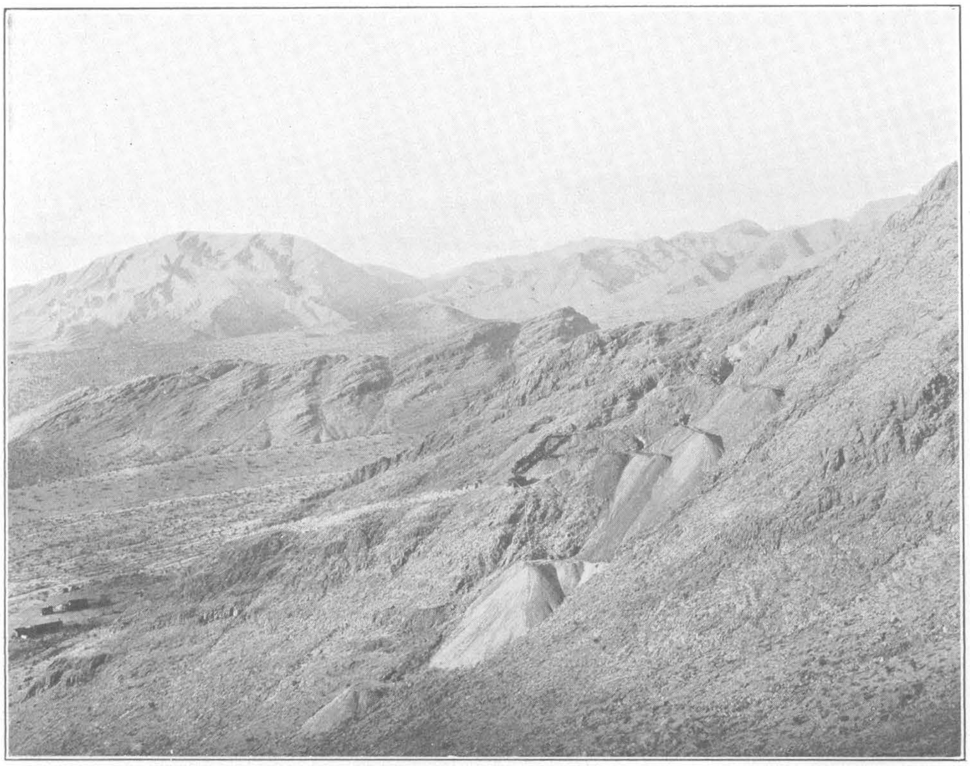
PLAN OF THE WORKINGS OF THE BOSS MINE, NEVADA

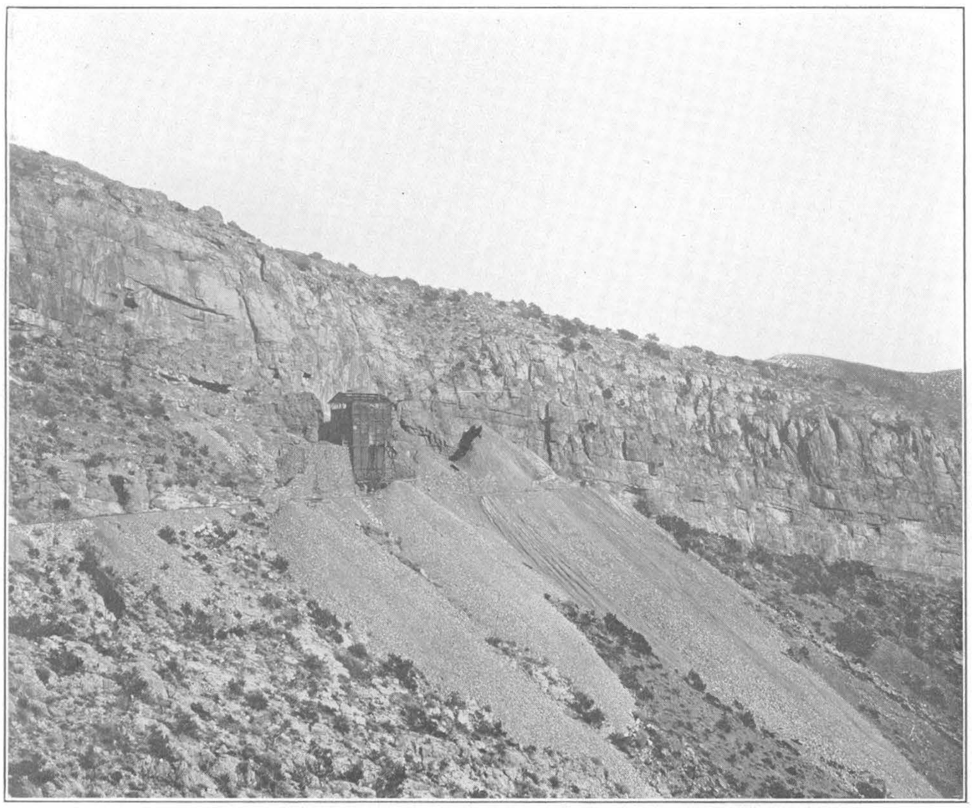
Intermediate and 500-foot levels omitted

1931



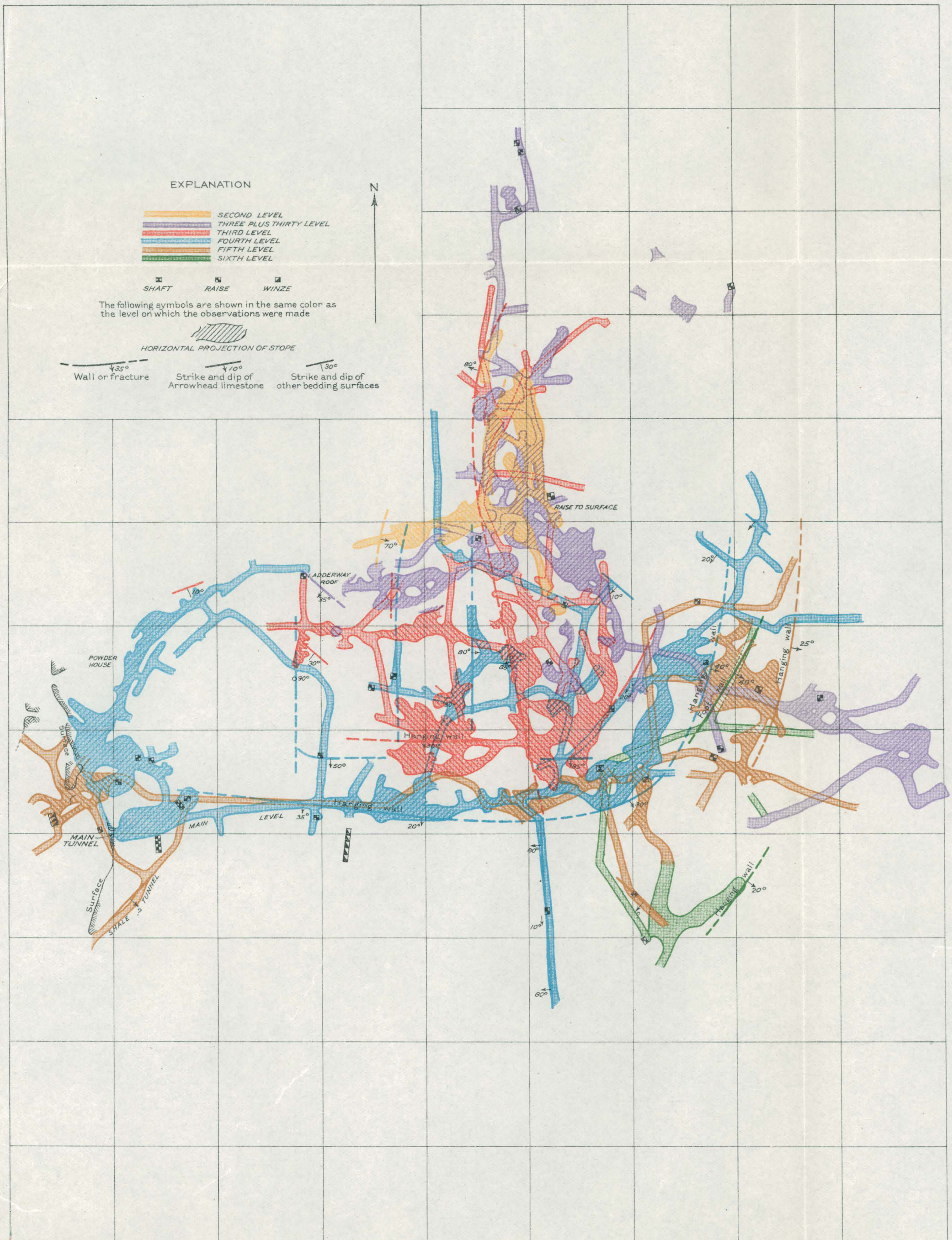
A. BOSS MINE, NE. ¼ SEC. 34, T. 24 S., R. 57 E.

The workings explore a crushed zone which lies between dolomitized limestone of the Monte Cristo formation on the right (east) and similar rocks of the Sultan formation on the left (west).



B. POTOSI MINE, SOUTH CENTER OF SEC. 12, T. 23 S., R. 57 E.

The mine workings explore a zone at the base of the Yellowpine limestone.



UNDERGROUND WORKINGS OF THE POTOSI MINE, NEVADA

0 100 200 300 Feet

1931

ENGRAVED AND PRINTED BY THE U.S.GEOLOGICAL SURVEY

from the Whale to the Boss mine in the SW. ¼ sec. 26, T. 24 S., R. 57 E. The Azurite claim was located in 1899 by W. H. Smith and C. W. Cook, and most of the other claims prior to 1903. The first work was done by the Nevada Mining & Smelting Co., which is reported to have shipped two cars of copper ore prior to 1902. The Nevada Copper Co. was organized in 1902 and, although it did considerable work, shipped only one car of ore before the Azurite Mining Co. was organized in 1911. Most of the present work was done by lessees during 1916 and 1917, and they shipped most of the ore.

Of the production shown in the following table, all but 56 tons of the copper ore was shipped from workings on the Azurite claim; 56 tons was taken from shallow workings on the Sandy claim; the lead and zinc ore came from the upper tunnel on the Rosella claim.

Production of Azurite mine, 1910–1920

Year	Crude ore (tons)	Gold (ounces)	Silver (ounces)	Copper (pounds)	Lead (pounds)	Zinc (pounds)
1910	20	0.81	67	8,135		
1913	43	2.50	231	11,706		
1916	503	22.00	848	123,200	3,600	22,950
1917	196	6.16	503	50,497	5,301	
1920	94	3.69	183	28,976		

The workings on the Azurite claim include a main tunnel 260 feet long that trends generally southwest from a point 250 feet above the floor of Shenandoah Gulch. (See fig. 25.) The ore from this claim came from two blind levels, 12 and 35 feet higher. On the Gulch claim, below the Azurite, there is a shaft inclined at 30° for 50 feet, then vertical for 120 feet, but this is not accessible. On the Rosella claim there is a lower tunnel 390 feet long, which developed no ore, and an upper tunnel 200 feet higher and 50 feet long, at the end of which there is a 40-foot inclined shaft. This claim yielded all the lead and zinc ore that has been shipped.

The Azurite main tunnel explores a zone at the base of the Anchor limestone, which is extensively dolomitized here. The Rosella tunnels are in beds near the top of the Bullion dolomite. In this area the beds strike northwest and dip 15° to 20° SW. The only igneous rock on the claims is a dike of basaltic rock 3 to 8 inches thick, which is struck in the lower Rosella tunnel and followed 35 feet. It trends N. 54° W. and dips 80° SW. It is probably similar to the dike west of the Kirby mine, the age of which is considered as late Tertiary.

The sources of copper ore in the Azurite tunnel were three shoots, one of which cropped out at the surface. The largest shoot was explored above and below the upper level and the smallest was explored from a winze below the intermediate level. No relation between these separate shoots was recognized. The second shoot is limited upward by a conspicuous hanging wall which trends N. 45° W. and dips 50° SW. Under this wall zones of dolomite breccia were cemented by copper sulphides. (See pl. 28, *A*.) These breccia zones trend northwest, parallel to the hanging wall, and like it dip more steeply than the bedding. The second shoot attained a maximum length of 40 feet, a width of 15 feet, and a thickness of 12 feet. The third shoot is scarcely 18 feet long on the drift but has not been explored to its limits.

The principal sulphide mineral found underground as well as on the dump is chalcocite. In some specimens it is associated with bornite and chalcopyrite in such a way as to indicate that chalcopyrite was the primary mineral and the others have been derived from it. By oxidation malachite, chrysocolla, and traces of azurite were formed. Limonite is common but not abundant as deep as the intermediate level. At the face of the smallest shoot pale-green feathery coatings of olivenite were found; evidently some arsenide was present in the original ore.

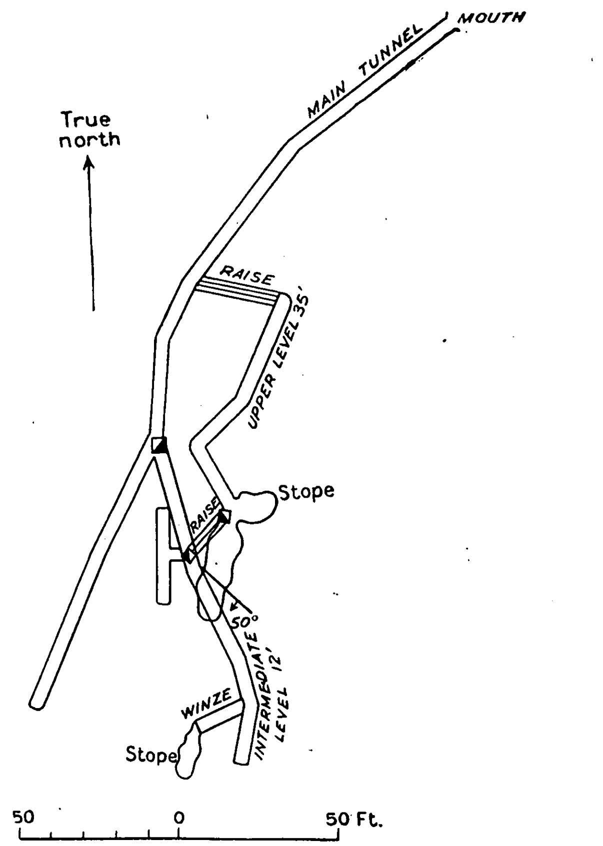


FIGURE 25.—Sketch map of Azurite mine

Quartz and similar compounds of silica are not conspicuous but must have been present persistently in the ore, as the smelting receipts report 50 to 60 per cent of insoluble matter, most of which must have been silica. In the face of the stope on the third shoot there are lenses of granular quartz which closely resemble those which occurred in the Boss mine. In the same shoot there are poorly defined lenses of bituminous material in the dolomite. Polished sections show minute round masses of chalcocite in a siliceous matrix that is saturated with bitumen. The conclusion is reached that this bitumen represents that which was once widely disseminated through the limestone. With the dolomitization of the limestone and deposition of sulphide minerals, the bitumen has been segregated in the porous material near the veins.

The silver content of the Azurite shipments is uniformly low and ranges from 0.6 ounce to the ton for ore containing 5 per cent of copper to a maximum of 3.35 ounces to the ton for ore containing 14.9 per cent of copper. The gold content has ranged from 0.01 to 0.06 ounce to the ton.

The upper tunnel on the Rosella claim explored a body of mixed lead and zinc ore that lay under a good wall, of which the strike was northwest and the dip 25° SW. The present workings show a lens of calamine-bearing material 3 to 8 inches thick; probably it was wider where it was stoped. This tunnel has yielded 43 tons of ore containing 30 to 33 per cent of zinc and 23 tons of ore containing 25 to 42 per cent of lead. The material on the dump now shows calamine, plumbojarosite, jarosite, aurichalcite, and malachite. According to local report, specimens of plumbojarosite from this tunnel contained 0.02 ounce of platinum to the ton, although Knopf,[48] reports that none is present.

It is reported that on the Sandy claim, adjoining the Rosella, shallow pits encountered a number of rounded boulders and contained chrysocolla with nuclear masses of chalcocite. Although no definite deposit was developed, 56 tons of 10 per cent copper ore was shipped from these workings. The property was not examined by the writer.

COPPER CHIEF MINE

The workings of the Copper Chief mine (No. 33, pl. 30) lie about 1,000 feet west of those of the Mobile. They include several short tunnels and shallow shafts which explore minor fractures in the Bullion dolomite. These workings have probably yielded some copper ore, but they are particularly interesting as a recent source of cobalt ore. During 1921 R. Munzberg and H. Hardy mined or sorted from the dump three lots of ore, which, when sold, yielded the returns given below:

Lot	Weight (pounds)	Cobalt oxide (per cent)	Net returns
1	12,966	10.86	$492.45
2	10,789	7.20	248.00
3	1,914	20	177.30

[48] Knopf, Adolph, op. cit., p. 12.

In contrast to that produced at the Columbia and Highline mines, the cobalt oxide from the Copper Chief was intimately intergrown with brown chert.

FITZHUGH LEE MINE

The workings on the Fitzhugh Lee claim (No. 35, pl. 30) are on the saddle of a low ridge in the N. ½ sec. 36, T. 24 S., R. 57 E. At this point beds of the Dawn limestone, now dolomitized, trend generally northwest and dip slightly southwest; the extensive synclinal axis of this region lies several hundred feet south.

The workings include a tunnel that extends from the west side of the ridge along a shear zone N. 60° E. for 50 feet. On the east side of the ridge there are several trenches and a short tunnel. The shear zone shows lenses of ferruginous chert with sporadic malachite and chrysocolla. The production is shown in the table below:

Production of Fitzhugh Lee mine, 1915–1917

Year	Crude ore (tons)	Silver (ounces)	Copper (pounds)
1915	21	70	7,290
1916	2	18	860
1917	6	37	1,612

ROSE MINE

The Goodsprings Dividend Mining Co. owns five claims west of Kirby Gulch, near the center of sec. 31, T. 24 S., R. 58 E. (No. 37, pl. 30). Three of these were located early in the history of the camp—the Rose, by A. G. Campbell and A. E. Thomas in 1887; the Lucky, by Harsha White in 1889; and the Summit, by T. C. Williams and D. G. Lewis in 1895. The principal workings are on the Rose claim and include a tunnel and two branches that have a total length of about 110 feet on the north side of a prominent ridge. From the face of the eastern drift there is a shaft about 85 feet deep with an average slope of 60°.

These workings explore a nearly vertical shear zone that trends N. 32° E. in beds of dolomite that lie about 300 feet below the top of the Goodsprings formation. At this point the beds trend west and dip steeply north, as they lie along the north side of a persistent anticline. The shear zone is one of several that trend northeast in this locality, but this one contains the largest ore deposit. There is little copper underground at present. Apparently the ore bodies were lenses of ferruginous chert, around the border of which there were copper minerals. There are small stopes in the shear zone above the incline, but these are only 3 to 4 feet wide. Probably the lenses of copper minerals were narrower. Chalcocite is reported to have been present, but apparently the principal minerals were malachite, chrysocolla, cuprite, and copper pitch, which formed veinlets and irregular masses in the dolomite near the chert lenses. As in other similar deposits, dioptase forms a drusy coating on fractures.

As at the Columbia west shaft cobalt oxide replaces the wall-rock dolomite outward from fractures. (See pl. 27, *B*.) Although hand specimens can be found that would contain 5 to 10 per cent of cobalt oxide, the total quantity of cobalt-bearing material is small.

The total shipments from the mine are not recorded. One car containing 9.84 tons shipped by a lessee in 1918 contained gold, 0.01 ounce to the ton; silver, 1 ounce to the ton; copper, 14.54 per cent; iron, 13 per cent; and insoluble matter, 31.6 per cent.

On the south side of the ridge covered by the Rose claim, probably on the Black Jack claim, there are two groups of explorations. The northern and higher group includes an inclined shaft about 60 feet deep, which follows a wall that trends N. 70° W. and dips 40° to 50° NE., and a lower tunnel, 385 feet long, that trends northwest. The shaft explored an iron-stained breccia zone that lies under the wall and appears to have contained lenses of cherty lead carbonate. In some specimens the carbonate is outwardly altered to yellow plumbojarosite. Many small lumps of pure pyromorphite were found on the dump, and pyromorphite appears to have been common in the product shipped. The lower tunnel encountered no ore shoots, and there is no stoping.

About 1,000 feet farther south on the west side of a ravine there is a vertical shaft about 175 feet deep, untimbered and therefore inaccessible. It follows a wall that trends N. 10° E. and dips 85° W., along which there is a zone of iron-stained breccia 3 feet wide. Here and there the breccia is splashed with malachite.

Both the ravine north of the Rose tunnel and that on the Black Jack claim, which drains southward, yielded angular fragments of hard cherty lead carbonate. The total quantity collected and shipped is locally reported to exceed 200 tons, which contained more than 50 per cent of lead. Similar fragments were readily collected from near-by deposits, but it is interesting that a much greater quantity was found in the western part of the ravine than was mined from near-by prospects.

COLUMBIA MINE

The St. Anthony Mining Co. is the owner of the Columbia and six adjoining claims, which lie south of the Ripley-Jean road in the N. ½ sec. 33, T. 24 S., R. 58 E. (No. 43, pl. 30). The Josephine claim was located in 1883, but most of the work is on the Columbia claim, which was located in 1886. According to local report, a prospector, Von Trigger, had located the ground and mined 10 tons of copper ore as early as 1880. From 1898 to 1903, when the Columbia and Boss mines were optioned to Emory Hershing and associates, there was some exploration and a mill was built on the present site of the Yellow Pine mill. This was the first mill erected in the district. In 1906 the property was bought for $20,000 by Joseph Dederich, who still owns it.

There is no accurate record of production prior to 1902, but that since 1906 is shown in the accompanying table. Probably the total production is slightly less than 3,000 tons of copper ore.

Production of Columbia mine, 1906–1928

Year	Crude ore (tons)	Gold (ounces)	Silver (ounces)	Copper (pounds)	Zinc (pounds)
1906	420	36. 28	1, 119	44, 041	--------
1907	125	--------	600	75, 000	--------
1912	65	--------	127	19, 010	--------
1913	810	1. 00	1, 019	230, 518	--------
1914	505	. 67	784	135, 363	--------
1915	359	--------	467	96, 930	--------
1916	140	--------	115	23, 466	22, 908
1917	62	--------	83	11, 808	7, 094
1918	42	--------	85	11, 864	--------
1919	9	. 08	9	2, 080	--------
1928	14	. 42	73	2, 963	--------

The principal workings are two shafts about 800 feet apart. The eastern shaft and the workings from

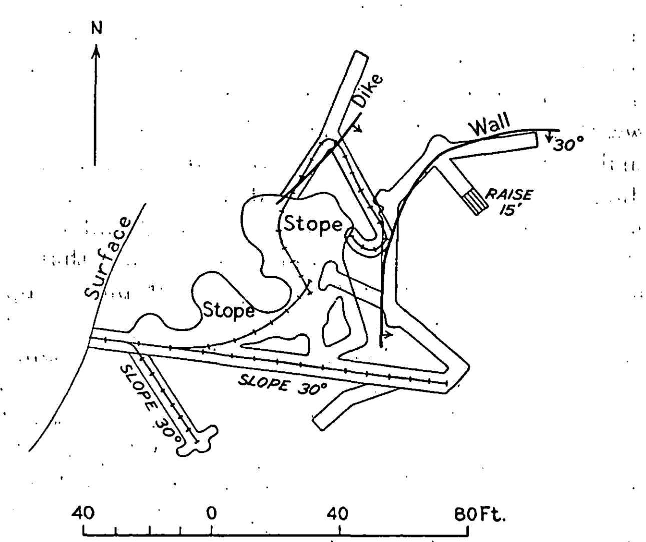


FIGURE 26.—Sketch map of Columbia mine

which most of the ore has been mined are shown in Figure 26. For the upper 25 feet the slope of the shaft is 15°; for the remaining 80 feet the slope is 30°. Most of the ore has been found above a level about 40 feet below the collar of the shaft; no ore was found on the lower level, and there are no stopes. The western shaft is about 110 feet deep on the slope, which ranges from 38° near the surface to 28° at the bottom. The total explorations include about 500 linear feet of shaft and drifts.

Both shafts explore zones near the middle of the Sultan limestone and the beds are completely dolomitized. Near the western workings the beds strike east and dip 30° S., but they turn gradually toward the northeast, so that at the eastern shaft they strike N 55° E. and dip 25° SE. Farther east they trend east again and then southeast.

In the eastern workings an area about 70 by 90 feet has been irregularly stoped to a maximum height of 20 feet. Above the upper level the ore all lay above a sill of granite porphyry 2 to 3 feet thick, which is nearly parallel with the bedding and is much sheared and decomposed. The sill was not found on the lower level, but there is a persistent wall which cuts the bedding. If the ore body were projected downward it would lie above this wall. From the data that can now be obtained the ore minerals appear to have been deposited in a breccia zone roughly parallel to the bedding above both the wall and the sill. Only traces of copper minerals were found in the workings, but specimens from the dump show dolomite breccia cemented by iron and copper oxides in which there are sporadic traces of chalcopyrite and chalcocite. In some specimens there are lenticular masses made up of tenorite and iron oxide in which there are sporadic grains of chalcocite. The tenorite forms plumose aggregates, and the borders adjacent to the dolomite are vague and irregular.

Probably chalcopyrite alone was the original sulphide mineral. The absence of quartz and other gangue minerals is conspicuous. Where the dolomite is close to chalcopyrite or the oxides resulting from its weathering, it is locally stained green, evidently by malachite. Azurite is very rare, but chrysocolla and dioptase occur on fractures and in druses. The final coatings on such druses are chalcedony and quartz, then calcite. The average grade of the ore that was shipped indicates that large masses of pure copper minerals, such as chalcocite, chalcopyrite, and malachite, were rare; probably much of the ore resembled that now found on the dump.

A black oxide of cobalt sporadically replaces the dolomite near the copper minerals but is much less abundant than in the workings of the western shaft.

Near the bottom of the western shaft and east of it there is a stope about 30 by 50 feet in area and largely 5 to 7 feet wide. This stope underlies a well-defined wall whose strike nearly coincides with the bedding and whose dip is 3° to 5° steeper. There is 1 to 12 inches of gouge under this wall and above the shoot. The ore contained the same minerals as that from the eastern shaft.

There is a well-defined fault west of the shaft that strikes N. 10° E. and dips 80° W., and on either side of it the dolomite country rock is sporadically replaced by cobalt oxide. (See pl. 27, *B*.) The cobalt oxide forms dendrites along fractures, much like manganese oxides in many regions. The black dolomite does not contain more than 6 per cent of cobalt, however, but locally there are richer veinlike lenses. During 1921 Frank Miller, of Goodsprings, mined and shipped three lots of cobalt ore having the weights and cobalt content indicated below:

Lot 1. 4,826 pounds; 5.13 per cent of cobalt.
Lot 2. 3,799 pounds; 13.42 per cent of cobalt.
Lot 3. 549 pounds; 29.18 per cent of cobalt.

To judge from the local associations of the cobalt and the information gained elsewhere in the district, the cobalt was present as sulphide or arsenide along the fault referred to and migrated into the near-by dolomite during weathering.

MINOR PROSPECTS EAST OF COLUMBIA MINE

Among the many prospect pits in the S. ½ secs. 27 and 28, T. 24 S., R. 58 E., only one deserves mention, probably on the Kentuckian claim, where an inclined shaft 35 feet deep to a level 65 feet long explores a shear zone 45 feet wide that trends N. 15° E. and dips 55° NW. in dark dolomite of the Goodsprings formation. The zone contains lenses of ferruginous chert along the fractures of which there are coatings of malachite, chrysocolla, and a greenish vanadate, probably cuprodescloizite.

LINCOLN MINE

The Lincoln mine (No. 55, pl. 30) is on a low ridge adjacent to the wash of Ivanpah Valley, in the NE. ¼ sec. 13, T. 25 S., R. 58 E. Five of the seven claims were located by E. W. Lincoln and others in 1905. The total production is probably greater than the summary presented herewith but does not exceed 60 tons of ore. Most of the ore shipped has contained about 12 per cent of copper and 15 ounces of silver to the ton, but one lot of 2,700 pounds, shipped by J. A. Egger in 1917, contained 97 ounces of silver to the ton.

The principal working is an inclined shaft 350 feet long, which begins with a slope of 16° but attains a maximum of 35° near the end. (See fig. 27.) The workings explore a zone of pale-gray dolomite about 800 feet below the top of the Goodsprings formation, which locally trends northeast and dips 10° NW. In the lower 100 feet of the shaft there is a well-defined wall that trends N. 15° to 25° W. and dips 80° SW. Near this wall there are lenses and rounded masses of ferruginous silica, in and around which there are veinlets and small masses of chrysocolla, the largest 3 by 4 by 4 feet. Other copper minerals may have been present, but chrysocolla is the most abundant of those remaining. Specimens of iron-bearing chert given to the writer by Mr. Egger show thin films of silver chloride and bromide on fractures. Ore was found at several places, but the largest stope, near the central part of the shaft, is 25 by 25 by 12 feet. The general distribution of ore appears to be determined by the wall referred to above. Specimens of dolomite breccia on the dump contain sporadic patches of black oxide of cobalt.

Production of Lincoln mine, 1910–1917

Year	Crude ore (tons)	Gold (ounces)	Silver (ounces)	Copper (pounds)
1910	6	--------	89	1, 775
1913	15	0. 30	578	4, 178
1917	25	--------	416	5, 142

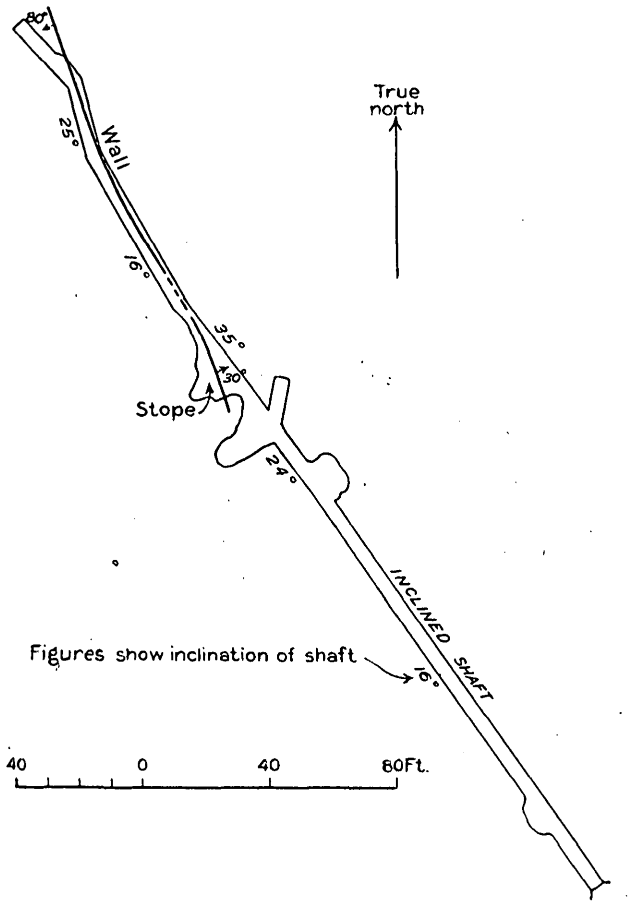


FIGURE 27.—Sketch map of Lincoln mine

ZINC AND LEAD MINES

POTOSI MINE

Location and history.—The Potosi mine (No. 1, pl. 30) is high on the west slope of a prominent ridge that extends southwestward from Potosi Mountain. It is 11 miles northwest of Goodsprings and 21 miles southwest of Arden, the nearest railroad point. The camp, which is at Potosi Springs, half a mile north of the mine and 700 feet below it, is connected with it by aerial tramway and narrow-gage track.

There seems to be little doubt that the deposit was the first to be explored in the district and possibly was the first source of lead in Nevada. The early history is given on pages 69–70. According to Owen,[49] it was the cause of local excitement in 1861. It was examined by C. A. Luckhardt in 1870,[50] when it was known as the Comet and owned by the Silver State Mining Co. Luckhardt wrote:

> Work was commenced by a cut at the bluff on the western slope of the mountain, which exposed the vein for 30 feet in width and 40 feet in length, presenting a mass of ore and country rock, the former predominating by far. An incline of 40 feet traverses the vein diagonally below this cut; and here horizontal drifts, 70 feet long, have been run on the vein. The lower workings show the metal (galena) to exist in seams and bunches, varying from 4 to 9 feet in width, of solid compact ore, separated by barren bunches of gangue. These bunches and seams of ore at the surface are as likely to yield 5 as 500 tons of ore; there is no regularity observable in their occurrence. * * * A sample of ore, regardless of waste, from ore seams 6 inches to 11 feet in width, taken along the vein for 336 feet in length, gave 31 per cent lead and $39.06 (about 30 ounces) silver per ton, and no gold.

The mine was examined and briefly described by G. K. Gilbert, geologist attached to the Wheeler expedition in 1871.[51]

Except for the meager record that it was worked as a local source of lead from time to time, little more is recorded until 1904, when it became the property of the Potosi Zinc & Lead Co., of which the Mahoney brothers, of San Francisco, were the principal owners. According to A. J. Robbins, who first saw the mine in 1892, there were at that time a small hearth and piles of cordwood near the foot of the present aerial tramway. The completion of the railroad from Salt Lake City to Los Angeles in 1905 permitted the shipment of the ores, and it produced steadily until 1920. It was examined by Bain[52] late in 1905, and he was impressed by elements of similarity between this deposit and those in the Mississippi Valley, which appear not to be related to igneous rocks. Late in 1913 it was purchased by the Empire Zinc Co. for a price reported to have been $125,000, and in 1926 this company sold it to the International Smelting Co. Although the Empire Zinc Co. shipped more than half the output, a review of the old maps indicates that it accomplished this largely by efficient methods of mining in ground known to be ore bearing rather than by greatly extending explorations or by discovery of new shoots.

Production.—There is no record of the early production of lead ore from the Potosi mine. It certainly amounted to several hundred tons, but as little, if any, found its way out of the region unsmelted, it was probably less than 1,000 tons. Since 1905, when the railroad reached Arden, lead ore has been

[49] Owen, J. R. N., in Whitney, J. D., California Geol. Survey, vol. 1, pp. 469–474, 1865.

[50] Raymond, R. W., Statistics of mines and mining in the States and Territories west of the Rocky Mountains for 1870, pp. 168–174, 1871.

[51] Wheeler, G. M., Preliminary report concerning explorations and surveys principally in Nevada and Arizona, 1871, pp. 52–53, 1872.

[52] Bain, H. F., A Nevada zinc deposit: U. S. Geol. Survey Bull. 285, pp. 166–169, 1906.

a small part of the total production. The table presented below summarizes the records submitted annually by the owners to the Geological Survey.

Production of Potosi mine, 1905–1927

Year	Ore [a] (tons)	Gold (ounces)	Silver (ounces)	Copper (pounds)	Lead (pounds)	Zinc (pounds)
1905	1,754		3,665.56		290,063	685,659
1906	8,500				570,175	2,885,246
1907	3,637					1,849,322
1908	1,248					738,532
1909	500				70,907	306,000
1910	1,743		3,833		150,161	1,055,805
1911	2,473		9,692		239,993	1,565,498
1912	6,561		1,950	2,805	206,692	3,496,873
1913	6,740		2,387	5,721	290,383	3,901,683
1914	2,034					1,210,414
1915	8,229				329,160	5,875,506
1916	12,205		794		95,225	8,372,816
1917	10,118		830		126,800	6,623,200
1918	4,966		644		102,853	3,030,522
1919	706					440,470
1920	528	3.09	3,359	7,592	310,059	46,240
1924	53		291	816	29,239	
1925	[b] 920	10.80	6,210	6,320	38,700	892,450
	36					25,560
1926	[b] 558	4.08	3,237	1,961	66,775	450,782
	287	.05	704	94	31,576	174,935
1927	[b] 661	5.95	2,859	1,777	41,571	555,820
	35	.18	192	754	18,813	

[a] Crude ore unless otherwise indicated. [b] Concentrate.

Until 1913, when the Empire Zinc Co. took control of the property, the zinc ore was shipped in the crude state. That company decided that it would be economical to calcine the material, and a vertical kiln was erected at the base of the aerial tramway.[53] The following table records the quantity and composition of the raw material charged as well as that produced. It is interesting to note that the loss in weight included not only carbon dioxide and water but some zinc, which was presumably reduced and volatilized during the process.

Results of calcining carbonate ore from Potosi mine

Year	Crude ore		Calcined ore		Loss in weight (per cent)	Zinc loss (per cent)
	Tons	Zinc content (per cent)	Tons produced	Zinc content (per cent)		
1914	4,710	31.5	3,587	39.2	23.3	6.0
1915	10,983	32.9	8,692	38.7	20.8	6.8
1916	13,759	35.5	10,732	42.1	22.0	7.5
1917	10,285	33.9	7,624	42.0	25.8	7.9

Geology.—The Potosi deposit lies in the massive Yellowpine limestone, and its stratigraphic position, therefore, is exactly the same as that of the Yellow Pine deposit, but the structural relations are entirely different. Inasmuch as Gilbert and others have been misled by the local structure, doubtless because of inadequate time for study of the near-by region, a sketch is presented that sets forth the writer's interpretation. (See fig. 28.) The ore-bearing limestone, 80 feet thick and dolomitized near the ore body, crops out as a vertical cliff (pl. 33, *B*) and is underlain by the shaly Arrowhead limestone, 12 feet thick, which crops out and is encountered in many places underground. In a broad way the beds trend east and dip gently south. For several hundred feet north of the main tunnel the Arrowhead limestone is flexed sharply downward, and as the beds 500 feet or more farther west along the track to the tramway are vertical or dip west, it is easy to get the impression that they are stratigraphically higher than the ore-bearing limestone and that the mine lies near the crest of an anticline. When the local areal relations are examined closely, however, it is clear that the beds west of the mine are stratigraphically lower than the ore-bearing limestone, that they are upturned under the Keystone thrust farther west, and that a normal fault, which drops the west side 40 feet, passes a few feet west of the mouth of the tunnel. It is this fault, which trends N. 30° W. and dips steeply west, that produces the sharp flexure in the Arrowhead limestone. A similar fault crops

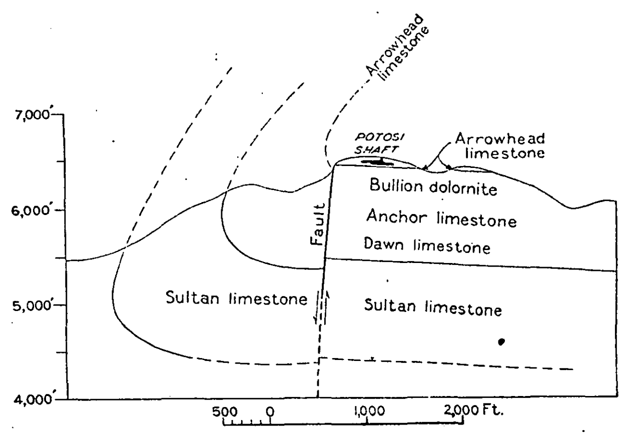


FIGURE 28.—Vertical section N. 80° E. through Potosi mine

out along the cliff 500 feet north of the tunnels. The displacement of both faults increases toward the southeast.

The underground workings reveal complicated structural conditions. (See pl. 34.) This examination indicates the outstanding structural relations of the ore deposit, but more comprehensive and detailed study would doubtless throw further light on it. The structure of the beds that inclose the ore body is shown by exposures of the shaly Arrowhead limestone as well as sporadic partings in the overlying bed. In detail the beds form a shallow syncline, the axis of which lies in the western part of the mine and pitches south. This axis clearly lies west of the principal ore-bearing ground. The faults in the mine are separable into two groups, both of which appear to have played an important part in the localization of ore, as they appear to be premineral. If any postmineral faults are present in the Potosi mine they have not been recognized.

The most persistent fault is that which forms the hanging wall of the deposit. It has been explored on

[53] Zinc, vol. 2, pp. 207–208, New Jersey Zinc Co., 1917.

four levels in the eastern part of the mine, where it marks the upper limit of many stopes. It is a broadly curved, simple surface, concave toward the ore body. The only conspicuous striae on its surface are found in the stopes between the fourth and fifth levels, where they pitch directly down the dip of the beds. From the positions of the Arrowhead limestone it is clear that there has been movement on this surface, the inner or northern block having moved upward a few feet. The Arrowhead limestone is locally crumpled along the hanging wall above the fifth level, and the relations indicate that this fault was formed during the period of thrust faulting. On the sixth level a fault is exposed that appears to be part of a complementary underlying surface that marks the lower limit of ore deposition in this part of the mine. Briefly, the principal ore body lies in brecciated dolomitized limestone between these two surfaces.

The other group of faults trends generally north and dips steeply either east or west. One of these faults passes through the center of the principal ore body and seems to have played an important part in its localization. On the fourth level south this fault is marked by a breccia limited by smooth walls on which the striae dip 10° S. Although there has been some movement on this fault, it has probably not been large. Some of the minor faults are marked by a breccia cemented by coarse white calcite.

The ore bodies in the mine may be considered in the light of their mineral content and structural relations. The bodies earliest worked near the outcrop were largely lenses of galena with minor oxidation products, which lay nearly parallel to the local bedding. The western stopes show their distribution. In the central part of the mine zinc minerals greatly exceed those of lead. In the northern workings and, curiously, in the higher levels, blende is rather abundant. It is also present on the third level in the central part of the workings and is abundant in the stopes below the fourth level in the eastern part of the mine. The masses of clean blende are rarely more than a few inches in diameter. Commonly small crystals are disseminated through granular gray dolomite, and elsewhere larger terminated crystals form a zone between gray dolomite and white calcite. Plate 28, *B*, shows a typical association of blende, gray dolomite, and white calcite. Such mixtures of blende and gray dolomite form tabular masses, 6 inches to 6 feet thick, roughly parallel to the bedding, and also cement irregular zones of dolomite breccia. Galena is present in many places in the central and western parts of the mine, but the quantity is rarely large, and it is usually not associated with blende. Where the galena has weathered, the green stains of copper minerals are present near by, and locally malachite is abundant.

Most of the ore bodies in the central part of the mines were nearly pure hydrozincite, but here and there veinlike bodies of smithsonite lie along watercourses. If calamine was ever abundant in many of the larger bodies present conditions give no such impression, for it is only sparsely distributed as a layer of crystals on hydrozincite. The bodies of hydrozincite show a wide range in shape and size. Even a glance at the map indicates the great irregularity in the shape of the larger bodies, but it is impossible to convey a comprehensive impression of the shape and distribution of the individual masses. The company's maps record stopes on no less than 20 levels, 6 to 30 feet apart vertically. As many of these levels overlap they display a maze of stopes and drifts that is bewildering. Most of the larger stopes are distinctly tabular and lie roughly parallel to the sloping hanging wall, so that they extend from one level to another 20 or even 50 feet higher, vertically. From such stopes, minor projections extend outward in diverse directions. Other stopes are smaller and rudely spherical and show meager if any continuity of ore with that of near-by stopes. The average stoping height is 5 to 10 feet, but some stopes are as much as 15 feet high, normal to the roof. In the northern part of the fourth level several stopes nearly circular in plan are as much as 20 and 25 feet high.

It seems clear that the arc-shaped hanging-wall fault has served to confine both the zinc and lead solutions which deposited the original blende and galena and the solutions which, as the result of recent weathering, deposited hydrozincite. To judge from the present distribution of blende and galena, it seems clear that the most persistent northward fault has been the site for deposition of the sulphides and that it is premineral. The other northward faults probably also controlled the local deposition of both sulphides. The most satisfactory explanation of the relations of the sulphide minerals assumes that the hanging-wall fault is related to the early folding and thrust faulting and that the solutions which introduced the zinc and lead rose along the northward faults and spread out northeast and west, largely in the breccia under the hanging-wall fault but locally along bedding planes.

At a number of places on the second and third levels the relations of hydrozincite to dolomite and calcite show that hydrozincite is deposited by replacing the other minerals. Where smithsonite has been found, as on the second level north, it lies along open watercourses and does not appear to have replaced any carbonate rock. It is not clear how far, under weathering conditions, zinc has migrated from the blende which was its source. In most places it seems that the zinc has not migrated more than a few feet, but some bodies of hydrozincite are sufficiently remote from distinct faults and are so related to the disturbed bedding surfaces as to indicate that the contained zinc has been derived from bodies of blende as much as 25 or 50 feet distant.

From the present distribution of the bodies of hydrozincite and those of blende it seems that the oxidizing waters, entering at the surface, descended along bedding surfaces and faults and moved downward and southward before moving westward toward the valley. Although the known bodies of hydrozincite are practically exhausted, others may be found south of the present workings and at deeper levels. Bodies of blende also should be found in that part of the ground.

DAWN MINE

The Dawn mine (No. 4, pl. 30) is 9 miles northwest of Goodsprings, between the Contact and Ninety-nine mines. The claim was located by A. Munzebrook in 1910, and although a little work was done in the next few years, most of the shipments were made by the Dawn Mining Co. in 1918. The principal exploration is an inclined shaft, which extends southwest into a ridge for a distance of 200 feet. The workings explore a crushed zone in the upper part of the Bullion dolomite. The beds trend N. 20° W. and dip 60° NE., and the breccia zone trends N. 40° to 50° E. and dips 45° SE. About 100 feet north of the mouth of the shaft there is an extensive northwestward-trending normal fault, one of those parallel to the Ninety-nine fault.

The principal mineral encountered was light-colored hydrozincite, but some calamine, together with galena and its oxidation products, was generally present. One prospect 50 feet southeast of the shaft yielded an intimate mixture of siliceous limonite and wulfenite. The shipments were derived from two stopes, both of which were limited on one side by good walls that trend N. 40° E. and dip 45° SE.; the larger was 25 feet long, 30 feet high, and 1 to 4 feet wide. Doubtless the primary ore lay along fractures that cut obliquely across the bedding.

Production of Dawn mine, 1917–1920

Year	Crude ore (tons)	Silver (ounces)	Lead (pounds)	Zinc (pounds)
1917	8	36	1,534	3,504
1918	146	808	68,148	23,803
1919	40			27,224
1920	14		4,838	7,358

PAULINE MINE

The Pauline mine (No. 5, pl. 30) lies half a mile northeast of the Contact mine, on the west edge of sec. 22, T. 23 S., R. 58 E. About 250 feet of work has been done, but most of it is in a tunnel that extends generally northwest. The tunnel is driven in dolomitized Yellowpine limestone at the top of the Monte Cristo formation, about 75 feet above the Contact thrust, along which the beds are thrust upon the Aztec sandstone. Some ore has been stoped above the tunnel along a zone that trends N. 40° W. and lies parallel to an extensive normal fault 75 feet to the southwest. This relation fortifies the impression obtained elsewhere that the Ninety-nine and other near-by faults are premineral.

Although there is no record of shipments, some material has doubtless been shipped. The dump contains a number of lead, zinc, and copper minerals, but probably the most abundant is cuprodescloizite, which forms mammillary crusts around rock fragments.

The Aztec claim, which has been explored by a shallow shaft near the trail to the Contact mine, likewise yielded many specimens of an olive-green vanadate.

CONTACT MINE

The Contact mine (No. 6, pl. 30) is the southernmost of the group of mines that lies north of Goodsprings on the east slope of the mountains. It is about 8 miles north of the town. It was located by A. L. Chaffin in 1906, but little work was done until 1915, when the Goodsprings Contact Mining Co. was formed. Most of the work was done during 1916 and 1917, but none has been done since 1919.

The Contact mine explores a deposit in the Bullion dolomite near the base of a large block of Monte Cristo and Bird Spring limestones, which are thrust eastward along the Contact fault upon the red Aztec sandstone. The fault is clearly shown along the hill northeast of the mine, where it has been explored by several prospects; it trends about N. 10° E. and dips 15° W. The beds form part of a broad southward-pitching anticline, which has been traced a mile south and 6 miles north, but it is much broken by later faults. At the mine the beds strike S. 65° W. and dip 50° to 70° SE. At the collar of the Contact shaft the Contact thrust fault lies about 250 feet vertically below the surface. The workings explore a zone about 150 feet stratigraphically below the basal sandstone of the Bird Spring formation, which is exposed on the ridge southwest of the mine.

There are two principal workings—a tunnel that extends about 160 feet southwest and a shaft on an incline of about 40° several hundred feet west of the tunnel. The tunnel explored a zone parallel to the local bedding. From the shaft there are drifts northeast at 90 feet below the top and at the bottom, possibly 300 feet in all. Ore was stoped west of the shaft from a roughly triangular area, 40 by 50 feet and as much as 6 feet thick in places. This ore occurred in dolomite breccia recemented by reddish dolomite in a zone parallel to the local bedding, trending approximately N. 70° W. and dipping 40° SW. To judge from what may be seen now, the ore was largely earthy hydrozincite and calamine, locally associated with galena and oxidized lead minerals. Cuprodescloizite and aurichalcite are found here and there.

Production of Contact mine, 1912–1925

Year	Crude ore (tons)	Silver (ounces)	Lead (pounds)	Zinc (pounds)
1912	27	3	345	16, 705
1916	290	----------	----------	170, 284
1917	345	1, 037	64, 634	119, 971
1925	19	----------	----------	12, 470

PILGRIM MINE

The Pilgrim claim (No. 9, pl. 30) was first located in 1892 by A. G. Campbell, but little work was done until 1908, when it was acquired by Harvey Hardy and associates. The present group of seven claims is owned by the Pilgrim Mining Co. They are about 5 miles northwest of Goodsprings.

The principal working is an inclined shaft, which extends westward at 32° to the 90-foot level and then

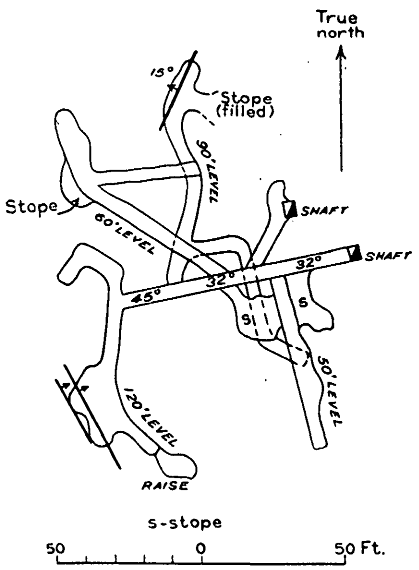


FIGURE 29.—Sketch map of Pilgrim mine

45° to the 120-foot level. There are also drifts south at 40 feet and north at 52 feet. (See fig. 29.) The country rock is dolomitized thin-bedded limestone in the lower part of the Bird Spring formation, but the 40-foot level south struck sandstone, probably a bed that lies near the base of the formation. In a broad way the beds strike northwest and dip gently southwest. They are considerably folded locally, however, and cut by numerous curved joints; these conditions are not surprising, as the Potosi thrust lies only a few hundred feet to the east, slightly buried under the wash. If the Red Cloud dike extends much farther northwest than the surface exposures, it lies 800 feet west of the Pilgrim shaft.

Lead minerals were more abundant in the mine than those of zinc. Although galena is common in the lower workings as coarse crystals in cavernous dolomite breccia, it is less abundant than cerusite above the 60-foot level. The material shipped from the upper stope was largely gray crystals of carbonate of lead that passed a half-inch screen and contained 15 to 25 per cent of lead and 15 to 25 ounces of silver to the ton. Lenses of earthy hydrozincite are more abundant in the lower levels, and that from the face of the 90-foot level has a pale lavender color. Calamine is widespread, and wulfenite is found here and there.

The largest stope lies above the 60-foot level south of the shaft, extends irregularly over an area 40 by 50 feet, and is 1 to 4 feet high. Its roof is a wall that extends N. 55° W. and dips 25° SW. and probably coincides with the bedding. At the north end of the 90-foot level a stope lies below a curved wall that trends east of north and dips at low angles to the west; probably this wall also coincides with the bedding but is at a lower stratigraphic position than the upper stope.

Although there are minor faults that cut across the beds, most of the ore lay along folds in the bedding planes, some of which are very irregular in detail. One breccia zone, locally cavernous, extends northward from the stope above the 60-foot level south of the shaft to the stope at the face of the 90-foot level north. The sporadic distribution of ore minerals is clearly due to the complicated structure of the beds where they overlie the Potosi thrust fault.

At a shallow shaft several hundred feet northeast of the main Pilgrim shaft there is a vein or bedded lens of nearly pure pyromorphite, in places as much as 8 inches wide. The strike of the lens is west and the dip south, but it ended abruptly westward against a slip.

Production of Pilgrim mine, 1908–1927

Year	Crude ore (tons)	Gold (ounce)	Silver (ounces)	Copper (pounds)	Lead (pounds)	Zinc (pounds)
1908	21	0. 53	332	-------	25, 190	-------
1909	1	-------	-------	-------	1, 209	-------
1911	7	. 13	62	-------	7, 310	-------
1916	152	-------	548	2, 600	45, 996	53, 500
1917	77	-------	838	1, 114	30, 735	19, 149
1918	46	-------	310	-------	33, 773	-------
1925	15	-------	-------	-------	3, 360	6, 340
1926	17	-------	11	-------	3, 647	9, 528
1927	8	-------	-------	-------	1, 971	3, 180

PRAIRIE FLOWER MINE

The Prairie Flower claim (No. 11, pl. 30) is 4 miles northwest of Goodsprings and half a mile northeast of the Yellow Pine mine. It was located in 1901, but little work was done before 1908, when, with the Solio claim, it was sold to S. E. Yount and W. E. Allen for $6,000. They began work and, after striking lead ore within a few weeks, sold it to Jesse Knight and Alonzo D. Hyde for $12,000. The Prairie Flower Mining Co. was formed, and the ore body was explored to a depth of 110 feet from the old shaft. During 1909 and 1910 the company produced 10 carloads of high-grade lead ore and about 30 carloads of oxidized zinc ore, 1,314 tons in all. From September, 1911, to 1913 it was leased to G. Meacham, R. Duncan, and J. A. Fredrickson, who sank the shaft to its present depth—300 feet—and mined 203 tons of lead and zinc ore. In 1917, under lease to the Prairie Flower Leasing Co., the new or Hale shaft, several hundred feet south of the old shaft, was sunk to 200 feet and drifts run north and south. In 1923 this shaft was sunk to 400 feet, and crosscuts were run east and west. Early in 1927 the 400-foot level east was connected by a raise with the old Prairie Flower shaft. At the present time the company is controlled by the Yellow Pine Mining Co.

Production of Prairie Flower mine, 1908–1918

Year	Crude ore (tons)	Gold (ounces)	Silver (ounces)	Copper (pounds)	Lead (pounds)	Zinc (pounds)
1908	22	-------	187	38	25, 238	--------
1909	105	-------	-------	-------	--------	67, 204
1910	1, 209	10. 63	5, 010	4, 730	363, 517	388, 111
1911	40	19	123	232	19, 302	10, 873
1912	44	-------	-------	-------	--------	26, 924
1913	119	-------	-------	-------	--------	79, 909
1915	57	-------	-------	-------	--------	39, 760
1916	346	-------	2, 085	-------	92, 648	156, 400
1917	339	-------	1, 406	666	124, 322	9, 457
1918	20	-------	182	-------	9, 439	3, 527

The rocks exposed at the surface near the Prairie Flower shaft include the Yellowpine limestone and the Yellow Pine sill of granite porphyry. The Arrowhead limestone does not crop out on the surface but has been repeatedly struck underground. The sandstone at the base of the Bird Spring formation is present in the workings near the north winze of the Yellow Pine mine (fig. 30), but in several places farther north it is represented by nearly black sheared shale, locally 2 to 5 feet instead of 23 to 28 feet thick. At the bottom of the Solio shaft, 750 feet north of the old Prairie Flower shaft, the horizon of the sandstone is represented by a bed of chert cobblestones in dark clay. The beds trend N. 30° to 45° E. and dip 45° to 60° NW. As explorations are confined to two levels, it is not possible to make a structure contour map of the entire area, but portions of the explored ground are included in the map of the Yellow Pine mine forming Plate 36, *B*.

The Yellow Pine sill is struck on the 200-foot level from the new shaft but dips more steeply than the local bedding. There is a possibility that it follows a preintrusive thrust fault slightly steeper than the bedding, but it more probably follows the general zone of unconformity at the base of the Bird Spring formation.

On the 900-foot level north of the new shaft the drift passes through two blocks of porphyry that are probably faulted parts of the sill but may be small dikes.

For a short distance north and east of the old shaft the limestones near the ore are sporadically altered

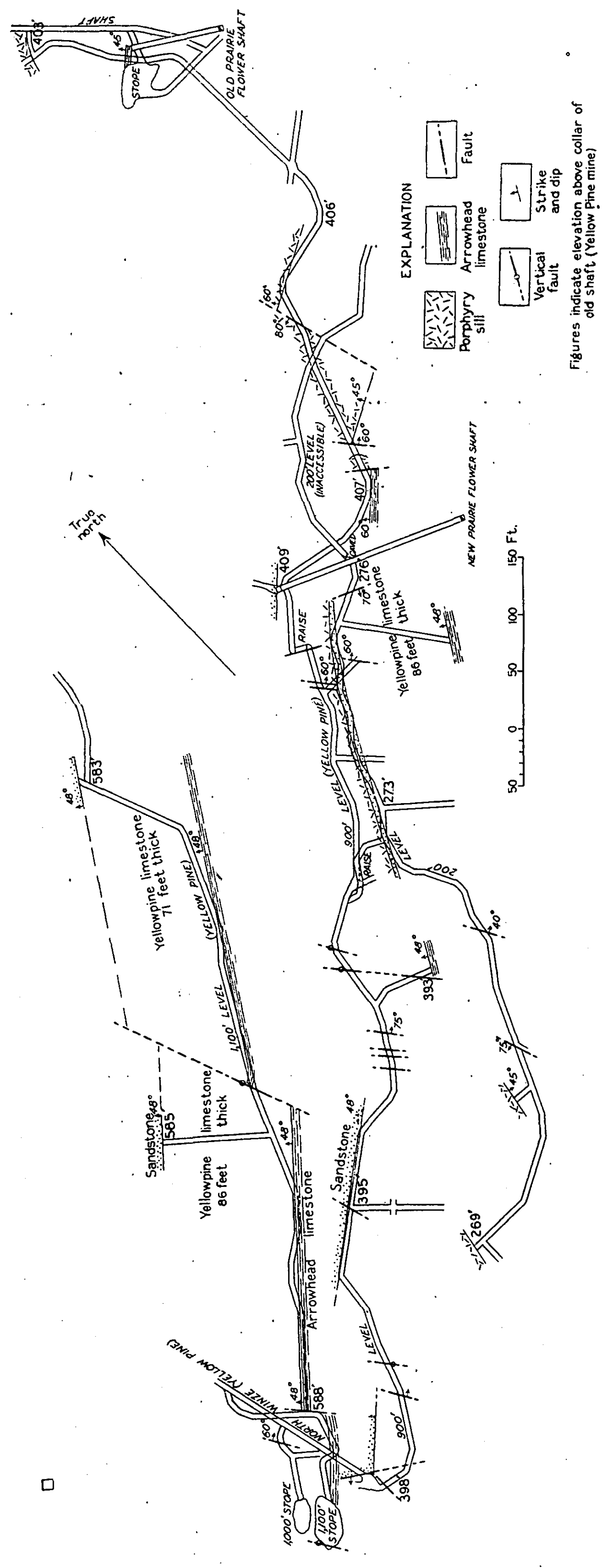


FIGURE 30.—Underground workings of Prairie Flower mine

to dolomite, and the ore body is entirely surrounded by it. In places the contact of the limestones and porphyry is marked by sheared gouges and no alteration of the limestones is noticeable.

The new shaft attempted to find ore under the Yellow Pine sill but was not successful. About 10 tons of low-grade zinc ore, which was dolomite partly replaced by calamine, was found on the 200-foot level north, but nothing more. Obviously this zinc had migrated downward from its original site of deposition as sulphide.

The old shaft explores a shoot that pitched about 60° SW. in a plane parallel to the local bedding. The present open stope, worked from the surface to the first level, about 110 feet on the slope below the surface, extends 40 feet along the level and is 6 to 15 feet wide. It is limited by a good hanging wall that trends N. 65° E. and dips 50° NW. and hence is nearly parallel to the bedding. It is reported that some ore was found on the lower levels and that the ore lay generally parallel to that above but was lower in grade. Explorations to the west or northwest meet the porphyry scarcely 25 feet above the shoot. From the first to the second level the shaft followed a cavern in the limestone covered with a mammillary crust and stalactites of aragonite.

From the record of shipments it is clear that zinc only slightly exceeded lead in the mine. Probably galena was the most abundant lead mineral, but on the dumps at present the arsenate, mimetite, is much more common. In many fragments all the galena except a few small kernels is oxidized to the sulphate and carbonate of lead. The most abundant zinc mineral in the upper levels now is calamine, although the earthy carbonate is not uncommon. Fragments containing calamine are locally covered with a thin yellow mammillary crust of a vanadate, probably descloizite.

YELLOW PINE MINE

The Yellow Pine Mining Co. owns a group of 12 mining claims (No. 12, pl. 30) that cover most of the ravine locally known as Porphyry Gulch, 4 miles west of Goodsprings. (See pl. 35, *A*.) The company owns the narrow-gage railway that connects the mine with the mill at Goodsprings and with the Union Pacific Railroad at Jean. Although the Rover and Hilo claims were located in 1892 and 1897 respectively, the Bybee claim, located by Addison Bybee in 1900, which lies between the other two claims, covered the ore bodies that gave the mine its early eminence. Recently the workings have been extended northward to mine large ore bodies under the Radio and Como claims, which were located in 1904. The original company was organized by J. F. Kent in 1901 with 250,000 shares, but in 1906 it was reorganized with 1,000,000 shares of $1 par value.

History.—The first ore shipped from the claims, 18 tons of oxidized copper ore, was obtained in 1906 from a shallow shaft 500 feet south of the Hale shaft, but no connection of this body with those of zinc carbonate that have made the mine famous has ever been established. Faint veinlets of brown jasper in the dolomitized limestone were the only evidence of ore near the shaft that yielded the copper ore; similar veinlets also crop out near the old shaft that encountered the first bodies of zinc ore in the mine.

Small bodies of mixed lead and zinc ore were found in 1907 in the old shaft 200 feet east of the Hale shaft, but the first large body of zinc ore was struck in this shaft at 110 feet. This body was followed southwest and led to the successive exploitation of the deeper bodies farther southwest and in 1912 to the sinking of the Hale shaft, from which all the ore bodies in the southern part of the mine to the ninth level were mined. In 1916, when conditions in the southern part of the mine were discouraging, exploratory work from the vertical shaft in the northern part of the third level encountered the ore body in the 350-foot stope, and from that time the development has been progressively northward. Early in 1922 most of the ore known south of the porphyry dike on the 900-foot level had been mined, when a raise from the 900-foot level north of the dike struck two large bodies of ore. The company then sank the new vertical shaft (completed January, 1924) from which all the recent work has been done. The present distribution of stopes is quite different from that of the ore bodies indicated by the work before 1916.

Milling.—In order to ship products that would yield the greatest profit the company has faced a peculiar milling problem. Most of the stopes have yielded an intimate mixture of galena and oxidized lead and zinc minerals rather free from gangue minerals. It has been the purpose to separate, as far as possible, the lead and zinc minerals and to throw nothing away.

The first mill used by the company in treating the ore from the Yellow Pine mine was that built in 1899 by lessees of the Columbia and Boss mines. When remodeled to treat Yellow Pine ore, it contained rolls, screens, Harz jigs to treat the coarse sizes, Richards classifier, and Overstrom tables.[54] In 1919, after a fire at the mine, the mill was remodeled and eight Diester-Overstrom tables, screens, jigs, and five oil-fired calcining furnaces were installed.[55] About 1920 the company permitted the United States Bureau of Mines to make exhaustive tests in an experimental plant to determine the feasibility of separating the lead and silver from the zinc by chloride volatilization.[56] Although the tests were encouraging, no attempt has been made to change the milling plant. The remodeled mill was

[54] Palmer, L. A., Some zinc-lead mills in California and Nevada: Met. and Chem. Eng., vol. 15, pp. 203-205, 1916.

[55] Yellow Pine Mining Co. Ann. Rept., 1919.

[56] Varley, T., Barrett, E. P., Stevenson, C. C., and Bradford, R. H., The chloride volatilization process of ore treatment: U. S. Bur. Mines Bull. 211, pp. 72-81, 1923

burned in September, 1924, and has since been replaced by a new mill.

Production.—The production of the Yellow Pine Mining Co. is recorded in the two accompanying tables. The first records the annual statements submitted to the United States Geological Survey by the company and shows the content of recoverable metals. The second has been assembled by the company and shows the classification of the material shipped as well as the total receipts, costs, and profits.

A review of the average content of the products shipped each year shows that the crude lead ore has contained 47 to 63 per cent of lead, 5 to 13 per cent of zinc, and 17 to 22 ounces of silver to the ton. The lead concentrate has contained 51 to 56 per cent of lead, 12.5 to 14.5 per cent of zinc, and 25 to 50 ounces of silver to the ton. As in other mines in the district where the crude ore has been milled to yield a lead concentrate, the silver content of the concentrate is two or more times that in the crude ore per unit of lead. The mixed lead-zinc ore has contained 13 to 16 per cent of lead, 27 to 30 per cent of zinc, and about 11 ounces of silver to the ton. The crude zinc ore has contained 34 to 45 per cent of zinc, 3.5 to 6.5 per cent of lead, and 1 to 6 ounces of silver to the ton. The zinc concentrate has contained 32 to 34.5 per cent of zinc, 4 to 6.5 per cent of lead, and 2.5 to 6 ounces of silver to the ton. The zinc slime has contained 32 to 35 per cent of zinc, 6.5 to 8 per cent of lead, and 3.5 to 6 ounces of silver to the ton. The insoluble matter, probably in large part silica, is commonly under 5 per cent, but some shipments of crude lead ore contain as much as 15 per cent.

Production of Yellow Pine mine, 1906–1928

Year	Ore mined (tons)	Ore shipped (tons)	Gold (ounces)	Silver (ounces)	Copper (pounds)	Lead (pounds)	Zinc (pounds)
1906	18						
1907	240			1,886	7,800	172,800	29,410
1908	640		2.03	7,800		561,595	88,319
1909	1,210		2.66	16,940	54	280,000	444,800
1910	1,505		5.71	5,798	790	371,747	744,043
1911	2,317	[a] 729	.89	12,951		458,216	210,257
		[b] 2,462	14.00	19,919		668,836	1,459,333
1912	19,378	[a] 18,199		205,915		5,792,929	8,653,172
		[b] 697		3,156		110,227	452,693
1913	16,687	[a] 16,583		176,411		5,022,172	8,035,455
		[b] 981		3,727		110,490	619,806
1914	15,472	[a] 14,621		114,345	1,423	3,575,586	6,849,895
		[b] 1,185		3,346		114,774	793,715
1915	16,136	[a] 15,436		81,169		2,985,643	8,029,100
		[b] 2,267		6,412		191,480	1,458,648
1916	20,581	[a] 20,105		91,564		3,622,064	9,861,318
		[b] 2,080		7,114		170,217	1,335,746
1917	19,976	[a] 19,573		147,170		4,457,766	8,953,341
		[b] 465		1,278		32,598	288,222
1918	8,200	[a] 7,862		89,218		1,694,890	3,784,326
		[b] 11,559		12,947		2,219,209	6,012,737
1919	10,900	[a] 10,310	22.17	101,269		2,932,342	4,952,916
		[b] 968	8.66	30,310	3,464	533,860	69,360
1920	14,353	[a] 13,891		83,600		2,709,500	8,153,880
		[b] 1,066		1,120		28,000	705,800
1924	20,402	[a] 7,620		77,959		2,582,269	2,401,738
		[b] 12,782		40,739	15,451	4,641,597	5,160,265
1925	14,946	[a] 3,343		16,174		952,953	1,363,956
		[b] 10,193		34,938		2,800,203	3,654,499
1926	2,521	[b] 2,521		1,430		351,533	1,277,307
1927	7,814	[a] 320	.25	5,831	4,670	353,678	
		[b] 5,510		479	134	919,455	2,635,756
1928	8,626	[a] 1,163	.48	19,836	33,747	1,200,573	
		[b] 2,385	1.13	1,062	5,656	424,416	1,074,527

[a] Concentrate. [b] Crude.

Production of Yellow Pine Mining Co., 1907–1929

Year	Ore shipped (tons)							Net value f. o. b. Jean		Costs		Net operating profit (+) or loss (−)	Miscellaneous income	Net profit		Dividends
	Crude lead	Crude zinc	Crude lead-zinc	Lead concentrate	Zinc concentrate	Zinc slime	Total	Per ton	Total	Total	Per ton			Total	Per ton	
1907	122.12						122.12	$31.14	$3,803.18	$13,816.60		−$10,013.42				
1908	645.73						645.73	28.35	18,311.79	18,475.12		−163.33				
1909							1,220.73	17.68	21,592.98	21,293.36		+299.62		$299.62		
1910							1,719.85	13.95	23,988.72	38,344.73		−14,356.01				
1911							3,334.80	14.80	49,356.89	108,620.56		−59,263.67				
1912	41.86		676.34	3,276.42	13,146.33	2,955.15	20,096.00	18.11	363,986.11	144,715.17	$7.21	+219,270.94	$1,134.02	220,404.96	$10.96	
1913	17.53	963.16		2,940.87	11,242.85	2,399.43	17,563.84	17.15	301,244.95	145,952.55	8.91	+155,292.40	1,802.17	157,094.57	8.94	
1914	34.21	1,151.27		2,143.98	7,536.52	3,303.12	14,169.10	13.48	190,991.75	111,881.67	7.89	+79,110.08	479.08	79,589.16	5.61	
1915		2,266.67		1,521.88	11,260.20	2,654.64	17,702.59	48.50	889,409.20	153,566.52	8.67	+735,842.68	548.10	736,390.78	41.60	$450,000
1916		2,080.46		2,292.81	14,242.92	3,569.19	22,185.39	44.30	982,563.35	220,037.08	9.92	+762,526.27	5,673.47	768,199.74	34.62	800,000
1917	2.68	411.18	50.97	3,155.97	12,895.89	3,513.44	20,030.14	32.81	662,887.21	247,548.46	12.35	+415,338.75	5,665.92	421,004.67	22.01	360,000
1918	322.20	1,613.80	9,622.70	1,343.00	4,781.90	1,738.10	19,420.50	27.09	526,261.81	206,556.44	[a] 10.64	+319,705.37	20,045.00	339,750.37	17.50	300,000
1919	865.91	102.38		2,217.28	6,704.10	1,389.92	11,279.59	28.29	319,140.33	164,542.51	14.04	+171,340.62	7,207.13	178,547.75	15.83	150,000
1920	28.31	1,038.42		1,900.61	9,758.00	2,133.00	14,858.34		383,848.52	243,346.52		+148,275.90	6,368.21	51,553.15		90,000
1921									8,885.32				3,572.23	5,075.60		
1922		330.00		140.00	790.00	250.00	1,510.00	22.02	33,247.42	37,253.91	24.67	+356.01	[b] 3,637.17	[c] 3,281.16		
1923		3,604.00	3,230.00	403.00	2,157.92	2,825.00	12,220.00	27.21	252,024.49	170,737.93	13.97	+81,286.56	1,826.05	83,112.61	6.80	90,000
1924	2,570.66	40.88	10,169.96	2,428.74	3,683.40	30.58	18,924.24	28.91	547,073.47	229,069.65	12.10	+318,013.82	−13,979.52	304,034.30	16.06	160,000
1925	2,506.78	1,640.04	7,685.97	523.51		1,179.62	13,535.93	27.21	367,440.13	168,515.63	12.45	+198,924.50	2,915.90	201,840.40	14.91	160,000
1926	121.27		2,152.87				2,274.14	23.89	54,330.17	53,076.66	23.34	+1,253.51	10,726.49	11,978.00	5.27	
1927	19.00	1,409.00	4,024.00	369.00			5,821.00	20.83	121,287.55	109,214.89	18.76	+12,072.66	−5,917.02	6,155.64	1.08	
1928	145.99		2,247.29	1,179.74			3,573.02	23.25	83,082.48	68,801.28	19.25	+14,281.20	−1,429.97	12,851.23	3.59	
1929	477.75		1,559.87				2,037.62	23.58	48,045.58	40,250.82	19.75	+7,794.76	2,091.15	9,885.91	4.85	

[a] Low costs owing to ore being shipped in crude state from Feb. 1 to Sept. 1, 1918, and mill closed down. [b] Expense. [c] Deficit.

Inclosing rocks.—The workings of the Yellow Pine mine explore a stratigraphic zone about 300 feet thick. The beds trend N. 20° to 45° E. and dip 30° to 45° W. (See pl. 36, *A*, and fig. 32.) They are cut by a dike of orthoclase porphyry and are overlain by the Yellow Pine sill of the same rock. The lowest beds penetrated by the workings include the upper part of the Bullion dolomite, which is coarse grained and light gray. It is exposed in drift 260 southeast on the 200-foot level and in drift 626 on the 600-foot level.

The Arrowhead limestone, which overlies the Bullion dolomite, is exposed in many places underground, and its thickness does not deviate much from 10 feet. It is made up of the characteristic layers of limestone 2 to 3 inches thick, now completely dolomitized, alternating with layers of shale one-eighth to one-half inch thick. (See pl. 6, *B*.) On account of the numerous exposures in the workings, the top was chosen as the surface on which to draw structure contours in order to portray the structure accurately.

The Yellow Pine limestone contains all of the ore mined, and hence most of the mine workings are in it. Where exposed in raise 717 above the 700-foot level in the south-central part of the mine, the thickness is 110 feet, but at the north end of the mine it is only 71 feet thick. As the bed is unconformably overlain by the basal sandstone of the Bird Spring formation (see p. 22), this decrease in thickness may be due to erosion of the bed before the sandstone was laid down. It is light gray, crystalline, and wholly dolomitized in the ore zone. The table on page 62 presents four analyses submitted by the company and shows that this bed is now 91.1 to 94.4 per cent dolomite. Although no analyses have been made from this bed where it is unaltered in this mine, the analyses of the same bed in the Christmas mine (Nos. 7a and 7b, p. 61) probably represent the approximate composition. As there is no visible effect of the orthoclase porphyry dike upon the ore-bearing dolomite, a sample collected 1 foot south of the dike in drift 907 on the 900-foot level was examined closely. It is largely light gray and fairly well crystallized, but it is cut by vague veinlets of lighter and more coarsely crystalline dolomite. The only foreign material consists of a small percentage of very perfect clear quartz crystals, mostly 0.1 millimeter long and 0.01 to 0.02 millimeter in diameter, which contain sparse inclusions. It is not clear whether this silica has been added as the result of the intrusion of the dike or represents the silica originally in the limestone, recrystallized during or after dolomitization. It seems certain that the intrusion of the dike has not produced much change in either the composition or the texture of the dolomitized limestone.

The basal sandstone of the Bird Spring formation is exposed at many places in the mine. (See pl. 36, *A*.) In the southern part of the mine two measurements of thickness were 28 feet each, but in the northern part two other measurements were 26 and 23 feet. The bed is uncommonly homogeneous in texture, and there are few traces of bedding. It breaks readily in angular blocks. The color is generally pale buff but locally is brownish. One specimen collected from the top of raise 916, in the northern part of the mine, is made up largely of subangular to angular grains of clear quartz 0.1 to 0.05 millimeter in diameter. The only other mineral present is plagioclase feldspar, of which a few grains were noted. Recent work on the Prairie Flower claim shows that the sandstone bed is represented in some places by a bed of black shale scarcely 2 feet thick and elsewhere by a zone of cobblestones, most of which are chert. (See p. 128.)

The Yellow Pine sill of granite porphyry is exposed at only a few places in the mine, although the Hale shaft is entirely in it as far as the 300-foot level. In the northern part of the mine a dike of similar rock 60 to 80 feet thick cuts across the beds. The rock has rather uniform texture throughout and like that at the Red Cloud mine contains a small percentage of disseminated pyrite and is otherwise altered.

Structure.—The general structural relations of the rocks within which the Yellow Pine ore bodies have been found are presented on page 46. It is the purpose here to describe those structural features observable underground that appear to have bearing on the origin of the deposit and the explorations for ore bodies. The content and relations of the ore bodies are described elsewhere.

The beds that inclose the ore bodies trend northeast and dip northwest. Only superficial observations are needed to show that there are many faults in the mine and that they have a bearing on the search for ore. Some are nearly parallel to the bedding in strike and dip, others are parallel in strike and opposed in dip, and still others cut directly across both the strike and dip of the beds. As the record of these faults on a mine plan such as that shown in Plate 36, *A*, leaves only an impression of confusion, Plate 36, *B*, has been prepared in an attempt to show the more notable of these faults not only clearly but accurately. In this illustration 50-foot contours have been drawn on the top of the Arrowhead limestone and on the most persistent faults exposed underground, just as if the overlying beds had been removed and one could look down on this bed and the faults. Such a map might be drawn upon any one of three surfaces—the top of the Arrowhead limestone, the hanging wall of the Yellow Pine ore bodies, or the base of the basal sandstone of the Bird Spring formation—for the exact position of each was determined in many places. A review of the nature of each of these surfaces indicated that a map on the first of them would probably be more nearly correct, as it was the simplest surface. The base of the sandstone is a surface of unconformity, and the hanging wall of the ore bodies is not continuous throughout the mine, whereas the bed of shaly limestone is not only persistent, but, as it lies between two massive beds, it probably assumes the form of simply curved, though faulted, surfaces. For some areas where the data were incomplete it was necessary to calculate the position of the surface of the limestone from that of one of the other surfaces. So far as possible, the positions of the surfaces of bedding and of the faults have been correlated by trigonometric calculations from one level to another. The result is probably fairly close to the reality; probably the horizontal positions of most of the contours on the shaly limestone are within 10 feet of the actual positions, and few are more than 25 feet away. Doubtless some errors have been made in correlating faults on one level with those observed on another, but these should be confined to areas where there are many fractures.

As shown in Plate 36, *B*, the strike of the beds shifts by slight changes from N. 20° E. at the south end of the mine to N. 45° E. at the north end. The dip is 39° in a block at the south end, but, beginning at a fault (A, pl. 36, *B*), it increases gradually from 32° to 39° near the crushed zone at the middle and to 48° at the north end, and in the Prairie Flower ground it is as much as 60°. In detail most of the blocks for which the data are good, especially in the southern part of the mine, appear to be limited by simple curved surfaces rather than planes; this is shown by the converging instead of parallel contours.

In general, structure-contour maps primarily reveal the forms of the surfaces contoured, but secondarily, if based on good and abundant data, they also indicate elements in the structural history that may otherwise be very obscure. They also suggest local areas where further data may best be sought to aid in unraveling the history of the deposit. In applying them to problems of metalliferous deposits certain precautions in their use should be emphasized. Contours are necessarily horizontal lines on surfaces viewed vertically downward, and contour maps reveal form alone. If, as here, they are drawn on a bed and on faults that cut the bed, they show only resultant surfaces and require additional data, such as reliable grooves or striae, to indicate movements on the faults. In other words, where a contour on a bed is offset by a contour on a fault (pl. 36, *B*), it should be clearly understood that the offset is not necessarily the horizontal component (strike slip) of the fault. If, in addition to the structure contours, reliable grooves or striae on the fault are known, the direction and amount of the displacement (net slip) can be calculated.

Figure 31 has been prepared to explain further this aspect of structure contours. The block *ABCD* represents a vertical cross section of an inclined bed, of which *AD* is the upper and *BC* the lower surface. It is assumed that the section cuts across an ore body, *O*, whose outline is indicated. At the left horizontal contours are shown at assumed altitudes of 100, 150, 200, and 250 feet, and they are projected to the right to meet the lower surface of the stratum at *b*, *c*, and *d*. What will be the effect upon the structure contour lines on this lower surface and upon the horizontal projection of the ore body if the block is broken along the plane of the section and displaced to new positions $A'B'C'D'$, $A''B''C''D''$, and $A'''B'''C'''D'''$? An examination of the diagram shows that if the block is moved upward along the dip of the bed to $A'B'C'D'$, there will be no horizontal offset in the structure contours, but the trace of the ore body, *O* is displaced to O'. If the block is moved upward at an angle lower than the dip, say to $A''B''C''D''$, the contours are displaced from a' to a'', b to b'', etc., and the ore body to O''. Similarly, if the block is moved horizontally to $A'''B'''C'''D'''$, the contours are displaced from b to b''', c to c''', and d to d''', while the ore body is displaced an equal horizontal distance to O'''. The following significant conclusion may be summarized.

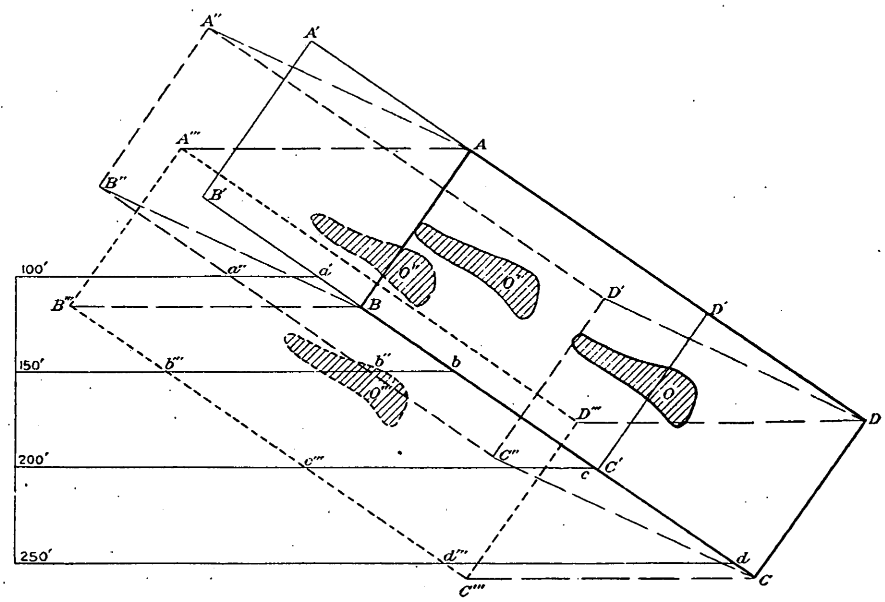


FIGURE 31.—Diagram to illustrate effect of faulting on structure contours

Where a stratum is broken by a fault, the shift in the contours on the stratum measures the difference between the dip of the stratum and the direction of movement on the fault. In other words, if a shift of an ore body along a fault can be proved from the maps and underground observations, and there is little if any shift of the structure contours, the direction of movement of the block must almost equal the dip of the bed.

From a consideration of this conclusion, it becomes clear that the effective solution of fault problems, such as have been met in the Yellow Pine mine, requires not only a clear picture of the form of the faulted blocks, such as is shown by a structure-contour map, but also trustworthy observations on the direction of movement on the faults, shown by grooves and striae. As striae commonly indicate only the direction of the latest movement on a fault, they are not highly reliable. The displaced line of intersection of a dike with a bed would be much better.

In the Yellow Pine mine the direction of movement on a fault also appears to indicate the epoch to which it probably belongs, even if other kinds of evidence are lacking, such as assuredly unbroken, unweathered ore minerals in the fault breccia.

Ore bodies.—In describing the ore bodies, attention will first be given to their mineral content, and later to their distribution, form, and relations to the faults that affect them. Zinc minerals considerably exceed those of lead throughout the mine, and although a few copper-bearing minerals are widespread, local concentrations are rare. Measured by the tonnage of the several products shipped, zinc minerals have been about four times as abundant as those of lead, but the zinc in the recoverable metal content of the shipments has ranged from two to three times the lead. The most abundant zinc mineral is hydrozincite, but here and there smithsonite and calamine are common. Small quantities of aurichalcite, azurite, and zincky clay are found. Doubtless zinc-bearing vanadates have been encountered, but none were recognized by the writer. In the recent deeper stopes galena is the commonest lead mineral, with cerusite, anglesite, and plumbojarosite next in order of abundance. Records indicate that cerusite may have been more abundant than galena in some of the older shallow workings. Probably anglesite was at no place the most abundant lead mineral, but it is widespread. Although the total quantity of plumbojarosite has probably been small, some of the upper stopes must have contained considerable, for the dump at the old shaft contains many lumps of it. Linarite and caledonite are very uncommon, but exceptionally fine crystals of linarite largely altered to caledonite, as much as 4 inches long, were found on the 900-foot level near the dike. Masses of crystalline mimetite were found in the large stope above the 900-foot level north of the dike; doubtless pyromorphite and vanadinite are also present, but they were not found. Of the copper minerals, probably malachite is the most abundant, but chrysocolla, azurite, and aurichalcite are also widespread. Radiating masses of stibnite and its oxidation products, as well as cinnabar, were found in masses of chert along fault Q at the north winze on the 900-foot level, where the sill is brought into contact with the ore-bearing limestone. Iron minerals are not common, but some of the higher stopes, such as that on the 200-foot level north, show lenses of limonite and limonitic chert with jarosite and beaverite. Minute grains of pyrite are disseminated through the dike on the 900-foot level.

Other than the dolomite that incloses the ore bodies, the only conspicuous mineral noted is chert, generally light or dark brown, and this is not widespread. Coarsely crystalline white calcite is not recorded, although it may have been present before the bodies were weathered. Quartz was not observed in the mine but may have been present in the upper levels as a product of weathering.

From this brief summary of the minerals noted in the mine it is clear that the original sulphide minerals have been thoroughly oxidized and that only traces remain to indicate their precise local distribution and relations. Zinc sulphide has not yet been found, and all of the galena is surrounded by a border of oxidized lead minerals.

From observations in many other mining districts it is known that the effect of weathering upon the original bodies of zinc and lead sulphides is to convert the metals first to sulphates, then to carbonates. Both these salts of lead are highly insoluble and rarely are found far from the place occupied by the original sulphide. The salts of zinc are much more soluble, however; hence they migrate downward along watercourses, and this must be borne in mind in considering the shape of the stopes of oxidized zinc minerals and their relation to the original bodies of sulphide minerals.

The distribution of the stoped ore bodies is shown on Plate 36, *A*. These are surprisingly continuous for 2,000 feet along the strike of the beds, when the number and displacement of the crosscutting faults is taken into consideration. In part this apparent continuity is due to local migration of zinc when the sulphide is weathered. The widths of the stopes are different in the different parts of the mine. Throughout most of the area south of the old and Hale shafts, the usual range in width is 3 to 10 feet, but in the 600 stope above the 600-foot level the width is locally 15 feet. The stopes in the northern part of the mine are uniformly wider, and those between faults K, L, and M range from 20 to 30 feet. Until recently a pillar of pure hydrozincite containing a little galena extended 30 feet from the foot to the hanging wall of the stope between faults K and L. (See pl. 36, *A*.) Doubtless much of the hydrozincite replaced dolomite, of which none remains, and the distribution of galena must be nearly the same as in the deposit before it was weathered. (See pls. 28, *C*, and 29, *A*.)

Although specific proof is no longer obtainable, the shapes of some stopes indicate the local migration of zinc downward during weathering. Thus, the rudely triangular stope from the 250 to the 300 foot level, adjacent to the old shaft, appears to have been formed by zinc migrating downward from the main stope above. Similar but smaller stopes in which one wall coincides with a fault are found rather widely.

In many parts of the mine, particularly south of the Hale shaft, the stopes are limited upward by smooth walls and although in places these walls seem to coincide with local bedding, elsewhere they appreciably depart from bedding in strike as well as dip. Thus, the hanging wall over the stope above the 600-foot level ranges from 10 to 35 feet stratigraphically below the overlying sandstone. In the same area the dip of the wall is 36°, although that of the inclosing beds is 32°. (See fig. 32, A.) In the northern part of the mine some stopes extend up to the overlying sandstone, whereas others near by are 30 feet lower. This discordance of dip between bedding planes and hanging walls of ore bodies, taken with brecciation of the dolomite on the lateral walls of the stopes, forms the basis for the conclusion that the sulphide ore bodies in the mine were deposited in a fault breccia rather than along bedding planes, as in many other districts.

In several parts of the mine there are superposed stopes. These are well shown on the 200-foot level south of the old shaft (cross section *b–b*, fig. 32, B), on the 500-foot level near the Hale shaft, and between the 900 and 1,100 foot levels, adjacent to the north winze. In each of these areas the lateral walls of the stopes show brecciation of the inclosing dolomite.

At a number of places in the mine, particularly on the lower levels in the northern part, under the large stopes on hydrozincite ore, there are bodies of smithsonite along fractures. In part the smithsonite is unaltered and rich enough to be mined as ore, but in some places it cements dolomite breccia and is too low in grade. Elsewhere the dolomite fragments have been dissolved and the remaining cavities partly or wholly filled with white hydrozincite and calamine. (See pl. 28, *D*.) Particular interest is attached to such occurrences of smithsonite because they indicate the earlier presence of bodies of zinc minerals at higher levels.

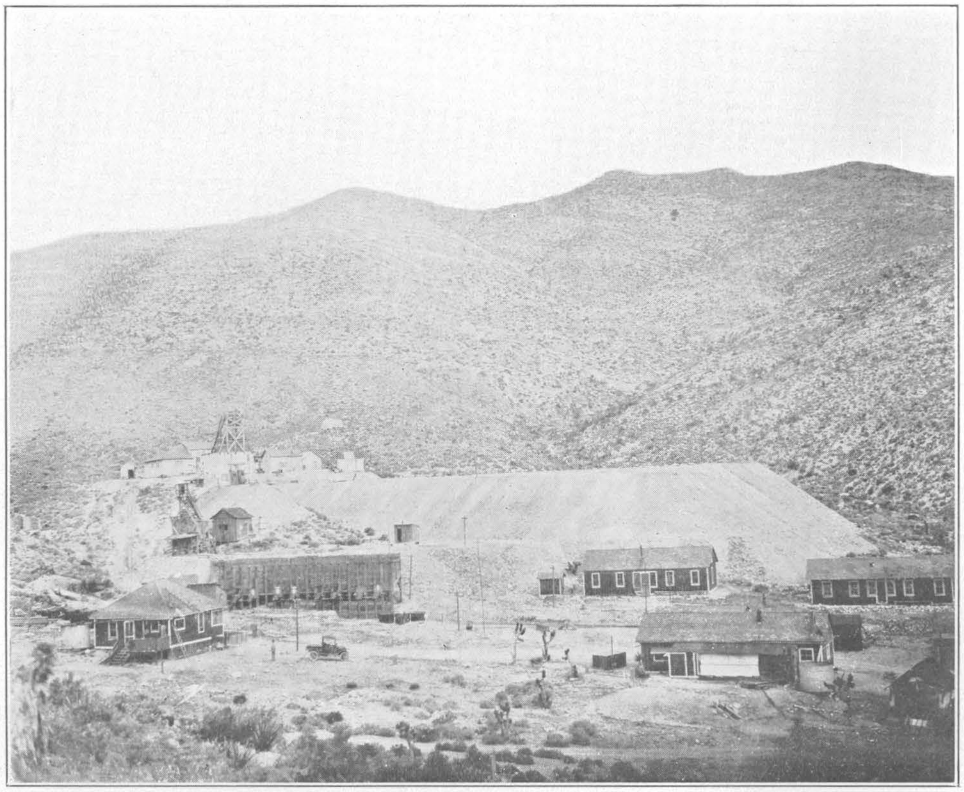
Faults.—During the examination of the mine it was the purpose to record the principal faults, although it was readily seen that, within the time available, it would be quite impossible to record all fractures. Most of those recorded are shown on Plate 36, *A*. It was also the purpose to determine whether the faults were formed before the sulphide mineralization (premineral), and therefore might have played a part in the localization of sulphides, or whether they were formed after the sulphide mineralization (postmineral). The postmineral group might include faults along which movement was either earlier or later than the oxidation of the sulphides.

The facts that in many places the strike and dip of the hanging wall of the ore body deviate from those of the local bedding and that the ore body coincides with a breccia zone indicate that the sulphide minerals were deposited along a fault fracture that must be related to the flat thrust faults of the region. If this is the case, it is a matter of some importance in the search for ore to determine whether the known ore bodies were localized on a single or several thrust faults and, as the ore bodies are not continuous in a given direction without break, whether the offsets were formed before or after mineralization. One may also speculate whether similar parallel flat thrust faults may not be found more deeply buried.

It will be profitable to review the present general distribution of ore shoots (stopes) in the light of the speculation whether their irregularities are most reasonably explained by postmineral or premineral faulting of a simple breccia zone on a thrust fault, as local criteria are lacking or very obscure in many places. The possibility should also be considered whether there may have been renewed postmineral movement on premineral faults. The simplest concept of the Yellow Pine shoots is that the sulphide minerals were deposited along a thrust fault in a simple pipe that plunged northward at an inclination of about 20° and that the shoot has since been broken by faults and weathered. This concept assumes that the solutions which deposited the sulphides had a source to the north and rose gently southward. But, as noted below, there can be no doubt that several cross faults were the sources of some mineralization, and it is necessary to consider an alternate concept that numerous premineral cross faults were channels of access of solutions to one or more breccia zones and that, although the breccia zones may have been continuous, they were broken before mineralization and local irregularities of form resulted from fortuitous differences in the cross faults. In considering irregularities of form of ore bodies, however, allowance must be made for the probable effect of migration of metals during weathering, and this is difficult to do with confidence.

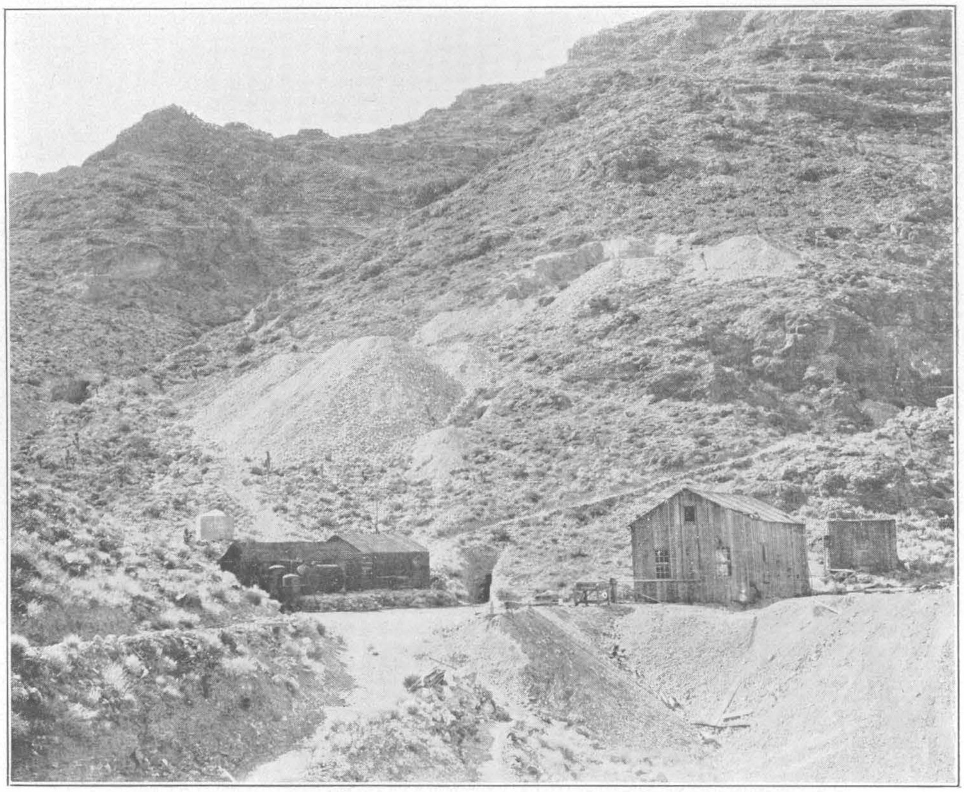
The only trustworthy criterion that a fault in this region is premineral is the presence of unbroken grains of galena in the dolomite breccia along the fault. The oxidized minerals of both lead and zinc may always contain materials that have migrated appreciably from the site of the original sulphides and therefore can not be used for this purpose. If many faults were explored extensively outside of the ore zone, it might be possible to use the presence or absence of dolomitization as a criterion, for areal work has shown that, except near centers of recent volcanism, dolomitization took place before and during mineralization but not afterward.

When it is proved that one fault in a mine or region is premineral, and its relations to another of different strike or dip are known, it is attractive to speculate whether most or all faults of similar strike and dip are not premineral and whether others of different strike



A. YELLOW PINE MINE AND CAMP, NW. ¼ SEC. 20, T. 24 S., R. 54 E.

The slopes of Shenandoah Peak (crest of ridge) are made up of thin-bedded limestones of the Bird Spring formation. The smooth slope behind the hoist is underlain by the porphyry sill.



B. SULTAN MINE, SOUTH CENTER OF SEC. 20, T. 25 S., R. 58 E.

The mine workings are in a breccia of dolomite fragments representing dolomitized limestones of the Bird Spring formation. The thin-bedded limestones above the mine workings are in the lower part of the Sultan formation. The lowest tunnel shown is No. 1, or the main working level.

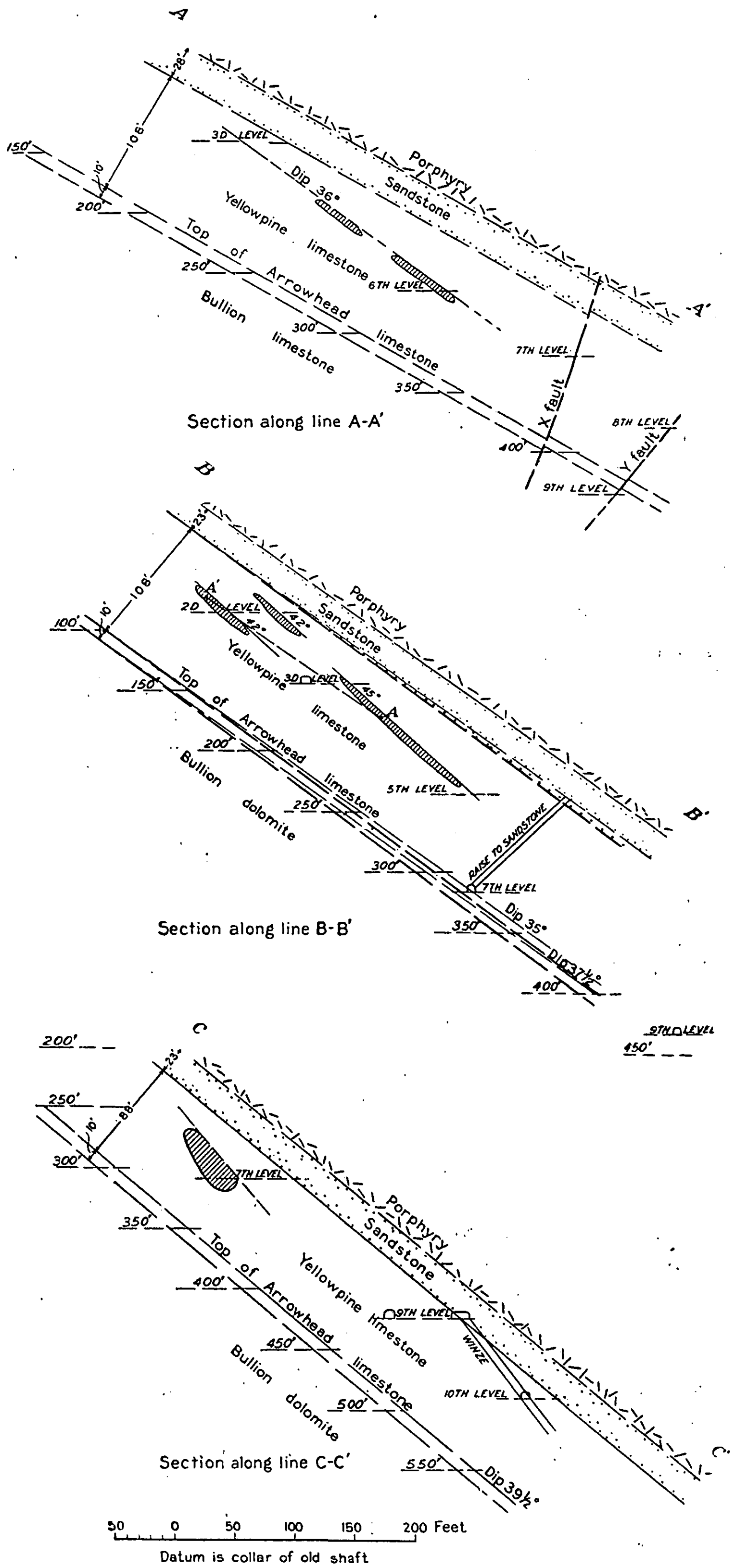


Figure 32.—Geologic cross sections of Yellow Pine mine. For lines of Sections see Plate 36, *A*

and dip may not be postmineral. This speculation is suggestive but not highly satisfactory when applied to the Yellow Pine mine, because, first, there are so many faults of almost similar strike and dip; second, intersections are rarely shown; and third, weathering of zinc minerals and their attack on wall rocks so widely destroys or obscures the evidence of the nature of the faults.

Faults that are assuredly premineral have been recognized in the following localities in the mine: Fault A on the 600-foot level, strike N. 50° W., dip 70° NE.; fault B (?) on the 700-foot level, strike N. 42° W., dip 75° NE.; fault L and others near by on the 1,000-foot level off the south winze, strike N. 72° W., dip 85° NE.; fault O occupied by the dike on the 900-foot level, strike N. 46° W., dip 75° SW.; and fault D on the 900-foot level, strike N. 58° W., dip 85° SW. When the range in strike and dip of these faults is considered it throws doubt on the value of any scheme of classifying faults on the basis of strike and dip alone.

Faults L and O noted above displace both the beds and the ore shoots (pl. 36, *A*) 80 and 90 feet, respectively, and on each the strike and dip of both contour of bed and ore shoot are approximately the same. The striae on the walls of fault L are nearly horizontal, but these indicate the latest movement only, and as the breccia contains unbroken galena, the conclusion is reached that it was formed before the mineralization and was probably the channel by which the sulphide minerals were brought to the adjacent ore shoots. The possibility of some postmineral movement on the fault can not be denied, although if it was appreciable it must have been nearly horizontal.

In several places persistent faults appear to cut off nonpersistent faults, which are not, however, assuredly premineral. Thus fault J, which limits a large ore shoot above the 300-foot level, and faults J′ and J″ trend N. 15° W., dip 70° NE., and appear to be cut off by faults I and K, which trend N. 50° to 60° W. and dip 68° to 78° NE. On all these faults the striae range from horizontal to 30° NW., but they are not reliable indications of net movement. The effect of fault I is to offset the contours on the shaly limestone 200 feet, but the ore shoot on the northeast side of it is roughly 200 feet vertically lower than those on the southwest side. Plainly, if the fault is postmineral and all of the displacement of the ore shoot is postmineral the striae are misleading. The most reasonable explanation of the local situation would assume that faults J, J′, and J″ are premineral and the source of the ore in the stopes higher up and that faults I and K are postmineral. If this is true, however, and if fault L is premineral, as stated above, it means that parallelism of faults does not necessarily mean similar age of fault and maximum movement, for I, K, and L are more nearly parallel than L and J.

If a continuous pipe of sulphide minerals were broken by a postmineral fault there should be a segment on each side of the fault, and the displacement should be confirmed by the displaced contours on bedding and striae on the walls. In several places ore bodies end downward against faults, and no extension is known, though existing workings should have struck it. In the southern part of the mine the ore body stoped above the 700 and 600 foot levels roughly ends southward against fault C, which is well shown on the 300, 700, 800, and 900 foot levels but is obscure in the stopes. On the lower levels the striae on the fault dip 10° to 15° NW., thus indicating an extension of the ore shoot on the 800 and 900 foot levels, but none is there. Instead, the only ore southwest of fault C is higher, lying between the 600 and 300 foot levels. Though no sulphides were found in fault C, it is probably a premineral fault.

Fault E is well exposed on four levels and especially on the 500-foot level, and the striae are horizontal or pitch northwest as much as 40°. The maximum strike slip on the contoured bed is about 16 feet, but the strike slip of the ore body indicated by the present stopes is about 60 feet. Striae are abundant on the fault at each level and largely pitch 10° to 20° NW., though some pitch 40°. All these data are consistent with the conclusion that the block north of fault E has moved upward and southeastward at an angle slightly less than the dip, but nothing observed proves whether the fault is premineral or postmineral. Probably it is a premineral fault along which there has been some postmineral movement.

The effect of fault F is shown in Figure 32, B. As with fault E, the block on the north side has moved upward and southeastward, but nothing observed proves whether it is premineral or postmineral. With the exception of fault I, all the faults of northwest trend, south of the dike, yield evidence of the same movement (net slip) as that on the faults C, E, and F just described. Such faults are clearly characteristic of periods of local compressive stress and, from what is known of the region, appear to be uniformly premineral.

The evidence of faulting near the granite porphyry dike is interesting. The walls of the dike, well shown on the 900-foot level, trend N. 45° to 50° W. and are nearly vertical. One wall is offset by a fault (N′) that trends N. 80° W. and dips 80° SW., but there is no evidence that the wall is affected by the parallel vertical fault (N) that offsets the sandstone about 50 feet (strike slip). That the fracture occupied by the dike is itself a fault (D) seems certain from the nature of the displacement of the sandstone on the two sides of the dike. The local situation is thus interpreted: It seems probable that all three fractures were formed before the dike was intruded along one of them; the movement on N took place before the dike was intruded and is premineral; the movement on N′ is later than the dike and may be either premineral or postmineral. The striae and movement on fault P indicate that it belongs to the thrust epoch. Fault Q is a premineral fault.

In the southern part of the lower levels (700, 800, and 900 feet) there are three persistent breccia zones that strike from due north to N. 10° E. and dip 52° to 85° E. (See pl. 36, *A*, faults X, Y, and Z.) They are impressive because they are breccia zones 3 to 8 feet wide, and the fragments are uniformly less than 4 inches in diameter and only slightly cemented. Striae and small grooves on the walls pitch 5° to 15° NE. Considered together, they appear to represent the fault shown on the surface 2,000 feet west of the Alice shaft. The displacement there noted, together with the striae underground, indicates that the western block has moved southward and upward relatively about 300 feet. On the 700-foot level, however, the shift in the ore shoot indicates that the block west of fault X has moved southward scarcely 100 feet. No ore has yet been found west of the principal break (fault Y) on the 800-foot level (drifts 801 and 851) and 900-foot level. It is not clear whether they are premineral or postmineral; probably they belong to the first group.

The type of displacement and general distribution of the faults that trend northwest in the mine have a bearing on the conditions of their formation. Along all the faults except fault I, south of the block bounded by faults S and R, the northwestern block appears to have moved forward, or southeastward, and upward, but from that block north, as shown by the workings on the Prairie Flower claim (fig. 30), the displacement is reversed. The block bounded by faults S and R appears to be the most advanced wedge of a number that, taken together, form a larger wedge. Also, thus far, except for the Prairie Flower shoot and sporadic patches of zinc minerals in the new shaft on that claim, no shoots have been found north of the block, and, except for offsets along faults, ore shoots extend continuously for 2,000 feet south of it.

Genesis of the deposit.—The summary of genesis is concerned with the structural and igneous history of the area and the effects of weathering on the transfer of lead and zinc rather than with the methods by which the original sulphides were deposited, for weathering has almost completely obliterated the evidence of sulphide deposition.

Here, as elsewhere in the district, dolomitization of the limestone seems to have largely preceded deposition of ore, as the ore shoots occur in dolomite breccia. The zone of brecciation appears to be rather simple over large areas, but locally there are several superimposed zones. The principal zone has great horizontal extent along the strike of the beds but in depth cuts across the beds. To judge from brecciation at this horizon elsewhere in the district, there may be other similar zones at greater depths in the Yellowpine limestone or in lower beds. Probably the brecciation preceded the intrusion of the sill, and that was earlier than the dike which fills a fault that probably cuts across the sill. Most of the cross faults of northwest trend were probably formed after the sill was intruded and before the dike, and they were followed by deposition of sulphides of lead and zinc. Probably there was later movement along the cross faults before weathering began to affect the sulphides. Solutions of zinc sulphate migrated locally downward, reacting near by with the dolomite wall rock to form hydrozincite or depositing smithsonite in open breccia more remotely.

According to this explanation, the cross faults were largely the channels by which lead and zinc were brought to the breccia zones, and exploration for additional deposits should be directed toward finding other zones in the Yellowpine limestone or lower beds at greater depth, where they are cut by the cross faults.

MIDDLESEX MINE

The Middlesex mine (No. 14, pl. 30) lies at the south end of the small valley locally known as Horseshoe Gulch, half a mile southeast of the Yellow Pine

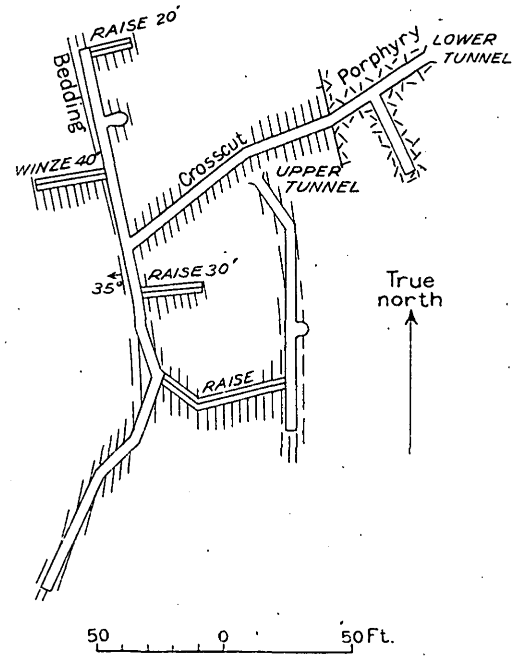


FIGURE 33.—Geologic map of Middlesex mine

mine and 3 miles northwest of Goodsprings. The claim was located in 1901. There are two tunnels—an upper 100 feet long and a lower about 400 feet long. These tunnels explored a bedding-surface fracture that trends generally north and dips 35° W. The fracture lies about 40 feet stratigraphically above a sill of granite porphyry which roughly follows the bedding of the inclosing dolomitized limestones near the base of the Bird Spring formation. (See fig. 33.)

The principal ore mineral is galena, largely in coarse cubic crystals embedded in white coarse dolomite.

Pale-reddish hydrozincite is present on the dump, and here and there galena is embedded in it. These minerals occur sporadically in the crushed and sheared dolomite under a persistent hanging wall. The shoots appear to be pipes that extend directly down the dip and here and there attain widths of 3 feet. There is no record of production, but it probably did not exceed 200 tons of lead or mixed ore.

The same zone is explored by three other tunnels within a distance of 600 feet west of the Middlesex tunnel, and some ore was probably encountered.

YELLOW PINE EXTENSION MINE

The Yellow Pine Extension mine (No. 15, pl. 30), also known as the Green Mountain or Alice from the names of two of the claims, lies half a mile south of the Yellow Pine mine, about 4 miles due west of Goodsprings. The principal claims were located in the following years: United States, 1889; Contact, 1892; Alice, 1892; and Green Mountain, 1899. Most of the ore has come from a shaft about 680 feet deep having an average inclination of 21° 30′. (See fig. 34.) The collar of the shaft lies at the end of a tunnel 165 feet long. The depth attained is 230 feet vertically below the tunnel, but it is only 160 feet below the ravine west of the mine. Recently two other inclined shafts have been sunk 700 and 1,200 feet north of the main tunnel. These are 200 and 160 feet deep, respectively, but they have not yet encountered ore.

The summary of production presented below is compiled from the records of the United States Geological Survey. According to A. J. Robbins, the present owner, it is a little low, and the minimum is probably about 3,000 tons. Most of the output has been zinc ore, largely ranging between 30 and 42 per cent of zinc. The remainder includes one car of lead ore, several cars of mixed lead and zinc ore, and several more of copper ore. Compared with the product of most of the other mines, the ore of this mine has had a high percentage of insoluble matter, probably in large part silica, generally ranging from 14 to 16 per cent. A rough estimate of the gross value of the output is $100,000 and of the net value, after paying railroad, freight, and smelting charges, $75,000.

Production of Yellow Pine Extension mine, 1909–1924

Year	Crude ore (tons)	Gold (ounce)	Silver (ounces)	Copper (pounds)	Lead (pounds)	Zinc (pounds)
1909	123					79, 055
1910	160					97, 280
1911	29	0. 27	94	764		16, 492
1912	191		261	1, 282	20, 439	109, 155
1913	255		107	3, 428		147, 799
1914	120	. 38	180	4, 427	2, 990	61, 661
1915	327		177	6, 680		169, 905
1916	626		322	14, 352	8, 865	318, 158
1917	565					336, 175
1918	225					150, 049
1919	49				6, 860	24, 990
1924	35				7, 446	18, 132

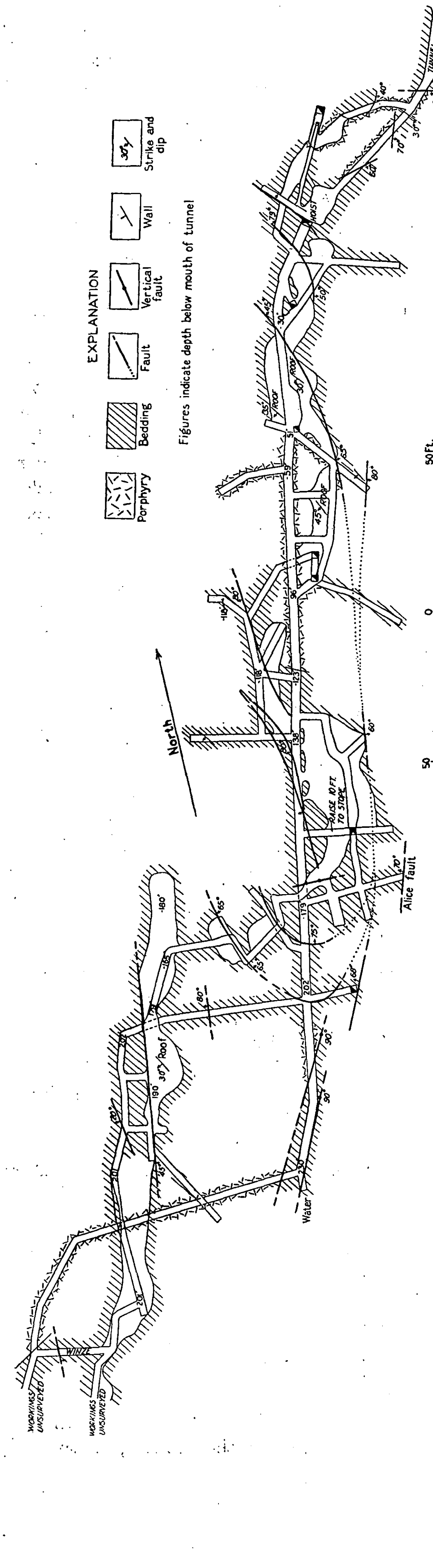


FIGURE 34.—Geologic map of Yellow Pine Extension mine

The general geologic conditions in the area surrounding the mine have been described on page 46. The shaft is sunk in beds of the Bird Spring formation that lie 100 feet or more above the base. In this area they are largely converted to dolomite. Even though they strike generally northwest and dip southwest, they are locally folded and much faulted. At three places in the mine sill-like masses of granite porphyry have been met. The shoots that have been the sources of ore underlie a persistent wall that lies only a few feet above the middle of the sills. In a broad way the wall conforms with the bedding; locally it cuts across it.

The upper mass of porphyry is sill-like and ranges from 6 to 10 feet in thickness. It terminates above and below against faults. The middle mass is exposed for 160 feet in the shaft. It is clearly a sill, 1 to 10 feet thick, and with depth its lower surface passes into the roof of the shaft. The shoot of zinc ore explored in this area lies in a zone of dolomite breccia 3 to 4 feet thick directly overlying this sill. There is a good hanging wall over the ore, but above it there is more breccia; clearly the ore is associated with a fracture that is not related to the bedding of the dolomite. The next lower shoot (123 to 179 feet vertically below the mouth of the shaft, fig. 34) appears under the sill, but it also is overlain by a persistent wall. The lowest body of porphyry is also a sill that underlies an ore shoot. It is cut off on the east by a vertical fault which, as will be shown below, probably belongs to the thrust epoch. It is not clear whether the three masses of porphyry are separate masses or not; probably the upper and middle ones were once connected. It looks, however, as if the lower sill were distinct from that explored above. Throughout the mine the porphyry is broken by many fractures and deeply weathered, so that it caves badly as time passes.

There are many faults in the mine; only the persistent or critical ones are shown in Figure 34. The most persistent fault lies east of the workings, and only a few drifts have crossed it. It is a zone of fine dolomite breccia at least 5 to 20 feet wide, and there are persistent striae that dip from the horizontal to 20° NE. Its average course is N. 25° E., but the dip, which is 45° to 80° SE., in the upper work, turns to 68° to 90° NW. in the lower work. Clearly the surface is curved, concave westward, and the movement along it has been nearly horizontal. From the regional geology it seems clear that the fault is one of several surfaces along which the eastern block has moved 3,000 feet northeast. A number of the other faults shown in Figure 34 are clearly related to this fault.

The shape of the ore bodies explored in this mine is unique in this district. Together they form a nearly continuous shoot at least 900 feet long, rarely more than 40 feet wide, and from 2 to 5 feet thick. Each is limited upward by a clean hanging wall, which is generally cut across breccia even though it roughly follows the bedding. The wall is hardly continuous throughout, for one body overlies a sill and the next underlies it. The principal mineral mined has been earthy hydrozincite, brown or white, which has replaced dolomite. Calamine is common, but largely on fractures that cut the hydrous carbonate. Smithsonite is reported but was not found. Aurichalcite is rather common; in fact, the northern or upper end of the lowest stope yielded 100 tons of copper ore in which there was some chalcocite. Galena was uncommon, but cerusite and other oxidation products, including a vanadate, were common.

All the ore shoots appear to be adjacent to faults, and most of them lie on the lower sides of faults. (See fig. 34.) The writer's observations indicate that faults determine the position of ore bodies and locally limit them and that none are assuredly postmineral.

Pools of water stand permanently on the lowest level, 230 feet below the top of the shaft but scarcely 160 feet below the overlying surface.

RUTH MINE

The Ruth claim (No. 17, pl. 30) is situated at the head of the wash 3 miles due west of Goodsprings. It was located in 1893 by A. S. Campbell and, after the Kirby, was one of the first lead mines to be worked. It was worked intermittently until 1903 and is reported to have yielded about 500 tons of lead ore up to that time. Since 1914 it has been leased five times and has yielded about 150 tons of lead ore in addition. The record of part of these later shipments is given below. The principal workings and source of all of the lead ore are shown in Figure 35.

Geologic conditions near the Ruth mine are exceptionally complicated. The shoot that was the source of most of the ore lay along a breccia zone parallel to the local bedding in dolomitized limestone, 500 feet or more above the base of the Bird Spring formation. These limestones are part of a block which is limited on the north by the Ruth fault and on the east by a thrust fault that dips 30° W., under which lie successively the Shinarump conglomerate and Moenkopi formation. On the west there is a normal fault that trends N. 15° E. and may be traced 4,500 feet south beyond the Cosmopolitan and Bell mines. The maximum displacement along this normal fault is about 400 feet near the Bell mine, and it decreases northward. As the Cosmopolitan shaft explores a copper deposit on this or an adjacent parallel fault, it is probably premineral. The flat thrust east of the Ruth mine has been explored by prospects on Rattler Hill, 1,000 feet south, which yielded a little lead ore. If the Ruth mine were explored 400 feet vertically below the tunnel level, the workings would probably pass into beds of the Moenkopi formation. Within this block the dolomite beds trend northwest and north, and then near the Ruth fault the bedding turns abruptly to merge with the fault, which trends northeast. The dip ranges from 35° to 50° W.

The principal mineral of the Ruth mine was silver-bearing galena, but here and there oxidized lead and copper minerals were found. Wulfenite in small tabular crystals was found on open fractures in the drifts off the tunnel. The galena appears to be persistently associated with dark chert, probably of the hypogene variety.

Little ore may now be seen, so that the relations of the galena are obscure. According to H. Hardy, who leased the mine in 1914, the galena formed lenses as much as 2 feet thick that alternately lay steeper and flatter than the general dip of the shoot. Compared with most of the other shoots in the district, this was simple and pitched straight down the dip. A little ore was also obtained from an underhand stope near the mouth of the tunnel.

The composition of the ore is shown by smelting receipts from the shipments made by H. Hardy in 1914.

Content of ore of Ruth mine

Weight (pounds)	Gold (ounces per ton)	Silver (ounces per ton)	Lead (per cent)	Zinc (per cent)	Copper (per cent)	Iron (per cent)	Silica (per cent)
28,413	0.01	24.5	33.5	Trace.	0.40	1.7	47.5
42,312	.035	24.6	37.8	0.8	.65	2.0	41.4
6,416	.032	26.7	50.0	.5	.12	2.1	24.0

Of the two cars shipped by John Egger in 1916 one contained 63 per cent of lead and 26 ounces of silver to the ton, and the other 23 per cent of lead and 16 ounces of silver to the ton.

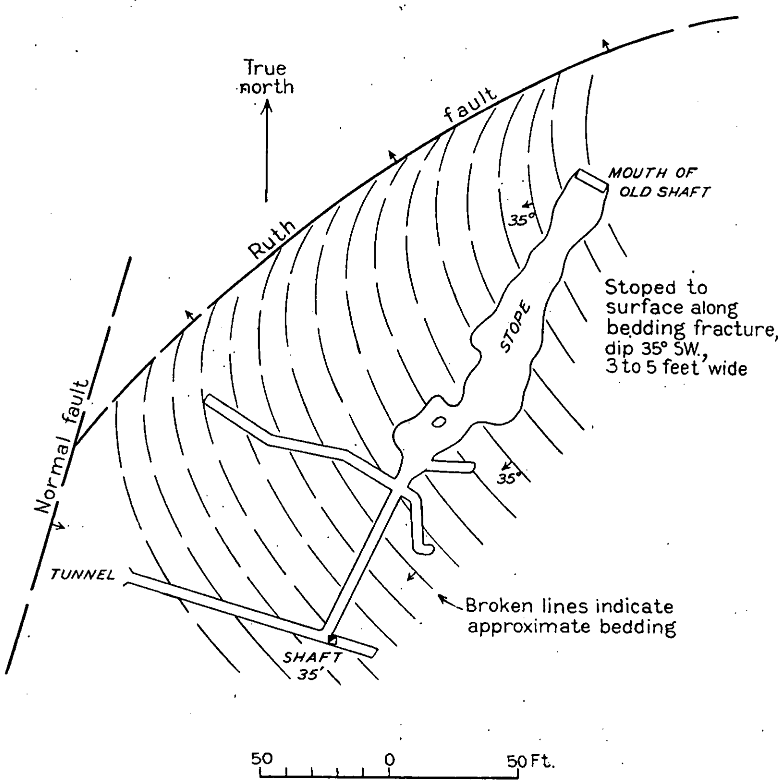


FIGURE 35.—Geologic map of Ruth mine

SHENANDOAH MINE

The Shenandoah mine (No. 31, pl. 30) is near the head of a deep gulch on the west side of the Spring Mountains, about 6 miles due west of Goodsprings ,but by road the distance is nearly 16 miles. It was first located by Jonas Taylor and J. A. Bidwell in 1883, and there was a brief reference to it in 1901.[57] Most of the present development work was done between 1915 and 1918. According to local report, the cropping of the Shenandoah ore shoot was the most conspicuous among the lead deposits of the district. It has been irregularly excavated for a distance of 100 feet on the surface.

Production of Shenandoah mine, 1908–1926

Year	Crude ore (tons)	Silver (ounces)	Lead (pounds)	Zinc (pounds)
1908	23	247	23,119	----------
1915	225	555	30,615	115,695
1916	677	281	26,740	389,134
1917	154	886	101,254	6,732
1918	26	63	11,267	11,222
1926	38	88	15,585	15,774

The workings include a crosscut tunnel 125 feet long from the end of which there is a raise to the surface at 35° slope. From this raise, 30 feet above the tunnel, a drift runs northwest 60 feet. The stope above this drift is limited by a good wall that trends northwest

[57] Eng. and Min. Jour., vol. 72, p. 179, 1901.

(fig. 36) and dips 45° SW. The stope follows a lens of brecciated dolomite in which there is sporadic galena over a width of 2 to 3 feet. The country rock is massive cherty limestone of the Monte Cristo formation, but it is dolomitized throughout this part of the range. As the prevailing strike is N. 40° W. and the dip 20° SW., it is clear that the breccia zone and ore shoot cut across the bedding. In a drift 25 feet below the surface the breccia is 8 to 10 feet wide, whereas at the surface it is 15 to 20 feet wide. In the upper levels galena is largely in the spaces between the breccia fragments.

The most abundant mineral at present is galena, but there is considerable carbonate and sulphate, as well as hydrozincite. Wulfenite is common, and according to local report was once abundant. Aragonite was noted along watercourses.

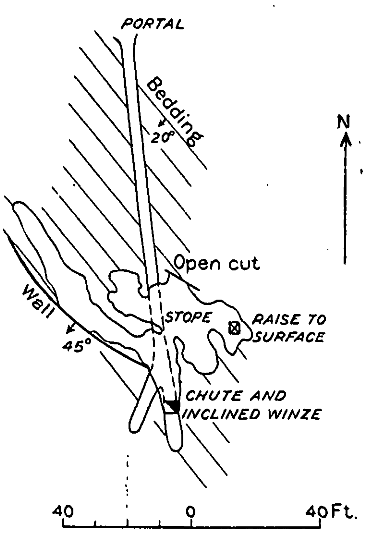


FIGURE 36.—Geologic map of Shenandoah mine

SMITHSONITE MINE

The Smithsonite mine (No. 32, pl. 30) is 1,000 feet northeast of the Shenandoah, at the head of the gulch. The Polly Pry claim, on which most of the work has been done, was located in 1908, but it was preceded by the Crown claim, located in 1904. The workings include a tunnel with 210 feet of drifts and a shaft 55 feet deep. These openings explore an area in the Bullion dolomite, which here trends N. 40° W. and dips 10° SW. (See fig. 37.)

There are two stopes—a flat stope in the northeastern part of the workings, 15 by 20 feet and 4 feet high, and a vertical stope that follows a northward-trending wall in the southwestern part of the workings. From what may now be seen the principal mineral was calamine, although some chrysocolla, malachite, and aurichalcite are present. There is more iron present in the form of limonite here than in most of the other lead and zinc mines of the district. The diverse structural relations of the shoots as well as the mineralogy indicate that the zinc which they contained has migrated appreciably. The relations of the lead minerals are not known, for none were found in the stopes.

Production of Smithsonite mine, 1915–16

Year	Crude ore (tons)	Copper (pounds)	Lead (pounds)	Zinc (pounds)
1915	94			59, 446
1916	333	14, 700	81, 870	21, 420

MOBILE MINE

The Mobile mine (No. 34, pl. 30) is high on the steep cliffs that limit the prominent ridge north of the Goodsprings-Sandy road, 7 miles due west of Goodsprings or about 11 miles by road. The mine is accessible by trail or tramway from the base of the ridge, as it is nearly 1,000 feet higher. It was located in 1896, but only a little work was done before December, 1914, when it was leased to W. S. Hutchinson and associates, of Boston, Mass. Before the lease was surrendered in 1916, 49 cars containing 1,768 tons of zinc ore with a little lead were shipped. The gross value at the smelter was $81,465, and the net value after paying railroad freight from Jean was $67,047. Only a little work has been done since 1916.

Production of Mobile mine, 1914–1916

Year	Crude ore (tons)	Gold (ounces)	Silver (ounces)	Copper (pounds)	Lead (pounds)	Zinc (pounds)
1914	152					100, 172
1915	1, 328		99		30, 412	799, 272
1916	781	1. 22	934	22, 276	4, 056	397, 664

There are two groups of workings—the main workings, which were the source of most of the ores, shown in Figure 38, and another group, 400 feet west, on the top of the ridge. The first group explores a shoot that lies roughly parallel to the bedding at the middle of the cherty Anchor limestone, here altered to dolomite. The second group—a series of trenches and drifts with shallow cover—lies higher in the section, near the base of the Bullion dolomite. The bedding

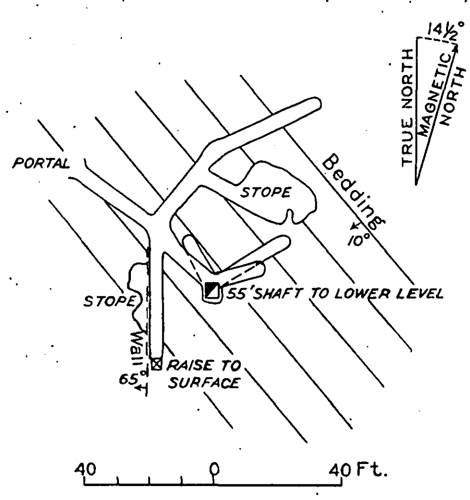


FIGURE 37.—Sketch map of Smithsonite mine

trends N. 45° W. and dips 10° SW. The mine is on the north limb of the syncline that lies north of the Rose anticline. There is one conspicuous fault underground, and another follows a ravine 800 feet west. Both trend northwest and dip steeply northeast, and the beds on the northeast side have dropped 15 and 75 feet respectively; probably both are postmineral.

The extent of the main ore body is shown in Figure 38. The principal ore mineral was probably hydrozincite, but only a little may now be seen. Galena and its oxidation products are present. Calamine may still be found here and there. In two places dolomite

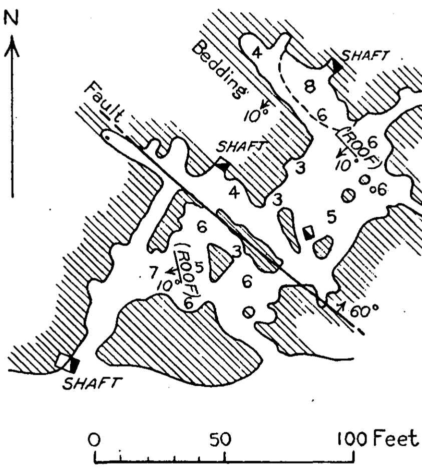


FIGURE 38.—Geologic map of Mobile mine

breccia contains considerable wulfenite in the form of flat waxen-yellow crystals, many of which are entirely covered with a coating of fine crystals of calamine. Dark-green cuprodescloizite is found here and there. The dolomite walls are much brecciated and either cemented by hydrozincite in process of replacing it or by other carbonates, such as aragonite. The breccia, however, is limited by a roof that is scarcely broken and is probably a bedding plane, as it dips gently southwest. Apparently, the shoot of oxidized minerals coincides closely with the original position of the deposit of sphalerite. Along the fault that passes through the middle of the deposit the northeast side has dropped 15 feet. It is a narrow, single break, and no ore was observed in the breccia.

KIRBY MINE

Location.—The Kirby group of four claims lies at the head of Kirby Wash, in the SW. ¼ sec. 30, T. 24 S., R. 58 E., about 5½ miles west of Goodsprings (No. 36, pl. 30). These claims were among the first to be located in the district, the May claim, which contains most of the development, having been located by Eugene Desty and John A. Kirby in October, 1887. The John claim, which contains two shafts, the Black Lime, which contains several tunnels, and the Desty were located about that time by A. G. Campbell. Later Campbell acquired the May claim and in the early nineties shipped lead ore to Barnwell. The Kirby mine was therefore the second to ship lead ore out of the district. Most of the development work, however, was done during the war by lessees. After four years of idleness the mine was reopened in 1924 and shipments were made by A. O. Jacobsen. The claims belong to the estate of A. G. Campbell. The principal workings include the inclined shaft on the May claim (fig. 39), 235 feet deep. There are three levels, 79, 116, and 169 feet vertically below the surface, but the deepest work, 211 feet below the surface, is at the bottom of the 110-foot winze from the second level.

Geologic features.—Structurally as well as mineralogically the Kirby deposit is one of the most uncommon and interesting in the district. The workings explore a series of veins that lie in a crushed zone in shale and dolomite a short distance east of an extensive fault. Only dolomite is shown on the surface, but at several places underground the workings crosscut 20 to 40 feet of alternating greenish shale and thin beds of dolomite. These beds are a part of the Goodsprings formation and lie about 200 feet below the Ironside dolomite. As shown on the geologic map of the district, the deposit lies about midway between an extensive syncline on the south and the Keystone thrust on the north. Dikes of granite porphyry lie several hundred feet west and north of the mine, and others lie farther north, near the Keystone mine.

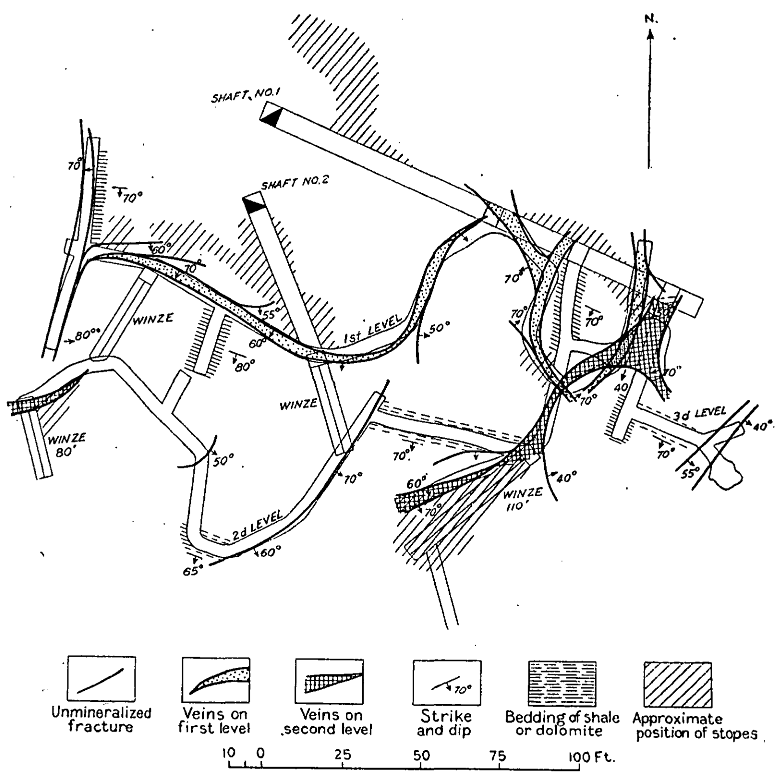


FIGURE 39.—Plan of Kirby mine

The fault trends N. 20° E. and is nearly vertical and therefore makes a right angle with the beds, which trend N. 70° W. and dip 70° to 80° S. There are other nearly parallel faults near by, and along several the west side has moved northeastward and slightly upward. They therefore appear to belong to the period of thrust faulting and represent the fractures along which some blocks moved farther northeast than others near by. The ore-bearing fractures have diverse strike but largely dip 50° to 70° SE. or S. and are therefore oblique to the major fault. Apparently the main fault has not been met in the underground workings.

Ore deposit.—The veins that have been worked in the Kirby mine are limited by well-defined walls that are highly irregular, both in plan and in vertical cross section. The material between the walls includes chert and its decomposition products, cerusite, plumbojarosite, jarosite, iron oxides, and clay, but the relative abundance of these minerals differs from one level to another. Where the explorations cut through the walls, the country rock is either fresh cream-colored dolomite or greenish shale, but in many places these rocks are stained with iron oxide.

The walls of the veins are not simple fractures but parts of an elaborate branching system, and only exploration can determine their persistence and relations in plan and cross section. Although two veins have been the sources of most of the ore thus far, minor fractures are locally ore bearing. No evidence has been obtained that any of the fractures underground are younger than the original sulphide minerals. Throughout most of the mine the distance between the walls ranges from 1 to 4 feet, but locally the stopes are 5 or 6 feet wide. The product of the mine has been largely valuable on account of its lead content.

It will facilitate an understanding of the nature of the ore deposit if the conditions on successive levels are described in detail. About 40 feet below the surface there is a short level northward, above which a vein 2 to 4 feet wide has been stoped to the surface. This vein is made up of lenses of dark-brown ferruginous chert with smaller included lenses of loosely coherent dark-brown powder, determined to be spherules of turgite that range from 0.005 to 0.02 millimeter in diameter. According to local report, some high-grade lead carbonate ore was mined from this stope.

The first level extends generally west from the shaft and follows a curving vein, first south and then west, which has been stoped to the surface along No. 2 shaft over a width of 1 to 5 feet. On this level the vein is made up of lenses of milky chert (pl. 24), which here and there contain disseminated cerusite and brown plumbic jarosite in a mass of decomposed chert. In places there are lenses of yellow plumbojarosite, some of which attain a thickness of 18 inches. (See fig. 40.) It is clear that the yellow plumbojarosite is an alteration product of the brown plumbic jarosite. In order to determine the character and extent of the alteration selected specimens of each have been studied and analyzed by W. T. Schaller, of the United States Geological Survey. His report is presented on pages 87–88. In the stope above the west end of the first level there was considerable turgite powder. Although cerusite is present as granular lenses, generally near the footwall, it is not as common as on the second level. Alunite forms snow-white powdery masses that are clearly recognizable in the hard fresh chert but obscure in the decomposed chert. On this level there are several prominent fractures that are spurs from the walls that limit the vein. Lead carbonates have been mined above the first level

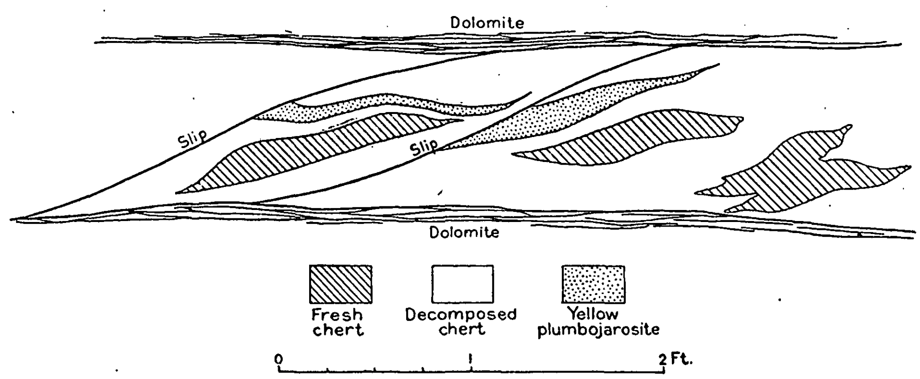


FIGURE 40.—Vein of chert and plumbojarosite on first level of Kirby mine

and between the first and second levels from another vein in the eastern part of the mine. This vein contains less chert and plumbojarosite and much more siliceous turgite and spherules of turgite than the vein mentioned above. The width ranges from 1 to 4 feet.

Most of the exploration from the second level follows the second vein, which has also been followed in a winze 110 feet deep on an incline of 60°. The largest stope in the mine, 3 to 6 feet wide, overlies the winze. This vein is largely plumbojarosite and cerusite in a clayey matrix, and there is little chert below the level. Recent work farther west explores the first vein, and there is an 80-foot winze at 70°. Here also there are little chert and considerable limonite. Along the winze from the first to the second level, under the vein, there is considerable white powdery alunite which replaces the green shale country rock.

On the third level no lead ore has yet been found. Near the face there are two conspicuous walls, and at the face a dike of fine-grained granite porphyry is exposed, but the precise relations are obscure. The dike is probably the same as that which is explored by two shallow shafts several hundred feet north of the Kirby shaft.

The outstanding features of the mineralogy may be summarized as follows:

Surface to 40-foot level: Siliceous limonite abundant; plumbic jarosite abundant; powdery turgite abundant; yellow plumbojarosite sparse; cerusite reported; cream-colored chert absent; alunite not observed.

Forty-foot level to first level: Chert, locally with plumbic jarosite, abundant; siliceous limonite sparse; turgite sparse; plumbojarosite abundant; cerusite abundant; alunite common.

First level to second level: Chert, locally with plumbic jarosite, common but only sparsely decomposed; siliceous limonite absent; powdery turgite absent; plumbojarosite abundant; cerusite abundant; alunite abundant in wall rocks.

Second level to bottom of 110-foot winze: Chert sparse; plumbic jarosite not noted; plumbojarosite abundant; siliceous limonite absent; earthy limonite common; cerusite abundant; alunite common in wall rock.

The explored part of the ore deposit is therefore characterized by cerusite and considerable plumbojarosite, with minor plumbic jarosite, in a gangue composed largely of chert. The unoxidized vein has not been explored, but undoubtedly it is largely pyrite and galena.

The chemical processes apparently involved in weathering of the deposit may be briefly summarized. (See p. 98.) By weathering, free sulphuric acid and ferrous and ferric sulphates were set free. The sulphuric acid attacked the clay gouge of the vein and shale in the wall, forming alunite and setting free silica, which, migrating locally, deposited chert. As most of the chert lies above the zone of abundant alunite, however, some of the chert must have another origin. The extent of decay of the chert in the upper levels indicates that some silica is being constantly dissolved above and deposited lower down in the vein. On the other hand, some silica is constantly being fixed in the surficial zone and, as erosion progresses, removed from the area.

There appears to be no pure potassium jarosite in the mine; all the jarosite probably contains some lead. Although it has not been identified, some plumbic jarosite must be present in the zone where alunite is formed; some undoubtedly has formed later through the attack of cerusite by sulphate waters bearing potash. In the upper zone of the mine plumbojarosite is constantly being broken down, leaving powdery turgite. Some of this lead undoubtedly reacts with plumbic jarosite lower down to make new plumbojarosite. It would appear that any plumbic jarosite not converted to yellow plumbojarosite remains stable until it is near or at the surface. Plumbojarosite does not appear to be stable at the surface in this region, however.

It is concluded that at the Kirby mine a jarosite chert zone is constantly being broken down by decay near the outcrop and re-forming about 100 feet lower, in part by replacing vein gouge and near-by shale and in part by deposition in open spaces. Potash, silica, and some of the lead are therefore kept in a surficial zone by a cyclic process.

Production.—The production of the Kirby mine can only be estimated approximately. The accompanying table, compiled from records submitted to the United States Geological Survey, includes that of the Ruth mine also. There is some error in reporting the zinc production for 1917, as the owner and those who live near by insist that sufficient zinc minerals to ship have never been found on any of the company's claims. The table probably includes also the production of the John mine. According to Mr. Allen G. Campbell, son of the original owner, a total of 65 cars of ore, or about 2,000 tons, has been shipped from the Kirby and John shafts, of which 15 cars were shipped prior to 1915.

The records of 24 cars shipped by a lessee, F. C. O'Kelley, during 1916, show a range for lead of 9.7 to 20.6 per cent and an average of about 14 per cent; a range of silver from 2.70 to 5.70 ounces to the ton; insoluble matter, 10 to 35 per cent; iron, 25 to 43 per cent; zinc, trace to 1.60 per cent. The gold content has never exceeded 0.025 ounce to the ton.

Lessees have shipped all the ore since 1915, and there is no record of profits from operation.

Production of Kirby, Ruth, and John mines, 1908–1925

Year	Crude ore (tons)	Gold (ounce)	Silver (ounces)	Copper (pounds)	Lead (pounds)	Zinc (pounds)
1908	[a]90	--------	1, 081	--------	72, 000	--------
1916	[a]29	--------	159	--------	13, 907	--------
1917	[a]1, 811	--------	7, 067	22, 800	539, 492	[b]171, 936
1920	[a]52	0. 52	430	55	31, 230	--------
1924	[a]112	--------	1, 688	--------	86, 915	--------
1925	[c]92	. 92	1, 110	--------	82, 564	--------
1925	[a]200	. 78	2, 153	--------	81, 599	--------

[a] Crude ore. [b] See above. [c] Concentrate.

JOHN MINE

On the John claim of the Kirby group there is a single shaft that has been the scene of most of the exploration and several near-by prospect pits. The shaft extends southwest for 40 feet on an incline of 38°; then vertically downward for 30 feet. A glory hole from which the shaft starts is about 50 by 25 by 40 feet and has been the source of most of the ore. These workings explore a zone under the Ironside dolomite, where it is broken by a fault that trends N. 15° E. and dips 80° W. Here, as at the fault on the west side of the Kirby mine, the western block has moved forward (northeastward) and upward, so that it is related to other faults of the thrust period. The country rock is the dark-gray dolomite of the Goodsprings formation, which here strikes northwest and dips 50° SW.

The detailed structural relations of the ore that has been shipped are obscure. There is now considerable jarositic chert and quartz in the form of a lens 5 to 10 feet wide along the fault, but most of the lead and copper minerals appear to have come from small pockets and lenses along minor fractures and bedding planes east of the fault, as at the Kirby mine. To judge from the shipments, the material on the dump, and what may now be seen in the workings, most of the product was hard cerusite which cemented fragments and filled pores of a spongy mass of ferruginous chert. Although a little cerusite surrounds a few sparse grains of galena, most of it appears to have been deposited by downward-moving surface waters. A little plumbojarosite was found here and there replacing jarositic chert. There are small quantities of oxidized copper minerals, largely in the upper part of the mine, but malachite is the most abundant. It forms intimate mixtures with ferruginous chert, locally in alternating layers.

According to F. A. Piehl, the mine has yielded 16 cars or about 500 tons of lead ore and 4 cars or 125 tons of copper ore. The records show that 220 tons of lead ore shipped in March, April, and May, 1916, netted $3,287 and that costs of mining and haulage to railroad were $2,814. The product is included with that of the Kirby mine.

WHALE MINE

The Whale group of seven claims (No. 38, pl. 30) lies 6 miles west of Goodsprings, about half a mile north of the road to Sandy. The Whale claim was first located in 1904 by Jesse Jones, who sold it to Addison Bybee for $227. It was relocated by Frank Tursick and Frank Miller in 1909, but for several years only assessment work was done. Several years later two cars of zinc ore were mined and shipped from a 75-foot shaft in the gulch 750 feet northeast of the tunnel, where most of the work has been done. This tunnel was driven and most of the ore was shipped during 1915 and 1916 by the Whale Mining Co. Only assessment work has been done since 1917.

The beds that make up the ridge on which the mine is situated range from the Ironside dolomite to the top of the Monte Cristo limestone. They trend about N. 70° W. and dip 35° to 45° SW. The mine workings explore a zone that includes the cherty Anchor limestone above and the Crystal Pass limestone below, but the ore is largely in the Anchor limestone. The Anchor, as well as the beds as low as the Ironside dolomite, is largely dolomitized on this ridge; locally, parts of the Crystal Pass limestone are unaltered. The principal faults on the ridge trend northeast and belong to the group on which the Kirby and Rose mines are located farther northeast. The ore in the Whale mine, however, does not appear to be related to one of these faults; that which is explored by the tunnel lies along a breccia zone that trends N. 65° E. and dips 65° SE.

The upper shaft is 75 feet deep with drifts at the bottom. It was the source of some hydrozincite with minor calamine, aurichalcite, and chrysocolla. By contrast, the lower tunnel (fig. 41) is reported by the owner to have encountered only calamine, and no other zinc, copper, or lead minerals were observed by the writer. Ore has been mined from four stopes and shows in drifts at two other places, but in each calamine is the only mineral present, and it replaces dolomitized Anchor limestone breccia near layers of chert, which is here largely white and slightly decomposed. The width of the stopes largely ranges from 2 to 5 feet.

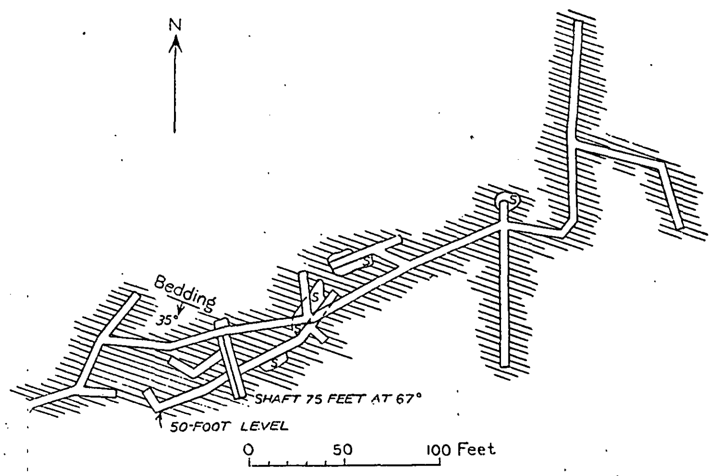


FIGURE 41.—Geologic map of Whale mine

The cause of the localization of the ore shoot in the shaft is obscure, but it seems clear that the calamine in the tunnel has been largely if not wholly formed by the solution of zinc as carbonate at higher levels and its deposition lower down, where silica was encountered. The conditions resemble those surrounding the occurrence of calamine in the deepest work at the Monte Cristo mine. It seems improbable that deeper work would encounter other zinc minerals.

On the eastern part of the Whale group of claims there are at least 12 short tunnels and shafts in an area 400 by 600 feet. One shaft is 60 feet deep. These workings explore sporadically distributed small veins that contain cuprodescloizite but here and there a little galena, calamine, and wulfenite. The cuprodescloizite forms dark olive-green crystalline coatings on vugs and open veins. The area within which these veins are formed is limited on the west by a crushed zone that trends north to N. 20° E. and roughly parallels the premineral faults that are more conspicuous farther northeast. No ore has been shipped, but if experience shows that vanadates can be profitably recovered by milling low-grade material the area will deserve attention.

The production of the Whale mine is given below; Frank Miller, the owner, estimates that the table is essentially complete.

Production of Whale mine, 1912–1917

Year	Crude ore (tons)	Silver (ounces)	Lead (pounds)	Zinc (pounds)
1912	26			13, 260
1915	92			49, 495
1916	320			163, 200
1917	99	98	21, 238	39, 913

BILL NYE MINE

The present Bill Nye claim (No. 39, pl. 30), coincides with that located as the Homestake as early as 1900. Little work was done before 1907, when it was relocated as the Bill Nye. In 1912 the tunnel included

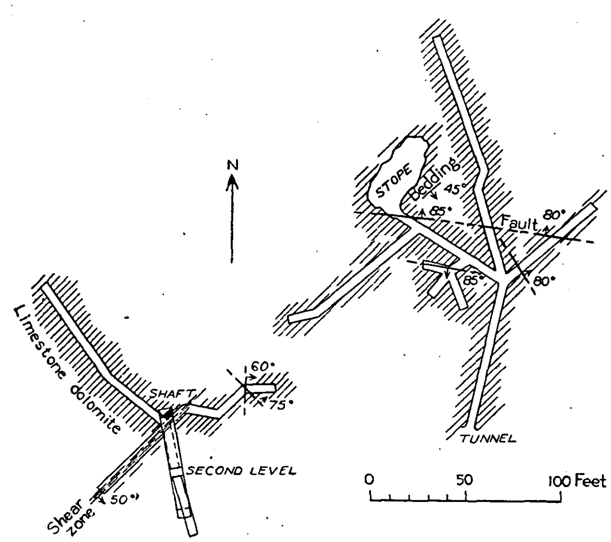


FIGURE 42.—Geologic map of Bill Nye mine

about 200 feet of work,[58] but no notable quantity of ore was struck until 1914, when a body of hydrozincite was found by W. E. Allen in a shallow pit several feet northeast of the present glory hole. By continuing the tunnel 8 feet the main body as outlined by the glory hole was met. Allen mined the ore shipped in 1914 and 1915; the Goodsprings Bill Nye Mining Co. shipped in 1916 and 1917. The remainder has been shipped by lessees.

Production of Bill Nye mine, 1914–1919

Year	Crude ore (tons)	Gold (ounce)	Silver (ounces)	Copper (pounds)	Lead (pounds)	Zinc (pounds)
1914	301				7, 094	200, 657
1915	306					203, 761
1916	250				12, 500	155, 125
1917	293		67		4, 744	196, 985
1918	155				9, 156	91, 030
1919	183	0. 50	29	6, 860	29, 070	74, 375

[58] Hill, J. M., The Yellow Pine mining district, Clark County, Nev.-U. S. Geol. Survey Bull. 540, p. 41, 1913.

The principal workings on the Bill Nye group are a tunnel which, with connected drifts, aggregates about 550 feet and a shaft 220 feet deep on an incline of 76° from which there are levels at 43, 66, and 137 feet below the surface. Most of the ore has come from a single stope above the tunnel level. (See fig. 42.)

These workings explore a zone near the base of the Bird Spring formation, the beds of which strike N. 45° to 55° E. and dip 45° to 55° SE. In most of the mine workings the beds are completely dolomitized, but a footwall drift on the second level off the shaft passes from dolomite into 60 feet of unaltered limestone. Several hundred feet east of the mine the same beds yielded a good collection of fossils of the Bird Spring formation (collection 55a). This is an area that presents structural complications. The beds near the mine are the upper part of a thick section that forms the south limb of a persistent eastward-trending anticline. Although there are few faults conspicuous on the surface near by, the Bill Nye thrust fault crops out on the ridge 1,000 feet to the south, and numerous walls and breccia zones are displayed underground. Several thousand feet to the east there are two conspicuous northwest faults of the premineral normal group, and one shows enough copper minerals to be explored by prospects.

The most abundant mineral at the Bill Nye mine was hydrozincite, which here and there contained grains of galena or its oxidation products, but lead represented a small part of the output. Calamine is present but not abundant. The principal body of zinc ore so far discovered is that which was mined from the stope at the north end of the tunnel. This stope is about 50 feet long, 10 to 20 feet wide, and 35 feet high at the point where it reaches the surface. It follows a breccia zone that is roughly parallel to the bedding and plunges southward. The breccia zone can be traced eastward on the surface but dies out without appreciably offsetting the beds. The ore body was limited on the south by a conspicuous shear zone that trends N. 85° W. and dips 85° N. This may offset the ore-bearing breccia, but if so, the displacement is probably not great, as a bedded breccia near by, in the proper place if allowance is made for dip and difference in altitude, was explored from the shaft and yielded ore. From the abundance of hydrozincite with the contained grains of galena and meager calamine and smithsonite, it seems clear that the original deposit of zinc sulphide lay within the space of the present stope and that the zinc migrated only locally, replacing the dolomite near by. It is therefore possible that the N. 85° W. fault is premineral and marks the channel by which the zinc sulphide was brought in.

The largest body of ore encountered in the shaft was a pipelike mass from 5 to 10 feet wide, 15 to 25 feet in stope length, and 50 feet in pitch length. It lay west of the shaft, largely above the drift at 66 feet. It is not shown in Figure 42.

AKRON MINE

On the Akron claim (No. 40, pl. 30), located in 1905, there is a shaft 95 feet deep, inclined at 52° to 63°, from which there are levels at 60 and 95 feet. A tunnel from the west meets the shaft 30 feet below the top. These workings lie about 1,000 feet east of the Bill Nye and at a slightly higher stratigraphic position. Here the beds are locally folded as well as crushed along northwestward-trending faults. Earthy zinc carbonate with some calamine was struck at several places, and it is reported that the mine has yielded 4 or 5 cars of zinc ore, which is not included in the production of the Bill Nye mine.

About 500 feet north of the Bill Nye shaft there is a 10-foot prospect sunk on a vein of yellowish-green cuprodescloizite which cements a dolomite breccia that lies parallel to the bedding. The width locally attains 5 inches of material that should contain 10 per cent of vanadic oxide. J. A. Egger and others mined and shipped 7 tons of this material.

SURPRISE MINE

The Surprise claim (No. 41, pl. 30) lies west of the Fredrickson and covers an area near the top of the ridge above the Columbia Pass road, 3 miles west of Goodsprings. From the end of a tunnel, 230 feet long, a shaft has been sunk 90 feet at an inclination of 40°. There are short drifts at several levels and at the bottom. These workings explore a breccia zone at the base of the Bird Spring formation nearly parallel to the bedding. In the upper part there is a stope 20 feet long by 15 feet high and 3 to 4 feet wide. There is a record of the shipment of 10 tons of mixed lead-zinc ore (25 per cent of lead and 15 per cent of zinc) and of 31 tons of ore containing 36 per cent of zinc. Most of the work was done during 1916 and 1917 by the Azalia Mining Co.

FREDRICKSON MINE

The Fredrickson mine (No. 42, pl. 30) lies 800 feet south of the main road over Columbia Pass, 2 miles west of Goodsprings. It was first located by Jesse Jones in 1897, but no assessment work was done, and it was relocated by J. A. Egger in 1905. The explorations above the 100-foot level, except some stopes, were made by Wadey and Fredrickson prior to 1912,[59] but those below that level were made by the Goodsprings Dividend Mining Co. from 1915 to 1917. Since then it has been leased several times.

[59] Hill, J. M., op. cit., p. 53.

Production of Fredrickson mine, 1909–1926

Year	Ore mined (tons)	Ore shipped [a] (tons)	Silver (ounces)	Copper (pounds)	Lead (pounds)	Zinc (pounds)
1909	--------	35	--------	--------	--------	23,733
1912	--------	15	--------	--------	--------	10,081
1913	--------	65	--------	--------	--------	39,576
1914	--------	100	793	--------	8,864	66,399
1915	496	[b] 400	3,107	--------	53,500	153,850
1916	200	[b] 139	844	--------	35,850	57,438
1917	--------	72	25	3,536	2,968	36,077
1918	--------	369	--------	--------	56,094	163,118
1919	--------	36	302	143	21,456	--------
1920 [c]	--------	46	45	--------	13,422	8,739
1926	300	13	499	62	13,214	--------

[a] All crude except in 1915 and 1916.
[b] Concentrate.
[c] From Singer mine, operated by Fredrickson and Springer.

The workings of the mine explore a zone in the Yellowpine limestone. At three places in the mine a fine-grained brownish shaly sandstone is exposed in the roof over the stopes. Doubtless it is the sandstone at the base of the Bird Spring formation, for characteristic fossils of the lowest zone of that formation were collected on the spur above the mine (collection No. 37a).

In this area the beds trend N. 40° to 50° E. and dip 20° SE. With regard to structure, the Fredrickson mine is one of several mines that lie within a short distance of the Fredrickson fault, largely within 1,000 feet and on the west side. The fault is marked by reefs of dolomite breccia as much as 30 feet thick and 20 feet high several hundred feet northeast of the mine. The base of the Bird Spring formation west of the fault abuts against dolomitized Sultan limestone east of the fault, so that the dip slip along it is about 500 feet. For a mile southeast of the mine the near-by beds are extensively dolomitized.

The workings are shown in Figure 43. The stopes of the mine may be considered in three groups. The stopes along and above the second level yielded lead-bearing hydrozincite that replaced dolomite underlying the shaly sandstone. The dolomite is not as much broken as in many other mines of this district where the ore shoot lies along a definite stratum, but there are several northwest faults of small displacement. Most of these faults dip northeast and are probably postmineral. The stope above the third level, locally called the "silver stope," was from 2 to 5 feet high and yielded crushed dolomite coated sporadically with silver minerals, probably largely chloride. This material was milled with the product of other parts of the mine and served to enrich the lead concentrate. It probably accounts for the high silver content of the product during 1915. The stope above the fourth level was from 3 to 6 feet high and yielded largely lead with very little zinc. The present walls show lenses of galena and oxidized minerals 6 to 15 inches thick and 5 to 15 feet long

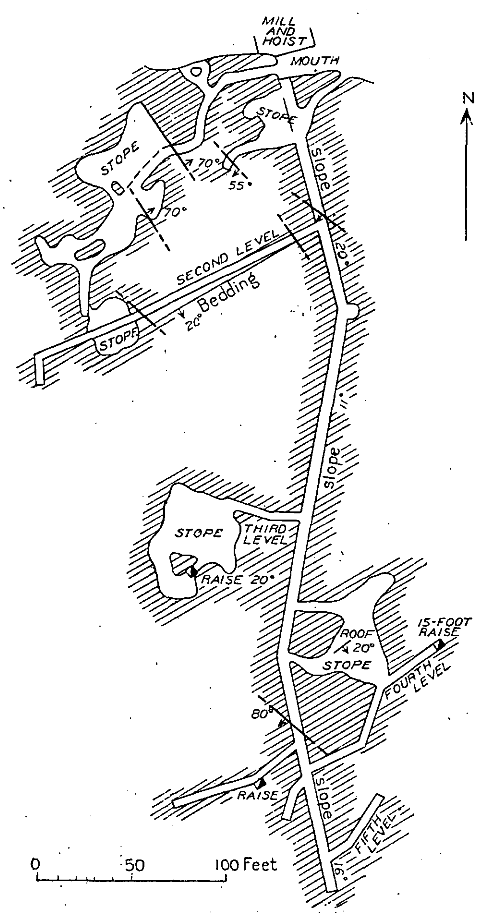


FIGURE 43.—Geologic map of Fredrickson mine

parallel to the bedding. An uncommon feature of this shoot is the persistent content of vanadium, the precise associations of which were not determined. According to one of the owners, most of the product of the shoot contained 0.75 per cent of vanadic oxide. No attempt was made to sort it out, and the vanadate passed into the lead concentrate of the mill. In this stope, as well as in that nearest the surface, thin coatings of carmine cinnabar were observed in the carbonate and sulphate of lead coating the galena.

ARGENTENA MINE

The workings of the Argentena mine (No. 44, pl. 30) lie near the crest of the narrow ridge about a mile southeast of the Fredrickson mine and about 3 miles southwest of Goodsprings. Most of the existing work has been done since January, 1926, by the Argentena Consolidated Mining Co. on the Galena claim, located in 1887 by A. S. Campbell and A. E. Thomas. Production began with the shipment of a car of lead ore in 1926. The principal workings are two tunnels, the northern of which extends from the west side to the east side of the ridge. (See fig. 44.)

Both of these tunnels explore the zone that includes the top of the Yellowpine limestone and the lower 100 feet of the Bird Spring formation. The Yellowpine limestone, as well as the limestones in the lower part of the Bird Spring formation, is locally completely altered to coarse, nearly white dolomite. In this area the Arrowhead limestone crops out on both sides of the ridge in such a way as to indicate that the ore-bearing ground lies near the crest of a low anticline. The sandstone at the base of the Bird Spring formation is nearly horizontal in the eastern part of the north tunnel, but in the winze farther west it dips 10° S., and the lower workings off the winze are in the Yellowpine limestone. The workings on the south tunnel lie in higher beds. In the approach to the mouth of this tunnel, a cemented breccia zone 15 feet or more wide is exposed. It appears to mark the position of the Fredrickson fault, although the Arrowhead limestone is locally dropped on the east side instead of the west side as it is farther north.

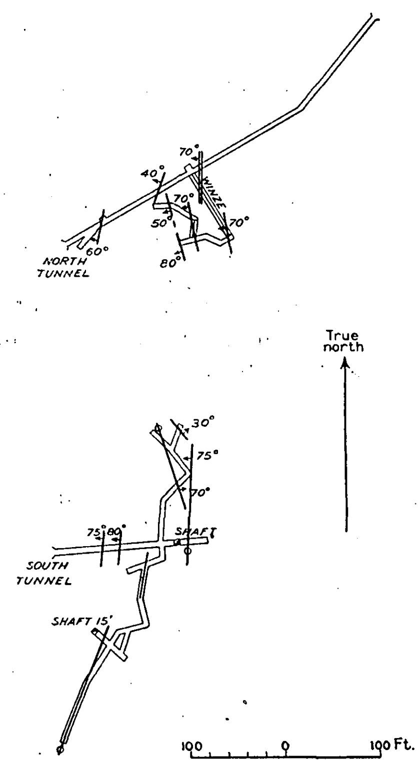


FIGURE 44.—Geologic map of Argentena mine

In the Argentena mine the zinc minerals, largely hydrozincite, greatly exceed the lead minerals, of which galena is most abundant. These minerals lie mainly in open breccia zones roughly parallel to the bedding of the limestones near the base of the Bird Spring formation, but several northward-trending steep fracture zones also contain both minerals. The strike of these fractures ranges from N. 20° W. to N. 10° E., the dip is largely steeply west, and they are clearly premineral. A number are shown in Figure 44. The ore-bearing ground in both tunnels is limited eastward by a northward-trending fault that appears to be continuous throughout the workings and post-mineral. On the east side of the ridge lower workings have encountered lead ore at the same horizon.

In addition to the common lead and zinc minerals a yellowish vanadate, probably descloizite, is rather common and is especially abundant on workings on the east slope of the ridge. It forms thin mammillary coatings on the dolomite breccia. In places the galena is embedded in brown chert which cements dolomite breccia. For 100 feet or more the drift south from the south tunnel reveals bedded veins of barite, locally 1 foot or more wide. The barite is coarsely crystalline and clearly replaces the dolomitized limestone.

Production of the Argentena mine, 1927–28

Year	Ore mined (tons)	Ore shipped (tons)	Gold (ounces)	Silver (ounces)	Copper (pounds)	Lead (pounds)	Zinc (pounds)
1927	.140	[a] 30		300		20,000	25,000
		[b] 40					
1928	1,245	[a] 249	1.40	2,489	760	109,581	

[a] Concentrate. [b] Crude ore.

VOLCANO AND NEAR-BY MINES

The Volcano claim lies on the east edge of Table Mountain, 3 miles southwest of Goodsprings. In an area scarcely 200 feet in diameter there are several short tunnels and shallow shafts that explore irregular shoots of galena disseminated through dolomitized parts of the Yellowpine limestone. The shoots are parallel to the local bedding, which is nearly north; the dip is 5° W. According to Allen S. Campbell, one of the owners, about 10 carloads (300 tons) of zinc and lead ore has been shipped from the workings.

The Prometheus claim adjoins the Volcano claim on the north. Some shallow tunnels and open cuts explore small shoots such as are exposed on the Volcano claim. According to the owner, C. A. Beck, the shipments include 20 tons of lead ore and 70 tons of zinc ore.

LOOKOUT, ANNEX, AND MOUNTAIN TOP MINES

The Lookout and Annex mines (No. 45, pl. 30) and the Mountain Top mine (No. 46, pl. 30) form a group that lies near the crest of a high ridge 3 miles south of Goodsprings. They are accessible by a road to the foot of the ridge, where trails lead to the several tunnels. The Mountain Top claim was one of those located by A. G. Campbell prior to 1893, and in that year it was referred to as one of the most promising in the district.[60] The Lookout was located several years later by Campbell, but the Annex was not located until 1907, when P. H. Springer recognized the fact that ore had been extracted north of the side line of the Lookout claim. These claims were worked intermittently until about 1913 and then almost steadily by lessees until 1919. In 1924 the Lookout and Annex produced ore. A number of separate deposits have been worked on these claims, but as they have many similarities and the records of production of the first two claims have not been kept separate by the owners, they will be described as a group.

All the deposits on these claims lie in a thin stratigraphic zone, probably less than 100 feet thick, near the base of the Bird Spring formation. In this area the limestones dip gently west, so that the outcrop of the zone closely follows a contour around the hill. The Fredrickson fault, which is traceable from the north 2 miles and from the south in Deadmans Canyon, doubtless passes along the east edge of the hill but is obscured locally by numerous minor fractures. As in the valley south of the Fredrickson mine and in Deadmans Canyon, this fault is the channel from which rising solutions have spread outward into the beds on both sides and converted the limestone into dolomite.

There are 13 openings along the outcropping zone in a distance of 3,000 feet, and although probably all have been sources of ore, most of the output has come from four. At the northwest end a tunnel extends 75 feet south, and from it stopes have been extended irregularly both ways about 40 feet; the range in height is 3 to 5 feet. These workings explore a horizontal zone of broken dolomite in which coarse masses of galena are sporadically distributed. No zinc minerals were noted in the workings, but many fragments on the dump were coated with an olive-green vanadate, probably cuprodescloizite. This tunnel was probably the source of a shipment of 36 tons of ore in 1918 that contained 9.26 per cent of vanadic oxide and was sold for $2,602. This is the largest shipment of vanadium-bearing ores yet made from the district. Of the material sorted from this shipment, 5.38 tons contained 11.50 ounces of silver to the ton and 43.90 per cent of lead.

Several hundred feet east of this tunnel is another, which extends S. 35° W. 125 feet and from which flat stopes extend 40 feet west and 60 feet east; the range in height is 4 to 10 feet. In these workings there is a persistent zone 1 to 2 feet thick that contains many irregular masses of coarsely crystalline galena embedded in dolomite, but masses of galena were also found sporadically above this zone. Here it seems clear that the distribution of galena is determined by the flat zone of crushed dolomite, nearly parallel to the bedding. Zinc minerals are not conspicuous, but a little brown hydrozincite is present here and there, and screenings from the lead ore contain 18

[60] Eng. and Min. Jour., vol. 55, p. 38, 1893.

per cent of zinc. The only other conspicuous mineral in the deposit is coarsely crystalline white calcite, which is deposited near the galena, largely in the spaces between the dolomite fragments. Some polished specimens of galena-bearing dolomite show a persistent border of chert around the galena, but this is not invariably present. This deposit appears to have contributed most of the production from the Lookout and Annex claims.

Within the next 1,500 feet southeast on the east end of the Lookout claim two more deposits are explored, the largest extending over an irregular area 40 by 70 feet. These deposits appear to have yielded galena ore only.

About 1,000 feet farther south there are five explorations in an area 150 by 350 feet. The largest of these deposits is an open cut from which several short tunnels and a 40-foot shaft have been made. These workings were the source of most of the production of the Mountain Top claim. As at the Lookout openings, the dolomitized limestone is much broken along a zone roughly parallel to the bedding, and coarse crystals of galena are irregularly distributed through the dolomite, largely in groups parallel to the bedding. Zinc minerals, notably hydrozincite, are more common here than elsewhere on the ridge, and oxidized copper minerals are also common. Ferruginous chert is intimately associated with the ore.

About 1,000 feet southwest of the principal Mountain Top workings there is an open cut with a 100-foot tunnel and small stopes. These workings explore a deposit that closely resembles those worked on the Lookout claim.

The following table of production submitted by the owner to the United States Geological Survey includes the shipments of the New Year, Mountain Top, and Lookout mines but not the Annex. According to Allen G. Campbell, son of the owner, the combined production of the Mountain Top and Lookout is about 2,000 tons of ore of all classes. Probably the production from the Lookout claim is 400 to 500 tons, mostly lead ore, and from the Mountain Top 1,500 tons, mostly zinc ore. According to J. A. Fredrickson, the Annex claim has yielded 10 cars, or about 250 tons, mostly lead ore. Of 10 cars of zinc ore shipped by Mr. Fredrickson in 1915, the net weight was 292 tons and the range in zinc content 30.5 to 39 per cent. The gross value at the smelting plant in Colorado was $13,558, and the net return to the shipper was $10,507 at Jean.

Production of New Year, Mountain Top, and Lookout mines, 1912–1926

Year	Crude ore (tons)	Gold (ounces)	Silver (ounces)	Copper (pounds)	Lead (pounds)	Zinc (pounds)
1912	119	-------	182	-------	41, 600	62, 537
1914	502	-------	348	114	27, 108	279, 754
1915	1, 040	-------	456	36, 567	32, 274	511, 500
1916	4, 192	250. 07	1, 252	15, 236	618, 926	1, 279, 639
1918	617	7. 61	2, 127	76, 217	109, 096	84, 468
1925	39	-------	18	-------	8, 104	17, 559
1926	85	-------	9	-------	10, 772	44, 788

Production of Annex mine, 1913 and 1919

Year	Crude ore (tons)	Gold (ounce)	Silver (ounces)	Copper (pounds)	Lead (pounds)	Zinc (pounds)
1913	7	0. 04	131	30	8, 376	-------
1919	92	. 30	779	5, 841	23, 000	14, 892

HOOSIER MINE

The Hoosier mine (No. 47, pl. 30) lies in a gulch 4 miles in a direct line southwest of Goodsprings, but by road the distance is about 8 miles. Although the Hoosier claim was located in 1886 by A. G. Campbell and A. E. Thomas, most of the work has been done during recent years on the Oklahoma claim, which was located in 1892 by the same men. Only assessment work was done before 1906, when it was sold to H. Joseph and associates, of Salt Lake City, who formed the Hoosier Mining Co. The present owners, the Galena Canyon Mining Co., of Los Angeles, bought the group of seven claims in 1917 for a price reported locally as $12,000. This company built a mill, but it was never used, and in 1924 it was sold and rebuilt in Mesquite Valley to treat ore from the Kirby mine.

The principal workings are several stopes within an area 300 by 200 feet, accessible by three tunnels. These workings explore a crushed zone of dolomitized limestone about 200 feet above the base of the Bird Spring formation. Consequently, it lies higher in the stratigraphic section than any other mine in the district. In this area the beds trend N. 20° W. and dip 15° SW. and are extensively dolomitized. The photograph reproduced in Plate 19, *A*, was taken at the Hoosier mine to show the presence at the middle of the section of a bed of dark-gray limestone about 20 feet thick in the midst of a group of similar beds now completely altered to dolomite. The view also shows a late normal fault that dips east, along which the eastern block has dropped 20 feet, but dolomitization did not follow it.

The largest stope of the Hoosier mine lies at the eastern or upper end of the explored area and extends irregularly northward about 150 feet from the two upper tunnels. Over most of the area the stope is 3 to 6 feet wide but in several places it attains 12 feet. It is limited upward by a good wall, apparently a bedding plane, that trends N. 20° W. and dips 15° SW. Above this wall the beds are not much disturbed, but below it the dolomite is brecciated and recemented by coarse white calcite. Galena is the most abundant mineral; it forms coarse crystals or lenses in the dolomite breccia, but in the walls of the large stope it is largely altered to cerusite. In the lower or western workings, fresh galena forms coarse angular masses in the dolomite, but the white calcite is absent, and the rock is very hard and coherent. Zinc minerals, largely hydrozincite, are common in the large stope but absent in the lower ones. Distinct faults are uncommon, but one was observed in the upper stope that trends N. 65° E. and dips south, along which the ore zone is faulted 3 feet; it is probably postmineral.

On the Van Henry claim, 1,000 feet to the south, there are two tunnels, 60 and 150 feet long, which explore lenses of hydrozincite at a zone slightly higher than that in which the Hoosier bodies lie. The lenses are limited by a wall that is parallel to the local bedding in strike but dips more steeply.

On the Hermosa claim, 3,000 feet north of the Hoosier workings, owned by Charles Kennedy, zinc minerals were found along a bedded breccia zone in beds of the Bird Spring formation, and galena was found along a prominent wall that trends north and northeast and dips west; doubtless it is a premineral fault. The workings have yielded several cars of lead ore which contained an uncommon assemblage of oxidized lead minerals—carbonate, molybdate, and phosphate.

Production of Hoosier mine, 1906–1928

Year	Crude ore (tons)	Gold (ounces)	Silver (ounces)	Copper (pounds)	Lead (pounds)	Zinc (pounds)
1906	50	-------	-------	-------	50,000	-------
1912	100	0.34	189	214	26,028	23,460
1913	69	-------	178	46	28,463	-------
1914	26	.18	252	36	33,743	-------
1915	25	-------	-------	-------	-------	16,886
1916	464	-------	358	1,190	77,966	190,098
1917	682	2.66	2,385	1,251	393,764	10,230
1928	208	-------	418	-------	151,706	31,354

SPELTER MINE

The Spelter group of claims (No. 48, pl. 30) covers the west end of a ridge half a mile west of the Hoodoo mine. There are three tunnels, but lead ore has been found only in the upper two. The middle tunnel, 160 feet long, explores a shear zone roughly parallel to the bedding of Bullion dolomite. The area is much broken up and is limited eastward by a thrust fault along which the upper part of the Monte Cristo limestone rests upon the lower part of the Bird Spring formation. (See p. 51.)

According to Rex Ewing, one of the owners, the shear zone includes a shoot of cuprodescloizite and galena, 4 to 6 feet wide, which contains about 2 per cent of vanadic oxide. One sample collected over a width of 7 feet contained 3.65 per cent of vanadium oxide.

There is no record of production from the mine.

HOODOO MINE

The Hoodoo claim (No. 49, pl. 30) lies at the east end of a drain that extends westward in the cluster of low hills 7 miles southwest of Goodsprings. The claim was located by S. C. Root and R. R. Courtright in 1898, but very little work was done until 1911, when the Kansas-Nevada Mining Co. was organized; that company has done most of the work.

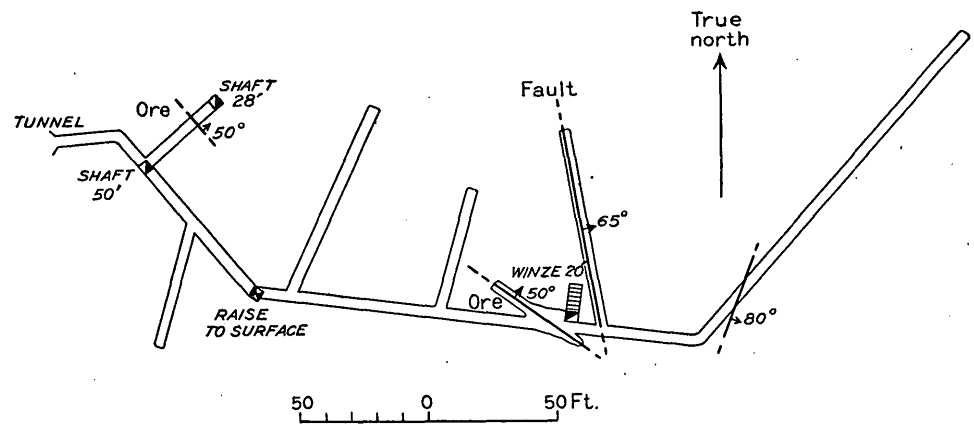


FIGURE 45.—Sketch map of Hoodoo mine

The workings include three tunnels, the longest of which contains 750 feet of drifts and several shafts and winzes. (See fig. 45.) All these explorations are found in a block of dolomitized Monte Cristo limestone that has been thrust upon beds of the Bird Spring formation. The fault is clearly shown in this area and doubtless continues southward under the wash and joins that which underlies the Singer and Tiffin mines. Here, as farther south, the base of the thrust block is a zone of dolomite breccia 100 feet or more thick, but dolomitization extends higher into the block. The tunnel (fig. 45) is wholly in breccia of Bullion dolomite, most of the fragments of which are less than 6 inches in diameter and so loosely coherent that a drift may be made by the use of a pick only. Structurally the block is a closely folded syncline that trends northwest with dips in excess of 50° on both limbs.

Several isolated bodies of lead and zinc ore have been struck in the tunnel. These bodies lay along shear zones that range in strike from N. 40° W. to

N. 30° E. and dip northeast or southeast. None of them appear to be as persistent as others near by, such as those in the Tiffin mine, but from their position in the thrust breccia this would be expected. Most of the lead encountered was free from zinc minerals. Galena and its oxidation products are common, and hydrozincite and calamine were noted. In the middle part of the tunnel an iron-stained shear zone trending N. 55° W. and dipping 50° NE. was struck. It deserves attention on account of its content of a vanadate, probably descloizite. According to Frank Williams, one of the owners, tests of samples weighing several hundred pounds show an average content of 2.5 per cent of vanadic oxide. Concentrates from such material show by analysis 36 per cent of lead, 8 per cent of zinc, and 15 per cent of vanadic oxide. Galena has not been observed in this shear zone, and the vanadate present has probably been deposited there by downward percolating surface water.

Production of Hoodoo mine, 1911–1927

Year	Crude ore (tons)	Silver (ounces)	Lead (pounds)	Zinc (pounds)
1911	30	91	12,151	16,082
1913	31			15,915
1915	54	432	21,680	20,400
1916	37			23,273
1917	171			106,589
1918	3			2,143
1927	9			5,552

ROOT MINE

The group of claims owned by the Root Zinc Mining Co. (No. 50, pl. 30) cover the north slope of Bonanza Hill, 8 miles southwest of Goodsprings. One of the claims was located as early as 1893, and it is reported that some ore was shipped at that time, but the principal claims of the present group were located in 1900 and 1901. S. C. Root, of Los Angeles, is the principal stockholder of the company.

The crest of Bonanza Hill is made up of beds of the Bird Spring formation that trend northeast and dip southeast at angles which increase southward from the north slope. The beds form the southeast limb of an anticline that trends northeast and pitches in that direction. The crest almost coincides with the ravine south of Root Camp. The base of the Bird Spring formation descends from the top of the ridge northeast to the base of the ridge east of the camp. Characteristic fossils were collected near the base south of the camp. (See p. 24, collections 46a, 46b.) As the beds that make up the low ridge northwest of the ravine are dark fetid crystalline limestones that yield fossils characteristic of the middle part of the Monte Cristo limestone, it is necessary to conclude that a fault extends northeastward down the ridge, along which the beds on the southeast side have dropped 100 to 200 feet. There are numerous joints and shear zones on this ridge along which such faulting could have taken place. There are also many faults along Bonanza Hill, but only a few seem to have sufficient displacement to warrant record on the map. These range in strike from N. 30° W. to north and dip steeply west. The most conspicuous lies west of the crest, trends N. 30° W., and dips 75° SW., and along it the west side has dropped 100 feet or more. As no bodies of lead or zinc minerals have been found on these faults, it can not be said with assurance that they are premineral, but they may be.

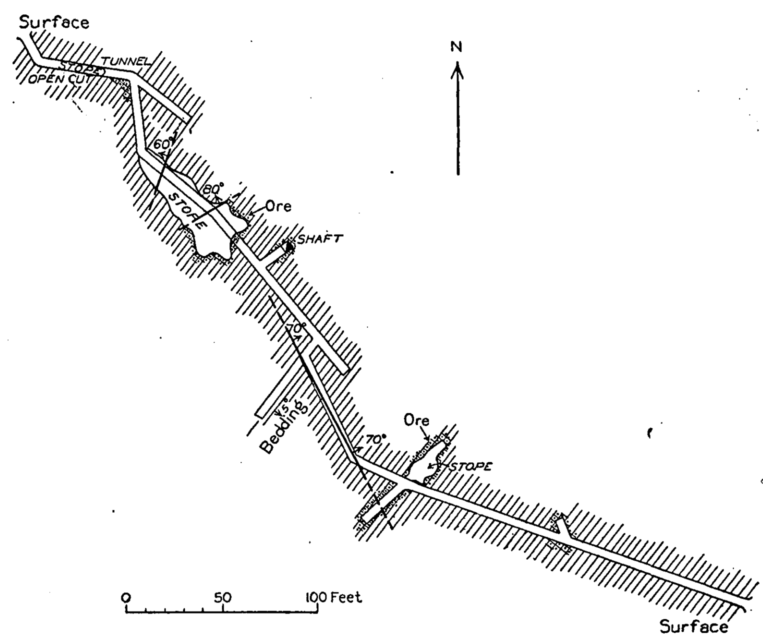


FIGURE 46.—Geologic map of Root mine

On Bonanza Hill there are a larger number of workings that have been a source of ore in a small area than in any other part of the district. The most productive part of the ridge lies north of the crest, but there are also many prospects south of it. On the Root claims three production areas may be recognized—one 2,000 feet southwest of the camp, in which lead minerals predominate over those of zinc in bodies which occur in the Monte Cristo limestone; another 2,000 feet south of the camp (fig. 46); and a third 1,000 feet southeast of the camp, in which zinc minerals predominate over those of lead in bodies which occur in the Bird Spring formation.

The lead-bearing area is about 150 by 500 feet, and it is explored by several tunnels and many pits. There is one stope as much as 100 feet long and 12 feet high that lies parallel to the bedding of the dolomitized Monte Cristo limestone; it follows a galena-bearing lens 1 to 3 feet wide. The ore is locally limited northward by a fault that trends N. 15° E. and dips 65° NE.

The lens yielded galena and its oxidation products, especially cerusite, linarite, and caledonite, as well as the common zinc minerals. Apparently most of the lead from the claims has come from these workings.

The longest tunnel, but doubtfully the source of most of the zinc ore, lies near the crest of the ridge and extends from the north to the south side. (See fig. 46.) Zinc ore, largely with little or no lead, was mined in at least five places, but no close relation of these bodies has been recognized. The largest stope and probably the source of most of the ore is flat and nearly parallel to the bedding. The bulge at the south end is limited by a northeastward-trending fault that seems to have been formed after the deposition of the zinc sulphide but before that mineral was altered to hydrozincite. A little calamine occurs here and there through the workings, but it is largely on fractures that cut the hydrozincite. These workings still yield many specimens that show the replacement of dolomite by amorphous hydrozincite.

The largest body of zinc ore on Bonanza Hill was encountered in a tunnel at the east end of the claims. Ore was first struck in the tunnel 100 feet from the mouth, but the largest body lay parallel to the bedding 75 feet farther in. It was explored by a winze to a depth of 40 feet and for a distance of 100 feet along the strike. The gross value of the zinc ore mined from the stope during 1915 and 1916 is reported to have been about $30,000.

The following summary of the production of this group of claims is compiled from the records of the United States Geological Survey. The separate annual shipments do not exactly agree with those recently submitted by Mr. Root to the writer, but his total—2,405 tons—is only a little lower than that given—2,575. Mr. Root thinks that the difference, 170 tons, was derived from other workings on the hill.

Production of Bonanza group, 1893–1926

Year	Crude ore (tons)	Gold (ounce)	Silver (ounces)	Copper (pounds)	Lead (pounds)	Zinc (pounds)	Total value
1893	60						
1900	11						
1903	20		155		28,000		$765
1909	22		373	131	30,675		1,530
1915	323					220,300	
1916	[a] 1,537		221		23,110	966,450	
1917	[a] 377		1,058		80,668	204,538	
1918	[a] 174		1,048		148,518	41,456	
1921	31	0.31	387		32,903		
1926	8	.10	105		5,946		

[a] A small part of the ore in 1916–1918, not exceeding 170 tons, was shipped by lessees from other near-by properties on Bonanza Hill.

TIFFIN MINE

The Tiffin claim (No. 51, pl. 30) adjoins the Singer on the west, and its principal tunnel is only 500 feet west of that on the Singer claim. It was located in 1905 by C. A. Beck, who mined most of the ore and still operates it. As in the Singer, the workings lie wholly within the block of dolomitized limestones of the Monte Cristo formation that are thrust over beds of the Bird Spring formation. The beds are much disturbed but locally strike northeast and dip 35° to 50° SE.

The principal workings are a tunnel, which contains about 400 feet of drifts, and four shafts and winzes. (See fig. 47.) The country rock is Bullion dolomite. Ore has been mined from at least four small shoots, three of which lie on a persistent fault or spurs from it, and the other lies on a minor fault that is probably related to it in age. The largest stope overlies No. 3 winze and extends irregularly up to the surface. The width ranges from 2 to 3 feet. Galena is the most abundant mineral now found, although hydrozincite is present here and there and must have been the most abundant in the shipments. The shoots seem to be good examples of ore on early normal faults.

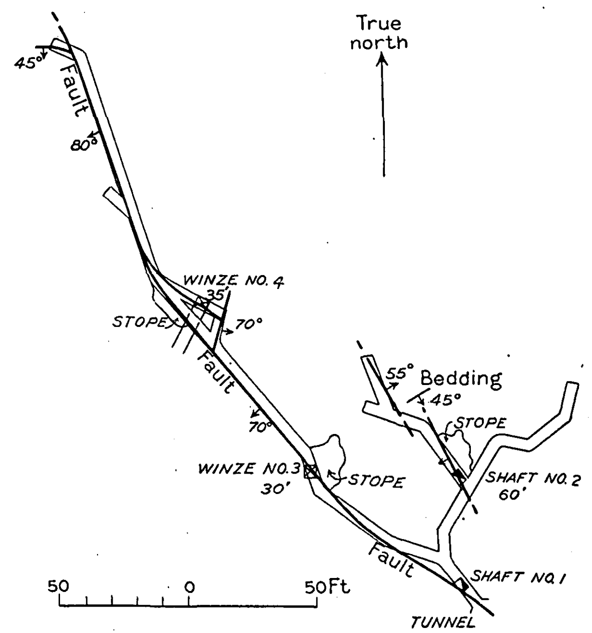


FIGURE 47.—Sketch map of Tiffin mine

Production of Tiffin mine, 1912–1926

Year	Ore mined (tons)	Ore shipped [a] (tons)	Silver (ounces)	Lead (pounds)	Zinc (pounds)
1912		6	3	8,040	
1915		3	12	2,520	
1916	80	[b] 40	500	24,000	20,400
		160	120	33,000	83,980
1917 [c]		16	67	7,840	3,068
1920		18		4,320	11,881
1924		15		3,600	8,925
1926		80		17,920	43,680

[a] Crude ore except as indicated.
[b] Concentrate.
[c] Includes small quantity from Eureka mine.

SINGER MINE

The Singer claim (No. 52, pl. 30) covers the east end of a low hill 7 miles southwest of Goodsprings. The claim was located in 1892 by four men, including W. E. Singer. In 1907, after a little work was done and two cars of ore were shipped, it was bought for $5,000 by Judge Erskine Ross, of Los Angeles, and J. H. Polk. It was operated by the Howard Mines Co. under lease during 1913 and 1914; by S. E. Yount and O. J. Fisk from 1916 to 1918; and by J. O. Fredrickson and P. H. Springer in 1920.

The workings include the main tunnel near the base of the ridge and several shorter tunnels 200 feet higher, the longest of which is 125 feet long. These workings all lie in the block of Bullion and Anchor limestones thrust over beds high in the Bird Spring formation. The breccia at the base of this block is about 100 feet thick and the higher beds are much broken by joints and faults. Except in a small area northeast of the mine the limestones are completely dolomitized. Near the mine the beds trend northeast and dip 50° SE. At the crest of the ridge above the highest tunnel a dike as much as 10 feet thick trends N. 80° E. and dips almost vertically. The rock is dark gray and rather coarsely crystalline but is much decomposed near the surface. In thin section it is seen to be largely brown biotite and brown hornblende with minor augite and labradorite but no orthoclase. The texture is coarser than that of the dike at the Puelz mine, but otherwise they closely resemble each other. Both are considered to be mica lamprophyre. (See p. 38.)

The principal tunnel is about 300 feet long, and the west branch terminates in a shaft 90 feet deep at an inclination of 45° to 50° S. There are stopes on both sides of the shaft outward for 35 feet and 4 to 6 feet wide. A stope also extends to the surface above the tunnel, a distance of 40 feet. The minerals include coarse crystals of galena and its oxidation products, earthy hydrozincite, and calamine. As shown by the extent and present distribution of the stopes these minerals lie along a brecciated zone in dolomite that trends roughly parallel to the bedding, or N. 60° to 70° E. and dips 60° SE. The stope on the west side of the shaft is limited westward by a fault that trends N. 45° W. and dips 80° SW. Although no galena was found on this fault it appears to be premineral. On the surface there are several minor faults that trend N. 45° W. to N. 10° E. and dip steeply southwest; they may also be premineral.

A tunnel about 100 feet east of the main tunnel shows dolomite breccia extensively covered with a thin coating of pyromorphite crystals of brilliant yellow and green color.

Of the ore produced, 213 tons was lead ore containing 27 to 60 per cent of lead and 2.8 to 11.0 ounces of silver to the ton. The remainder was largely zinc ore containing 20 to 35 per cent of zinc, but a few cars were mixed lead-zinc ore.

Production of Singer mine, 1913–1920

Year	Crude ore (tons)	Gold (ounce)	Silver (ounces)	Copper (pounds)	Lead (pounds)	Zinc (pounds)
1913	[a]124	0.30	481	209	124,074	----
1914	86	----	484	272	72,481	----
	14	----	168	----	11,431	----
1916	896	----	123	----	68,546	471,648
1917	26	----	51	----	14,246	----
1920	46	----	45	----	13,422	8,739

[a] Company's records show 142 tons of lead ore shipped during 1913. Difference is added to total.

PUELZ MINE

The Puelz mine (No. 53, pl. 30) is on a ridge that extends west from the south end of Table Mountain, 5 miles southwest of Goodsprings. The South Side claim was located in 1888 by A. G. Campbell and A. E. Thomas, and the Mongolian, upon which most of the work has been done, in 1907. There are a number of short tunnels and pits on the ridge, but the principal workings are on the north side near the high point. There are five tunnels, from each of which there are irregular stopes that lie roughly parallel to the bedding or N. 60° W., and dip 15° to 20° SW. Each of these tunnels explores the same zone in the upper part of the Bullion dolomite. Several hundred feet east of the easternmost tunnel the Puelz thrust, along which the local Bullion dolomite is thrust upon beds several hundred feet above the base of the Bird Spring formation, is marked by a broad breccia zone. Along the cropping of the ore zone there is a dike of dark-greenish igneous rock, much finer grained than that observed near the Singer mine. Without further microscopic examination it is regarded as a lamprophyre. It is broken in three places by normal faults that trend east and dip steeply north.

Probably the principal ore mineral was hydrozincite of the dark-brown earthy variety, but calamine is common both in druses and replacing the dolomite. These minerals, together with galena and its oxidation products, follow a brecciated zone parallel to the bedding.

Production of Puelz mine, 1915–1919

Year	Crude ore (tons)	Gold (ounce)	Silver (ounces)	Lead (pounds)	Zinc (pounds)
1915	121	----	----	3,500	74,936
1916	308	----	----	8,400	111,452
1917	169	----	158	15,448	101,616
1918	5	----	41	5,438	----
1919	8	0.08	36	3,060	3,332

SULTAN MINE

The Sultan group of 12 claims (No. 54, pl. 30) lies along the east slope of the prominent ridge a mile north of Little Devil Peak. The Sultan claim, which has yielded most of the ore, was located in 1896 by W. R. Sloane, but little work was done before 1910, and most of the ore was shipped during 1916 to 1918. A dry concentrating mill was erected in 1916. The property is now owned by Henry Robbins. (See pl. 35, *B*.)

The production of the Sultan mine is shown in the accompanying table, which exactly checks that recorded in the books of the owner. The owner's records show that 2,446 tons of crude zinc ore and concentrate and 1,289 tons of crude lead ore and concentrate have been shipped. Most of the zinc ore was shipped in 1915 and 1916; most of the lead ore in 1917 and 1918. The zinc ore contained from 28 to 42 per cent of zinc, 2 to 7 per cent of lead, 6 to 30 ounces of silver to the ton, and 3 to 13 per cent of insoluble matter. The lead ore contained from 30 to 60 per cent of lead, 6 to 14 per cent of zinc, 10 to 30 ounces of silver to the ton, and 1 to 3 per cent of insoluble matter. The gross value of 3,620 tons of both classes of ore was about $200,000, and the net value, after paying railroad freight and treatment charges, $155,000.

The Sultan mill, erected in 1916, is 500 feet east of the mouth of the main tunnel. As received from the mine the ore was delivered to three bins, from which it was passed over 1¼-inch screens. The coarse material was sorted to yield a smelting product; the undersize was crushed first in a jaw crusher and then in rolls and elevated to screens. Classified material was delivered to a Stebbins dry concentration table.

Production of Sultan mine, 1910–1920

Year	Ore mined (tons)	Ore shipped (tons)	Gold (ounce)	Silver (ounces)	Copper (pounds)	Lead (pounds)	Zinc (pounds)
1910		[a] 105					55,440
1915		[a] 778		720		35,580	465,729
1916	1,557	[b] 519		5,289		128,384	229,420
		[a] 943		7,218		107,612	458,842
1917	864	[b] 288		2,333		102,548	88,661
		[a] 434		12,785		368,186	
1918	1,143	[b] 381		13,000		327,384	
		[a] 147				15,615	81,117
1919	920	[b] 48		1,881		26,960	
		[a] 32				5,782	16,813
1920	204	[b] 51		1,443		37,516	
		[a] 10				1,937	5,226
1925	128	[b] 40		1,500	50	45,600	
		[a] 8		305	17	8,859	
1926	500	[b] 174	0.41	3,439		205,914	

[a] Crude ore. [b] Concentrate.

The geologic relations of the Sultan deposit are almost unique, and the mine workings yield data that are useful in interpreting the regional geology. The workings explore a part of the breccia zone that marks the position of the Sultan thrust fault. At this place it is wider than elsewhere and locally attains a width of 800 feet. The limits of the breccia zone are simple fractures, but between these fractures the material is in large part thoroughly crushed. In some areas the rock is merely broken but not much disturbed, so that traces of bedding remain. Elsewhere there are extensive zones of angular breccia in which few fragments exceed a foot in diameter. In the mine workings there are persistent fractures marked by clean walls in the midst of the breccia, and the ore bodies seem to be closely related to these. Most of the ore lies above and close to these fractures. They trend N. 30° to 45° W. and dip mostly 60° to 80° NE.; one is vertical. (See pl. 37.)

The rocks that limit the breccia on the southwest are limestone beds near the middle of the Sultan formation, which are slightly arched to form a local anticline. The beds northeast of the breccia zone are locally dolomitized limestones of the Bird Spring formation about 1,000 feet above the base. The breccia now consists wholly of dolomite fragments and, from fossils found in the mine, appears to be largely derived from the Bird Spring formation. In the main tunnel the breccia is cemented by white calcite.

From the dip of the fracture surfaces and the nature of the displacement one might conclude that the breccia follows a normal fault. That it is not a normal fault but a thrust fault, afterward tilted, is shown by the extent and regional relations of the breccia zone. The breccia zone and limiting fractures may be traced readily 3 miles southeast to Devil Canyon, where the zone ends abruptly at a cross fault, southeast of which there is an overturned anticline that extends beyond the New Year mine. Also, eastward from the Sultan mine, there are three blocks of brecciated and dolomitized Monte Cristo and Sultan limestones that rest on crumpled but undolomitized Bird Spring formation. The surface that separates these formations is obviously the eastward extension of the Sultan thrust, now broken by several normal faults. (See section I–J, pl. 2.) This area and the mine workings thus indicate that the entire ridge in which the Sultan mine lies has been tilted southwestward, toward Mesquite Valley, as much as 20° and possibly a little more.

The ridge east of the mine is made up of well-bedded fine tuffs that dip as much as 22° E. They lie on a surface that slopes about 20° E. and is cut across the breccia zone and adjacent limestones. The source of these tuffs may have been either the Sultan crater, a mile to the northwest, or the small crater that lies a mile to the west on the west side of the ridge. If the tuffs were deposited before the ridge was tilted 20° W., they would scarcely be expected to dip as much as 20° E. now. It therefore appears that the tuffs were deposited after the tilting of the range and that they may have been erupted in rather recent geologic time (Miocene?).

The Sultan mine has explored several bodies of zinc and lead ore in an area about 200 by 700 feet; the vertical range of the workings is about 300 feet. (See pl. 37.) The principal bodies may be regarded as parts of four shoots related to three fractures or faults. Each shoot is marked by the open-cut symbol on the map. The northwestern shoot (open cut No. 4) yielded mixed lead and zinc ore and probably was the smallest. Ore was found on several levels, and the largest stope, at an altitude of 4,072 feet, is flatter than the average dip of the local fractures. The next shoot southeast (open cut No. 3) was the source of considerable zinc ore unmixed with lead. In the open cut the ore, probably in large part hydrozincite, was limited on the west by one of the few westward-dipping faults in this area. Smaller bodies below lay above another fault that dips eastward. The third shoot, worked from open cut No. 2, appears also to have been a source of zinc ore only. It is limited on the west by an eastward-dipping fault (No. 2), probably the same as that encountered in depth farther north.

The largest shoot of the mine is the farthest south and includes the bodies removed from open cut No. 1 and from the shaft sunk from the tunnel. This shaft is about 310 feet deep with an inclination of 63°, and there are three levels. Some oxidized zinc minerals were noted on the surface and underground, but lead minerals, especially galena, were greatly in excess in the deeper working. Although a persistent fault lies under the body explored at the surface, it has not been struck in depth. There are several small stopes north of the shaft, but the largest, which was the source of most of the lead ore, lies south of it. (See pl. 37.) This stope extends from a point 20 feet above the first level nearly to the third level, a distance on the slope of 75 feet. The largest horizontal section occurs below the second level (3,931 feet), where it is about 125 feet long and 25 feet wide. It has the form of a pipe that plunges 60° SE. along a fracture that trends northwest and dips 45° NE. Stoping at the southeast end was stopped at a wall that trends N. 35° W. and dips 60° SW. To judge from what can now be seen on the walls, this stope included a number of lenses of galena-bearing hydrozincite which strike northwest and dip northeast at angles lower than that of the shoot as a whole. Such lenses as are now visible are from 3 inches to 2 feet thick and from 10 to 20 feet long. These lenses are rather distinct masses of mixed lead and zinc minerals without sharp limiting surfaces, and it is a surprise to find them in dolomite breccia that even now has so high a porosity. It is difficult to account for the restriction of the minerals to local lenses where the inclosing rock is so porous. It seems to have been a problem in mining to determine where to mine the single lenses and where to take a larger body that included several lenses. There is a lens of hydrozincite on the third level, but it contains no galena.

Without exact information concerning the original distribution of lead and zinc minerals in this mine, a positive conclusion can not be drawn, but at present the stopes, together with the record of production, indicate that the bodies of zinc minerals localized at the surface were the result of successive solution and redeposition of the zinc once present as sulphides in higher zones, now eroded. Nothing comparable to the bodies mined from the open cuts has been struck underground.

IRELAND MINE

The Ireland group of claims (No. 56, pl. 30) covers a low hill north of the mouth of Porter Wash, 5 miles south of Goodsprings. Within an area scarcely 500 feet in diameter there are eight shafts and shallow pits, the deepest of which is an incline on the north side of the hill 125 feet deep. The beds exposed on this hill are the mottled dolomitic limestones in the lower part of the Goodsprings formation close to the underlying Bright Angel shale. Most of the workings are in a thin-bedded dark-gray dolomite with brown mottling that overlies a 5-foot bed of micaceous shale. Below the shale there is a blue-gray limestone mottled with gray dolomite that shows no trace of bedding.

The ore shipped from the property has come from small lenses of lead, copper, and zinc minerals that are limited by irregularly disposed fractures in the mottled gray and brown dolomite. According to local report, several carloads of copper-bearing lead ore have been shipped from the hill.

STAR MINE

On the Evening Star claim (No. 57, pl. 30), north of the Monte Cristo mine, there are two tunnels that explore small shoots of lead and zinc ore along a fault that trends northwest and dips 75° SW. (See fig. 6.) On the south side of the gulch a 100-foot tunnel on the fault encounters sporadic nodules of galena. An 80-foot tunnel on the north side appears to have struck no ore but 30 feet from the entrance passed into a greenish gray biotite-bearing dike rock, now soft and much weathered. Both ore and dike lie in the fault and prove that the fracture was premineral. The fault separates Bullion dolomite on the west from beds near the base of the Monte Cristo limestone on the east, so that the west side has dropped about 300 feet relatively. The workings have yielded a little lead and low-grade zinc ore.

MONTE CRISTO MINE

The Monte Cristo mine (No. 58, pl. 30) is on the west side of Porter Wash 4 miles due south of Goodsprings. The claim was located by William Kennedy in 1907 and thus was the latest to be located among those mines that later became notable sources of production. Shipments were made first by Patrick Clarke in 1908, and it then passed to Douglas White and George Wheaton, who organized the Monte Cristo Consolidated Mining Co., which now owns it. According to White,[61] 100 cars of high-grade zinc ore were shipped during the first 10 months of ownership in 1908 and 1909. It is locally reported that prior to 1912 only high-grade zinc carbonate (smithsonite) was shipped and that the earthy carbonate (hydrozincite) was thrown on the dump. Under lease from September, 1911, to August, 1913, Duncan, Fredrickson & Belt shipped 145 cars of hydrozincite and calamine-bearing ore, some of it sorted from the dump. It has not been worked since 1919. The extent of the workings is shown approximately in Figure 51; a lower haulage tunnel that is now caved is omitted. The following table of production is probably complete.

Production of Monte Cristo mine, 1908–1919

Year	Crude ore (tons)	Zinc (pounds)
1908	425	289,000
1909	2,619	2,069,500
1910	285	201,278
1911	72	55,422
1912	249	174,968
1913	1,852	1,176,305
1914	1,274	776,737
1915	871	530,866
1916	1,044	638,350
1917	605	359,060
1918	171	110,352
1919	8	4,964

The deposit is uncommonly interesting because only zinc ore was encountered, and it was an exceptionally concentrated body, as one may readily suspect by the size of the workings and the meager dump. It lies wholly in the cherty Anchor limestone of the Monte Cristo formation, which is not as extensively dolomitized here as farther north. The limestone is well shown several hundred feet east of the mine, where the color is blue-gray and the texture dense and porcelainlike. It contains conspicuous layers of dark chert nodules. The strike is nearly north and the dip 25° W. The deposit is located between two faults that strike N. 35° W. and dip 50° NE. (See fig. 6.) Doubtless these faults were formed after the zinc sulphide deposit was introduced but before most of the oxidation to carbonate and silicate had taken place. They have been traced several thousand feet southeast.

The workings developed a shoot of exceptionally pure zinc ore that pitched about 20° SW. The upper limit of the stope is a bedding plane, but the sides and bottom were irregular in detail. A number of breaks are exposed, but only one seems to displace the beds. This break lies near the southwest end of the deposit, trends N. 40° W., and dips 80° SW., and the west side appears to have dropped. Hill[62] records another fault, which trends N. 50° E. and dips southeast, but this is not conspicuous and may have been destroyed by later work.

According to J. A. Fredrickson, who leased the mine in 1911–1913 and who kindly accompanied the writer during his visit to it, the first ore found and mined was hard gray smithsonite, and it made up a large part of the northern half of the shoot. Hydrozincite was encountered, as some may now be seen in the roof of the north end of the stope, but it was not

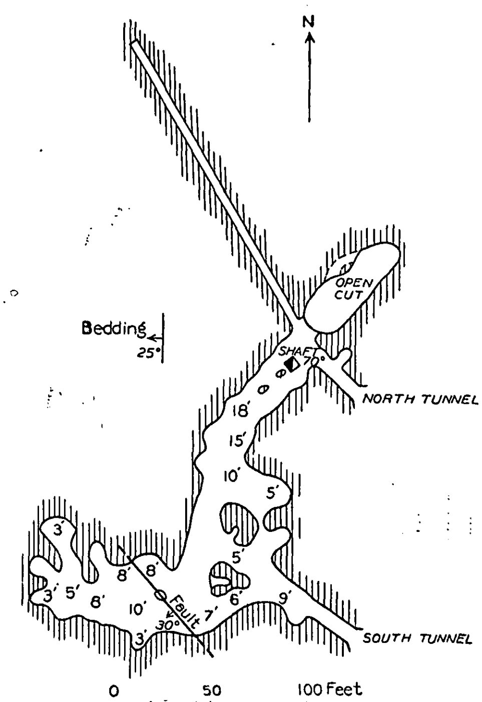


FIGURE 48.—Geologic map of Monte Cristo mine

recognized as a zinc ore and was thrown on the dump. When Fredrickson and associates obtained a lease on the mine in October, 1911, they pursued the shoot southwest and mined and sorted from the dump 145 carloads of ore that was largely hydrozincite with some calamine. No hydrozincite may now be seen in the southwest half of the stope, but calamine is common in the latest workings at the west end. In large part this calamine replaces both dolomite and chert, but here and there it is deposited in vugs and on cracks. Doubtless it formed a considerable part of the latest ore shipments.

The only other conspicuous minerals noted were wax-colored calcite, which forms large plumose masses near the open cut, and ferruginous chert, which occurs with the calamine that has replaced the original chert.

[61] White, Douglas, The zinc mines of southern Nevada: Am. Min. Cong., 12th ann. sess., Rept. Proc., pp. 401–411, 1909.

[62] Hill, J. M., op. cit., p. 55.

Both were probably deposited from surface waters during weathering.

If the record of the general distribution of zinc minerals as stated is correct, and it probably is, the deposit is unique in the district. The succession of the principal masses of minerals down the pitch of the shoot was smithsonite, hydrozincite, and calamine. According to the hypothesis worked out for the district in general, most of the hydrozincite was formed by the replacement of limestone or dolomite by zinc sulphate that had not moved far from the original zinc sulphide; the smithsonite was deposited lower down, and the zinc is largely that derived from hydrozincite, dissolved higher up. The distribution of calamine is what would be expected in a zone of carbonate rocks unusually high in silica (chert) content. Where smithsonite is more abundant than hydrozincite near the outcrop, as at the Monte Cristo mine, it is necessary to assume that the source of the zinc was a body of sulphide higher up in rocks now eroded and that the zinc did not migrate appreciably after being taken into solution as carbonate. The conditions indicate progressive enrichment of the zinc by successive solution and redeposition of zinc as carbonate near the surface. This distribution would be favored by a higher water table than customary or its slow recession downward as erosion took place.

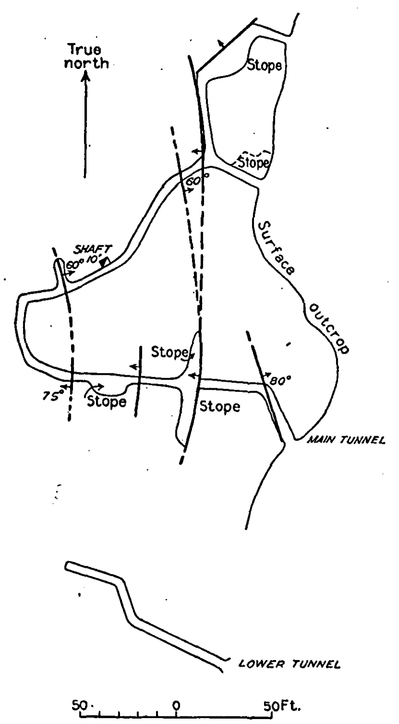


FIGURE 49.—Sketch map of principal workings of Accident mine

PALACE AND PORTER MINES

Particular interest is attached to the Palace and Porter mines (No. 59, pl. 30) because an opening on the Porter claim was the source in 1905 of the first shipment of lead ore by the Yellow Pine Mining Co. From a flat stope parallel to the bedding, an area 15 by 25 feet yielded 36 tons of lead ore, the net value of which was $1,985. The claims were first located in 1893, were patented in 1918, and are still owned by the company. According to J. F. Kent, these claims have yielded 250 or 300 tons of high-grade lead ore. They have not been worked extensively during recent years; one shipment of 30 tons in 1925 contained 241 ounces of silver and 35,835 pounds of recoverable lead.

The claims lie at the head of Monte Cristo Gulch, 5 miles south of Goodsprings. Most of the work has been done on the Porter claim, north of the gulch, where there are four tunnels, the longest about 200 feet long. These tunnels explore irregular, flat lenses of galena-bearing dolomite at the same horizon as that in the Accident mine. In addition to galena there is a little reddish hydrozincite. Coarse white calcite cements the dolomite breccia.

ACCIDENT MINE

The Accident mine (No. 60, pl. 30) is on the west side of Porter Wash, 5 miles due south of Goodsprings. It was located in 1901, but little has been learned of its early history. Most of the production has come from the operations of lessees between 1911 and 1919.

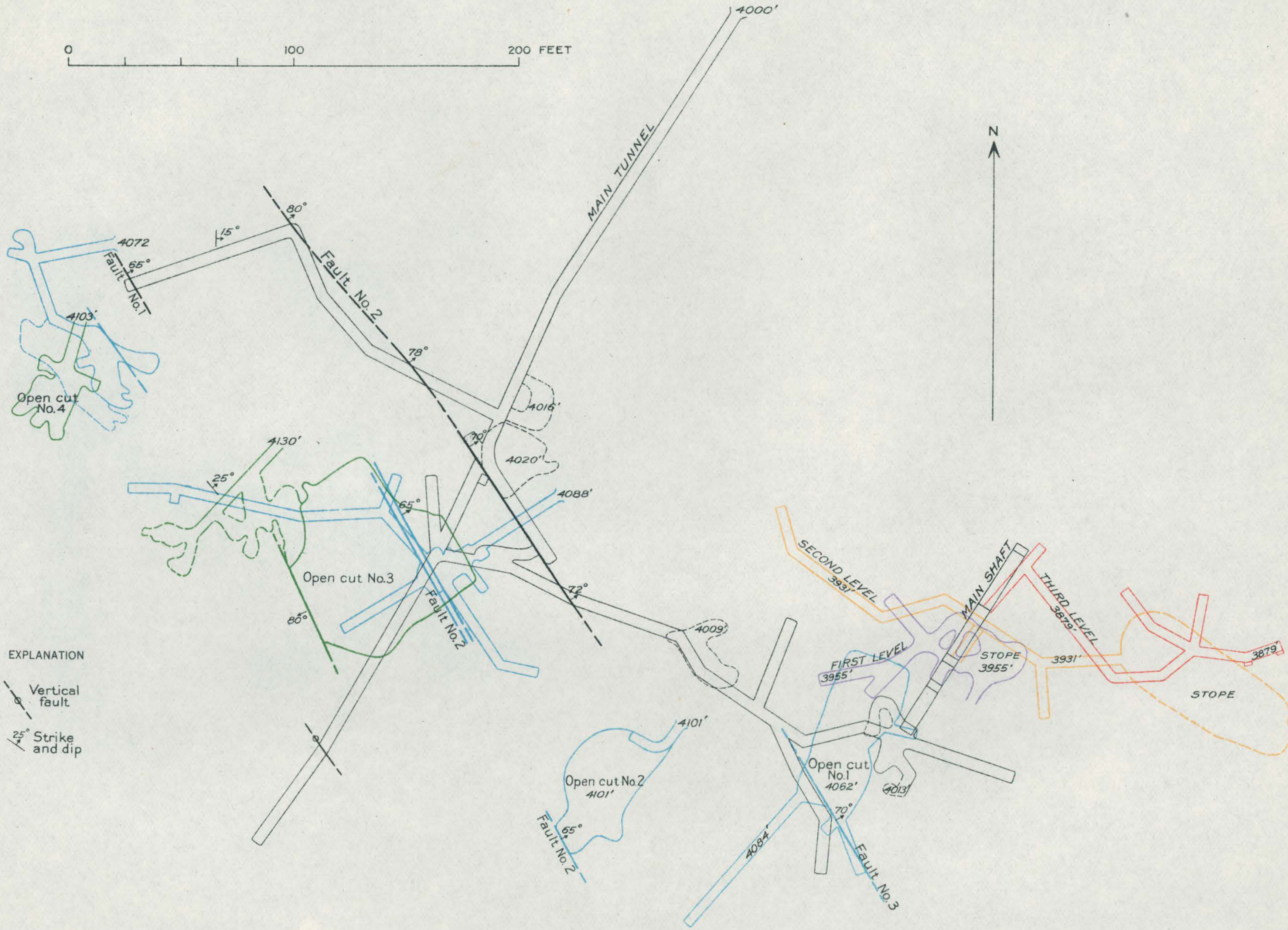
Production of Accident mine, 1911–1919

Year	Crude ore (tons)	Silver (ounces)	Copper (pounds)	Lead (pounds)	Zinc (pounds)
1911	25	204	--------	39, 791	--------
1912	314	2, 619	1, 939	244, 677	42, 798
1915	56	352	--------	74, 950	--------
1916	125	--------	--------	5, 040	47, 600
1917	127	1, 385	904	99, 336	--------
1919	9	--------	--------	480	6, 171

The mine includes several openings which explore a zone about 50 feet thick in the Yellowpine limestone. The main tunnel, which was the source of most of the ore, is shown in Figure 49. As shown in Figure 6, there are many faults in this region, and several smaller faults are exposed in the mine workings. About 75 feet east of the mouth of the main Accident tunnel there is a conspicuous fault breccia, which strikes N. 17° W. and dips 65° W. and which separates brownish-weathering Bullion dolomite on the east from alternating gray dolomite and limestone at the base of the Bird Spring formation on the west. This fault appears to be cut off on the north by an eastward-dipping fault. The beds near the mine trend nearly due north and dip 12° W. The ore occurs along a breccia zone which is nearly parallel to the bedding and which lies on top of a 15-foot bed of dolomitized limestone and underlies a thicker bed of blue limestone. Locally, the breccia zone is 1 to 3 feet thick and contains sporadic coarse crystals of galena; elsewhere it is inconspicuous and barren. There are two principal stopes, one in the northern part of the main tunnel, east of a post-mineral fault, and the other in the southern part, west of this fault. Where the southern stope ends against the fault there is angular galena in the breccia.

BULLION MINE

The Bullion mine (No. 61, pl. 30) lies near the top of a prominent spur that extends eastward from the range toward Porter Wash, 5 miles due south of Goodsprings. (See pl. 38, *A*.) The first record of the



GEOLOGIC MAP OF THE SULTAN MINE, NEVADA

1931

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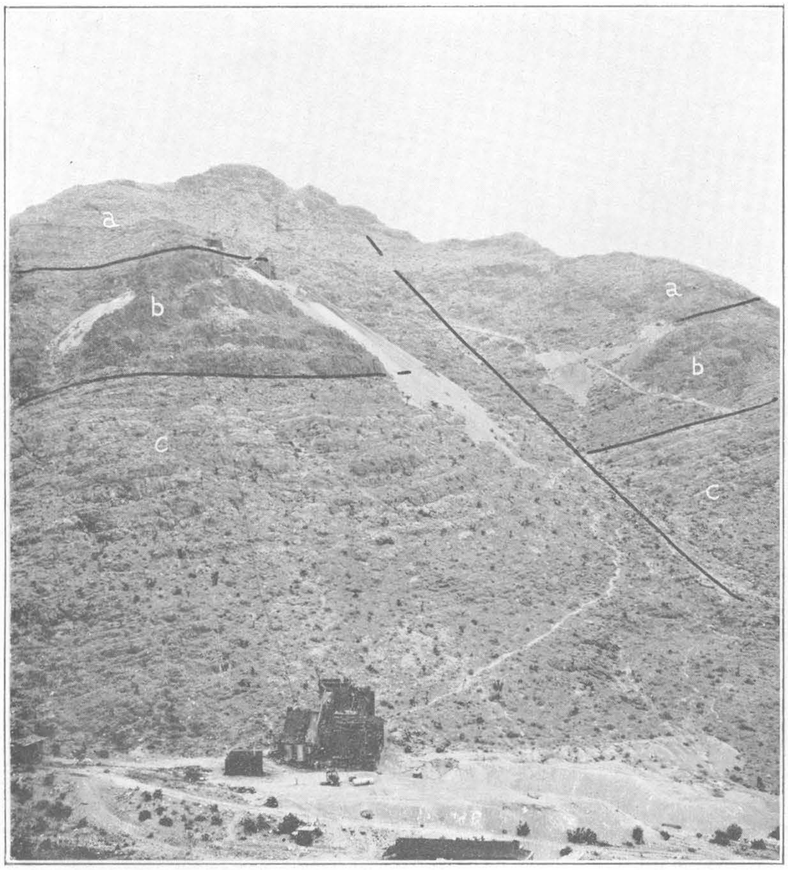
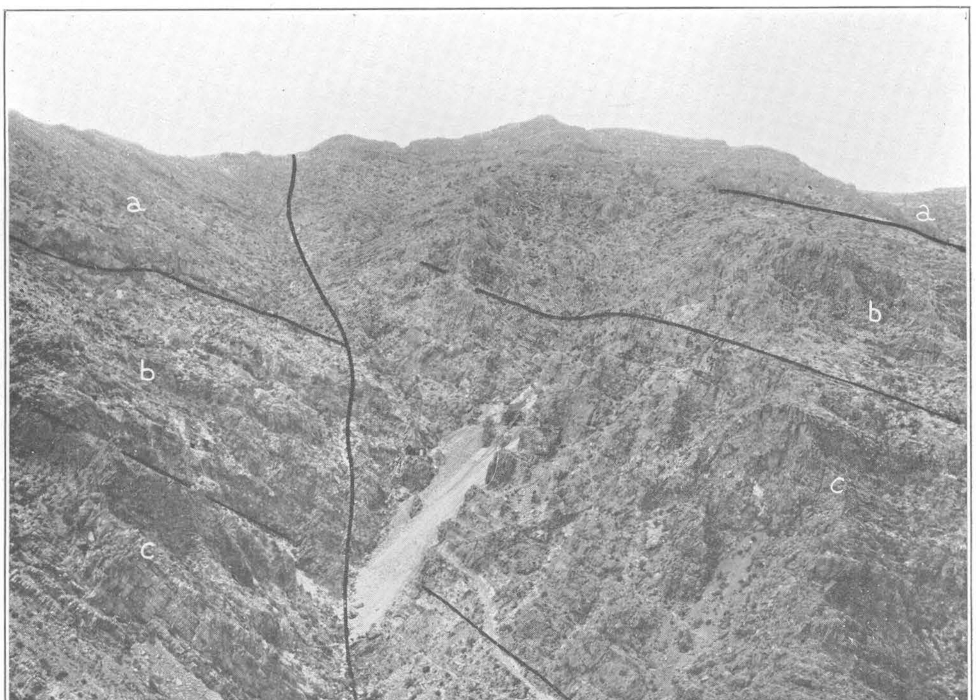


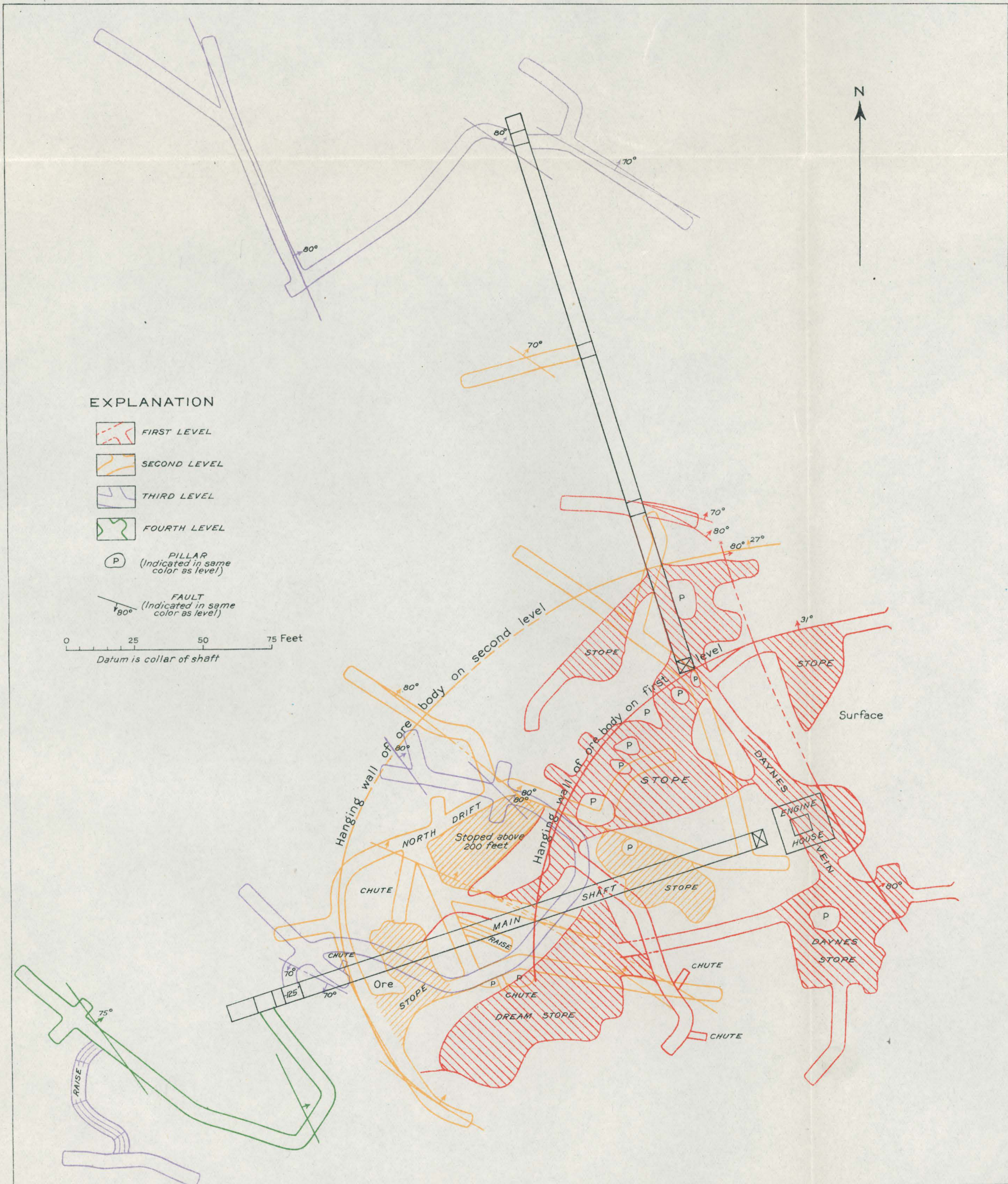
A. BULLION MINE (ABOVE) AND MILL (BELOW), CENTER OF SEC. 23, T. 25 S., R. 58 E.

The ore deposit occurs at the base of the Bullion dolomite; the ravine on the right marks the position of a late normal fault. a, Bullion dolomite member of Monte Cristo limestone; b, Anchor limestone member of Monte Cristo limestone; c, Dawn limestone member of Monte Cristo limestone.



B. ANCHOR MINE, S. ½ SEC. 23, T. 25 S., R. 58 E.

The ore deposit occurs in the Anchor limestone. The ravine marks the position of a late normal fault. a, Bird Spring formation; b, Bullion dolomite member of Monte Cristo limestone; c, Anchor limestone member of Monte Cristo limestone.



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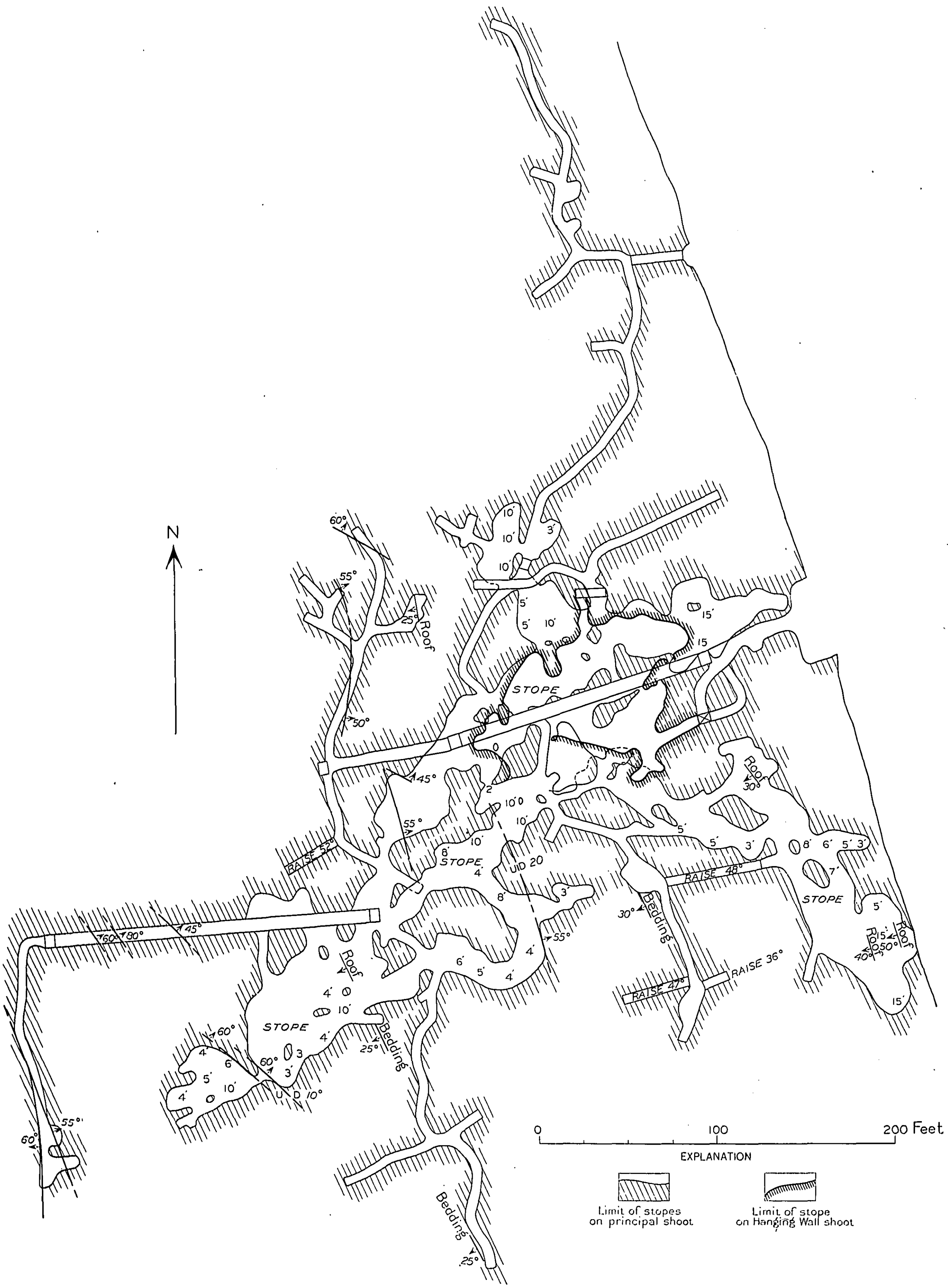
GEOLOGIC MAP OF THE BULLION MINE, NEVADA
1931



MAP OF ANCHOR MINE

Bullion claim dates from 1900, when W. H. Smith located it, but others may have filed locations earlier. According to local report, it was sold to S. E. Yount and G. E. Fayle in 1912 for $3,000. They built a mill in 1913 and sold it in 1916 to the present owner, the Bullion Mining Co., of Salt Lake City. Since 1919 it has been worked by lessees.

The total production of the mine to the end of 1923, as reported to the United States Geological Survey and the Bureau of Mines, is given below. Most of the product, 3,869 tons, has been lead ore containing 50 to 75 per cent of lead, 1 to 5 per cent of zinc, and 2 to 15 ounces of silver to the ton. About 300 tons of zinc ore containing 36 to 45 per cent of zinc has been shipped. The shipments of mixed lead and zinc ore have been 393 tons, largely containing 40 to 50 per cent of both metals combined. The second table shows the quantity and value of the shipments made by the Bullion Mines Co. after it acquired the property in 1916.

The principal workings include a shaft inclined westward under the hill from which levels are run at four depths and a long winze northward. Near the surface the slope of the shaft is 25°, but it increases to 53° at the third level and to 68° at the bottom; at that point it is 165 feet vertically below the mouth. (See pl. 39.) Another group of workings lies 700 feet northeast, but as a late normal fault follows the intervening gulch the ore bodies explored by both groups of workings were probably once closely associated.

Production of Bullion mine, 1913–1927

Year	Ore mined (tons)	Ore shipped[a] (tons)	Gold (ounce)	Silver (ounces)	Copper (pounds)	Lead (pounds)	Zinc (pounds)
1913		361		2,360	95	454,993	
1914		187	0.84	1,150	1,534	135,970	36,794
1915	411	[b] 137		1,191		173,078	
		264		1,580		292,386	23,123
1916	8,980	[b] 898		6,850		897,240	
		135					91,033
1917	10,000	[b] 1,036		7,403		623,150	
		206		902		114,992	84,243
1918		60		242		32,457	21,906
1919		39		309		48,980	
1920		301	.14	1,354		146,313	65,850
1921		139				44,718	69,397
1923		105.8	.34	351	130	39,674	32,816
1924		146		261		68,683	53,308
1925	863	[b] 151 113	.52	1,812	150	200,421	33,007
1926	1,613	[b] 150		1,328		152,675	
		113		474		54,000	33,000
1927		[a] 16		155		20,463	

[a] All crude ore except as indicated. [b] Concentrate.

Shipments by the Bullion Mining Co., 1916–1924

Year	Lead ore			Zinc ore			Total value	
	Quantity (tons)	Value		Quantity (tons)	Value		Gross	Net
		Gross	Net		Gross	Net		
1916	621.519	$34,298.93	$30,493.86	72.202	$2,784.83	$2,098.51	$37,083.76	$32,592.37
1917	1,195.345	58,206.35	51,092.85	69.301	3,304.69	2,735.49	61,511.04	53,827.34
1918	59.625	2,689.85	2,505.96				2,689.85	2,505.96
1919	38.267	1,769.22	1,476.64				1,769.22	1,476.64
1920	171.886	7,600.93	6,341.43	[a] 116.900	4,020.81	2,437.06	11,621.74	8,778.49
1921				[a] 138.725	5,268.58	3,362.60	5,268.58	3,362.60
1923	47.156	1,682.57	1,365.28	[a] 58.699	2,208.81	1,629.76	3,891.38	2,995.04
1924	37.616	2,255.83	1,969.88	[a] 108.501	3,827.10	2,569.27	6,082.93	4,539.15

[a] Mixed ore.

The ore bodies explored by the Bullion mine lie largely near the base of the Bullion dolomite, but in places they extend down into the Anchor limestone. In this region the Bullion dolomite is a distinct layer about 200 feet thick of white to cream-colored coarsely crystalline dolomite, broken by many fractures. Near the mine the Anchor limestone is completely dolomitized, and locally, as along the trail from the mill to the mine, the Crystal Pass limestone is also dolomitized. The beds trend N. 10° W. and dip 30° W. There are several normal faults in the neighborhood of the Bullion mine along which the beds are displaced from 100 to 250 feet. Most of these faults trend N. 30° to 45° W. and dip 45° NE. and belong to the group of postmineral normal faults. Although many well-defined breccia zones and faults are exposed in the workings, the displacements along them must be small, as none displace the beds on the surface as much as 25 feet. Most of these faults trend N. 30° to 60° W. and dip northeast and are doubtless postmineral.

The structural associations of the Bullion deposit are almost unique and find their nearest counterpart in those at the Potosi mine. At the Bullion, as at the Potosi, it is difficult to present a clear picture of the extent of the stopes and their relations. The outstanding feature is a persistent smooth hanging wall of rudely circular outline. This wall is continuously exposed on the first level, and two large sectors are shown on the second level. (See pl. 39.) The dip ranges from 20° to 31°, and it clearly cuts across the bedding of the dolomite. The deeper work from the winze northward is above this wall and does not encounter any ore. The deeper work off the main shaft westward is probably under this wall if it continues downward, but conditions are complicated by the presence of a southwestward dipping fault that may merge with the wall below the second level. Several of the faults that trend northwest and dip northeast cut across the hanging wall and are probably post-mineral.

The ore-bearing material is angular dolomite breccia, the fragments of which range from half an inch to 5 feet in diameter. These fragments are feebly cemented by a carbonate material, but there are still many unfilled voids. The ore bodies are rudely tabular masses, largely 3 to 6 feet wide, that are nearly parallel to the hanging wall. Galena was the principal mineral, although lenses of hydrozincite may still be seen in which that mineral replaces the dolomite. Part of the galena forms coarse crystals that replace the dolomite, but some have crystallized in the open spaces. Most of the stopes south of the shaft (Dane, Dream) range from 5 to 10 feet high, but in an irregular area north of the shaft one stope is 40 feet high. If there is a well-defined footwall under the stopes, as at the Potosi mine, it has not been found. No satisfactory explanation can be offered for the structural origin of such a body of breccia. If there were evidence of solution of the dolomite one might imagine that there had been solution along a minor breccia zone followed by collapse, somewhat like the supposed origin of the "flats" of the Wisconsin-Illinois lead and zinc field; but no such evidence has been obtained. It seems necessary to conclude that the breccia is related to movements that took place during the epoch of thrust faulting.

Some ore has been struck in the raises above the third and fourth levels, but it is not extensive and occurs in ground that has no open spaces.

Most of the galena in the mine is fresh and unweathered, but there is a little carbonate and sulphate as deep as the lowest work. Hydrozincite and calamine are the principal zinc minerals.

ANCHOR MINE

The Anchor mine (No. 62, pl. 30) is near the head of a deep gulch about 6 miles due south of Goodsprings. The mine workings lie 400 feet above the bottom of the gulch and are accessible only by trail or by tramway from the mill, 2,000 feet to the east. (See pl. 38, *B*.) Although the Monitor claim was located in 1893, all the workings are on the Anchor claim, located in 1897. One car of lead ore was shipped in 1908, but the principal activity on the property began in 1912, when it was sold by S. E. Yount and George Fayle to the Goodsprings Anchor Co. (Seeley W. Mudd, F. A. Keith, and associates), of Los Angeles, at a price reported to have been $30,000. The company ceased operations in April, 1919, but since that time several groups of lessees have worked the mine intermittently.

The mine is explored by a shaft 202 feet deep on an incline of 38°, from which there are three levels. From the third level there is a winze 212 feet deep at an inclination that decreases from 37° at the top to 29° at the bottom. The deepest work is 227 feet vertically below the outcrop. (See pl. 40.) In the development of the mine the workings were quickly extended downward, so that late in 1916 most of the area had been explored. None of the principal shoots were found after that time, and most of the subsequent work consisted of mining the earlier known bodies.

Production.—Records of production for the Anchor mine are available from two sources, the annual statements submitted by the owners to the United States Geological Survey and the books of the company. The two should agree exactly, but they do not. The company's records are presented in addition to those of the Survey because they show the number of tons of zinc, zinc-lead, and lead ore shipped as well as gross and net returns. The crude lead ore commonly contained about 50 per cent of lead and less than 10 per cent of zinc, but the concentrate made in the mill commonly contained slightly more of both lead and zinc. In the early years the zinc product commonly contained 35 to 42 per cent of zinc, but when the price of zinc rose to the peak, in 1915, shipments commonly contained 26 to 35 per cent of zinc.

The mill contained a grizzly, picking belt, jaw crusher, rolls, elevator screens, and Stebbins dry table. In 1924 a classifier and table adapted to wet concentration were installed, in order to re-treat the tailings from previous operations.

Production of Anchor mine, 1908–1928

Year	Ore mined (tons)	Ore shipped (tons)	Gold (ounces)	Silver (ounces)	Copper (pounds)	Lead (pounds)	Zinc (pounds)
1908		[a] 30					
1911		[a] 63		354		65,654	
1914		[a] 2,318		462		173,562	1,392,706
1915	207	[b] 67		460		42,886	19,884
		[a] 2,435		1,480		290,208	1,335,429
1916	3,744	[b] 712		7,655		842,977	
		[a] 1,343		2,485		477,196	520,523
1917	7,908	[b] 592		9,768		684,436	
		[a] 1,113		1,949		346,755	484,807
1918	7,573	[b] 576		7,371		729,902	
		[a] 501		1,828		233,882	201,245
1919	3,150	[b] 210		2,454		308,177	
		[a] 100		720		46,746	24,140
1924		[a] 126				31,827	70,874
1925	1,733	[b] 284	1.17	4,300	338	334,215	
		[a] 313		838		108,154	123,321
1926	1,769	[b] 337	2.86	4,420	502	354,042	
		[a] 269		1,080		228,426	20,150
1927	729	[b] 30		348		29,391	
		[a] 579		1,380	157	140,202	239,490
1928	509	509	.20	1,464	406	233,094	189,372

[a] Crude ore. [b] Concentrate.

Shipments of Goodsprings Anchor Co., 1914–1919

Year	Lead ore			Zinc ore			All ores			Dividends
	Weight (tons)	Returns		Weight (tons)	Returns		Weight (tons)	Returns		
		Gross	Net		Gross	Net		Gross	Net	
1914	62.6	$2,300.90	$1,925.17	[a] 2,209.5	$51,064.42	$31,628.70	2,272.1	$53,365.32	$33,543.87	----------
1915	242.9	11,140.89	9,646.23	2,180.8	147,729.50	124,837.14	2,423.7	158,870.39	134,483.37	$86,785
1916	1,223.9	73,694.56	65,275.92	949.8	43,626.89	34,932.97	2,173.7	117,321.45	100,208.89	44,000
1917	959.3	76,708.56	69,012.82	704.9	27,326.61	21,272.05	1,664.2	104,035.17	90,284.87	38,500
1918	759.5	58,730.99	51,915.72	321.8	11,969.93	8,392.25	1,081.3	70,700.92	60,807.97	11,000
1919	270.0	14,524.28	12,082.87	40.8	1,206.08	835.17	310.8	15,730.36	12,918.04	----------
	----------	----------	----------	----------	----------	----------	9,925.8	520,023.61	432,247.01	180,285

[a] Includes 240.8 tons of mixed lead-zinc ore, which yielded $5,567.68 gross and $3,158.39 net.

Local geology.—The deposit lies in a breccia zone that closely follows the bedding planes of the inclosing cherty Anchor limestone, here altered to dolomite. At the outcrop the ore zone closely coincides with the contact of thin-bedded, locally shaly limestone below with much more massive chert-bearing beds above. In this area the beds trend N. 25° W. and dip southwest at an angle that decreases from 35° at the surface to 20° in the deepest workings.

As shown in Figure 6, the Anchor mine lies in the midst of a number of faults that are conspicuously shown on the surface. The gulch that passes below the Anchor dump marks the position of a fault which dips east and along which the eastern block has dropped about 300 feet. The deeper part of the mine workings encounters several faults that trend west of north and dip east. Along several of these it can be proved that the eastern block has dropped as much as 20 feet, but on others, such as that at the bottom of the main shaft, there appears to have been little displacement. There can be no doubt that all these eastward-dipping faults are postmineral. On the lowest level of the mine the drift follows a breccia zone and wall that dip west. Although there are mineral-bearing faults in this region that dip west, this one is probably postmineral also.

Two groups of ore shoots may be recognized in the Anchor mine—one in which galena is equal to or greatly exceeds the zinc minerals, largely hydrozincite, and one that contains only zinc minerals. The shoots of the first group lie in brecciated massive dolomitized limestone overlying the shaly thin-bedded limestone; those of the second group in the underlying thin-bedded shaly limestone. From what may now be seen in the mine, it appears that the second group includes the zinc that has migrated downward from the higher bodies of mixed lead and zinc minerals and replaced the shaly dolomite. The most abundant mineral in the first group of shoots is galena, only a small part of which has altered to anglesite and cerusite.

In the area adjacent to the shaft galena forms poorly defined lenses as much as 6 and 8 inches thick and 5 to 10 feet long in zones of breccia parallel to the local bedding. In a part of the area explored groups of such lenses as well as irregular masses are distributed throughout a zone as much as 50 feet thick, so that it has been necessary to make superimposed stopes 5 to 10 feet or more high. The local distribution of galena along the wall of the open cut at the top of the shaft is shown in Figure 50. Here the galena appears to have been deposited in open crevices along

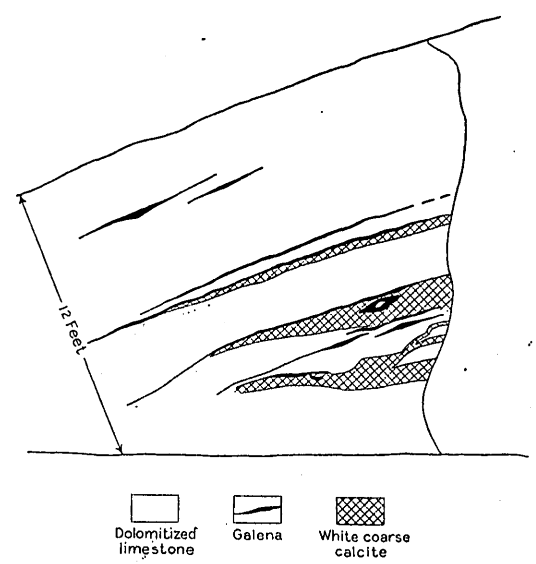


FIGURE 50.—Sketch of north wall of Anchor shaft

bedding planes and in minor fractures, and the remaining open space was subsequently filled with coarse white calcite. Similar relations were observed in a number of other places in the mine. The silver content in the galena has ranged from 1 ounce to each 5 or 6 per cent of lead in the concentrate made in the dry mill to 1 ounce to each 10 per cent of lead in the crude ore composed largely of unoxidized galena.

Zinc minerals are more abundant in the southern stopes, and the commonest mineral is pale-brown hydrozincite. Calamine is not abundant and commonly forms a thin crystalline layer on fractures in hydrozincite. Smithsonite was not observed. Where galena is present in the zinc stopes it is embedded in the masses of hydrozincite, itself formed by replacing dolomite.

On the 300-foot level south the walls are in places heavily coated with fine hairy crystals of epsomite.

Manganese oxide was noted at one locality on the 200-foot level north, one of the few places where it was seen in a lead or zinc deposit in the district.

VALENTINE MINE

The Valentine mine (No. 63, pl. 30) is the southernmost of the group accessible by Porter Wash and lies about 6 miles south of Goodsprings. It is owned by the Valentine Mining Co. and has been worked intermittently since 1910. The principal exploration is a shaft 310 feet deep, inclined 36°, from the bottom of which there is a crosscut 300 feet west and some drifts. There are also three short tunnels about 300 feet north of this shaft.

The inclined shaft closely follows the local bedding, and the levels at 50 and 100 feet explore a mineralized zone at the top of the cherty Anchor limestone, the same as that which contains the Anchor ore zone. The limestone is dolomitized adjacent to the ore body. The ore-bearing zone in the upper level is cut off by postmineral northwest faults, so that the lower part of the shaft and crosscut are in stratigraphically lower beds, the Dawn limestone. By crosscutting westward, however, the higher Anchor zone is again encountered.

Most of the ore has come from the 50-foot level, where there are sporadic lenses of earthy hydrozincite that contain grains of galena. The range in width is 6 inches to 2 feet. Good examples of the replacement of gray dolomite by brownish and white hydrozincite are common. At the point where the 50-foot level south meets the shaft there is a mass of stalactites of limonite, largely about half an inch in diameter, embedded in brownish hydrozincite. Cavities between the stalactites contain calcite crystals. The relations of the minerals indicate either that hydrozincite may be deposited in open spaces as such, which is uncommon, or that it has formed by the hydration of smithsonite, which is known elsewhere.

From the end of a crosscut north from the bottom of the shaft there is a raise along a lens of lead and zinc minerals that appears to lie on a westward-dipping fault, like those known in several places near by to be premineral. The lens contains a central core of coarse white calcite, adjacent to which there are coarse crystals of galena. Both are inclosed in a layer of smithsonite. The lens is cut off below by a fault that has a northwest strike and a northeast dip. The relations indicate that a premineral ore-bearing fault is cut off by a postmineral barren fault.

Production of Valentine mine, 1910–1918

Year	Crude ore (tons)	Silver (ounces)	Lead (pounds)	Zinc (pounds)
1910	60			34, 560
1916	35			18, 622
1917	153			81, 634
1918	36	65	2, 804	15, 544

CHRISTMAS GROUP

The Christmas group (Nos. 64, 65, 66, 67, pl. 30) includes two separate groups of claims. The Christmas and four other claims adjoin the New Year claim at the head of a narrow ravine a mile south of Devil Canyon. The Mountain Queen, Silver Gem, Eureka, and other claims form a group that extends from Little Devil Peak eastward nearly 2 miles north of Devil Canyon.

The Christmas claim was located in 1913, but most of the existing work was done between 1915 and 1917. The production from these workings was not kept separate from that of the other claims; probably a

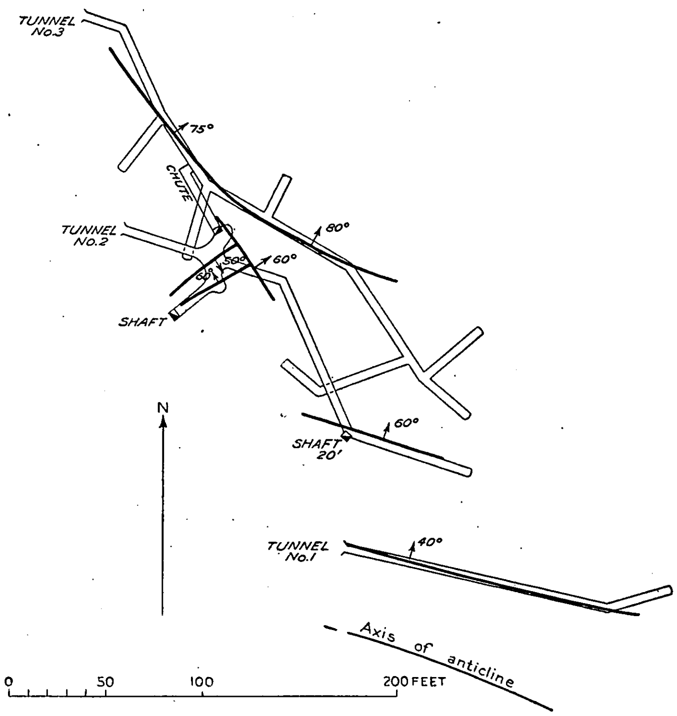


FIGURE 51.—Sketch map of Christmas mine

large part of that recorded by the company for 1916 and 1917 came from this claim. A dry mill was erected on the ground in 1916, but after a short run it was removed to another part of the district. This ore body is interesting because the ratio of silver to lead was uncommonly high—about 1 ounce of silver to 1 per cent lead. Most of the galena originally present was weathered to anglesite.

The workings on the Christmas group include three tunnels whose aggregate length is about 1,000 feet. (See fig. 51.) These tunnels explore a dolomitized breccia zone, which in the upper two closely follows a bedding plane near the base of the Yellowpine limestone but in the lowest cuts across the beds and passes downward into lower beds. Two ore shoots were encountered in these tunnels; the western and more productive yielded earthy hydrozincite, in which was embedded either galena or its oxidation products; the eastern shoot, worked only in the 20-foot shaft on the middle tunnel, yielded only 20 tons of zinc ore, probably in large part calamine. No ore was found on the lowest tunnel level.

The association of ore minerals and dolomitization is well shown in this locality. The thin-bedded dark-gray limestones at the base of the Bird Spring formation strike northwest and dip 20° to 35° NE. along the northeast limb of a minor anticline. The shaly Arrowhead limestone was not observed near the mine; the nearest recognized outcrop is near the Ingomar mine, 3 miles to the west. Near the Christmas mine the beds attain the maximum dip (35°) above the highest tunnel, but in the lowest tunnel they are nearly horizontal. On the surface, near the mine, the dolomitized limestone forms a nearly white irregular lens, parallel to the bedding of the Yellowpine limestone. Not only the breccia is completely altered to dolomite but the slightly fractured limestone on both sides for distances of 2 to 10 feet. (See analyses 7a, 7b, p. 61.) The ore minerals are found only in the dolomitized breccia.

The Silver Gem claim contains five tunnels and numerous trenches and shallow pits, whose aggregate length is about 1,400 feet. Three of these tunnels, aggregating 900 feet, explore a thin breccia zone, sporadically impregnated with galena, which lies closely parallel to the bedding of the inclosing limestones of the Bird Spring formation, here extensively altered to dolomite. These workings have yielded most of the several hundred tons of ore shipped from the claim.

In this area the limestones of the Bird Spring formation trend northwest and dip 12° SW. Except the Sultan fault, 1,000 feet to the west, the conspicuous faults near by trend northwest, dip northeast and are doubtless postmineral. There is no dolomitization of the limestone adjacent to them. Near these workings, however, there are some inconspicuous fractures, without appreciable displacement, along which there is considerable dolomitization. These fractures trend northeast and are nearly vertical, and although no extensive ore bodies have been found in them, there are breccia zones along bedding planes near by that contain lenses of galena. (See pl. 18 and analyses 10a and 10b, p. 61.)

Vanadinite and cuprodescloizite are common in the principal workings as well as in several pits near by. According to J. Doran, one of the owners, one lot of 14 tons of material was shipped in 1920 from these workings to the American Vanadium Co.

Two carloads (64 tons) of lead ore have been shipped from a 90-foot shaft on the Mountain Queen claim, 2,000 feet west of the Silver Gem tunnels. The material came from a breccia zone 2 feet wide that trends northwest and dips northeast. A small quantity of ore has also been shipped from shallow workings on the Eureka claim, 2,000 feet northeast of the Silver Gem.

Production of Silver Gem, Eureka, and Christmas mines, 1911–1922

Year	Crude ore (tons)	Gold (ounce)	Silver (ounces)	Copper (pounds)	Lead (pounds)	Zinc (pounds)
1911	29	-------	632	-------	38, 219	-------
1912	64	-------	1, 587	127	48, 090	-------
1913	334	0. 10	154	46	38, 430	231, 782
1914	27	-------	-------	-------	7, 739	11, 319
1915	72	. 98	430	-------	17, 876	30, 900
1916	856	-------	7, 900	-------	238, 780	143, 140
1917	104	-------	1, 304	-------	41, 949	32, 745
1918	44	-------	226	-------	24, 732	-------
1920	21	-------	322	-------	18, 702	-------
1921	66	. 74	967	22	50, 809	-------
1922	10	-------	113	-------	7, 179	-------

NEW YEAR MINE

The New Year mine (No. 68, pl. 30) lies near the crest of a high ridge at the southern edge of the district, 8 miles nearly due south of Goodsprings. On account of the location the output of the mine was carried by pack train down the trail a mile to a platform on the Devil Canyon road. The mine was located early by A. G. Campbell, but little work was done until 1912, when it was leased by J. Doran, who mined 17 carloads of ore. There were four successive lessees, but the greatest production came out during 1915 and 1916, when Wadey & Fredrickson mined about 50 carloads. No work has been done since 1918. It is estimated that the total output was 72 carloads, or about 2,400 tons, all of which was zinc ore except about 150 tons, of which about 90 tons was lead ore and the remainder mixed lead-zinc ore. According to Fredrickson's records of 23 carloads, the zinc ore contained from 34 to 42 per cent of zinc, 3 to 8 per cent of lead, 3 to 6 ounces of silver to the ton, and a trace of gold. These records show that the gross value of 21 cars (736 tons) shipped between November, 1915, and April, 1916, was $48,078, and the net value after paying railroad transportation and treatment charges was $39,104.

Some of the workings of the mine lie in the Yellowpine limestone, but the largest bodies of ore were found in the underlying Bullion dolomite, of the Monte Cristo formation. The limestones are completely dolomitized near the larger bodies, but one exploration, the westernmost on the claim, which yielded 90 tons of lead ore, was largely in unaltered limestone. So far as the writer was able to observe there is only one other locality in the district (Milford mine, see p. 164) where an ore body lay wholly in undolomitized limestone. Structurally the New Year mine explores a brecciated area near the crest of a minor anticline that plunges steeply northwest. This anticline lies distinctly northeast of the overturned anticline that ends against the Tam o' Shanter fault.

The workings include two shafts, a short tunnel, and several irregular stopes in an area scarcely 300 feet in diameter. The shafts are now inaccessible, but according to Mr. Fredrickson, who sunk them, they explored zones of brecciated dolomite that contained some ore. The principal breccia zone trends northwest, and 50 feet below the surface it connected with a horizontal body of zinc ore that lay parallel to the bedding. The stope from which the ore was removed was 40 by 70 feet by 3 or 4 feet high. The principal ore mineral was hydrozincite, in which grains and crystals of galena were distributed. Some smithsonite and calamine were found, but oxidized lead minerals were uncommon. Only in the westernmost tunnel did it pay to separate the lead from the zinc minerals.

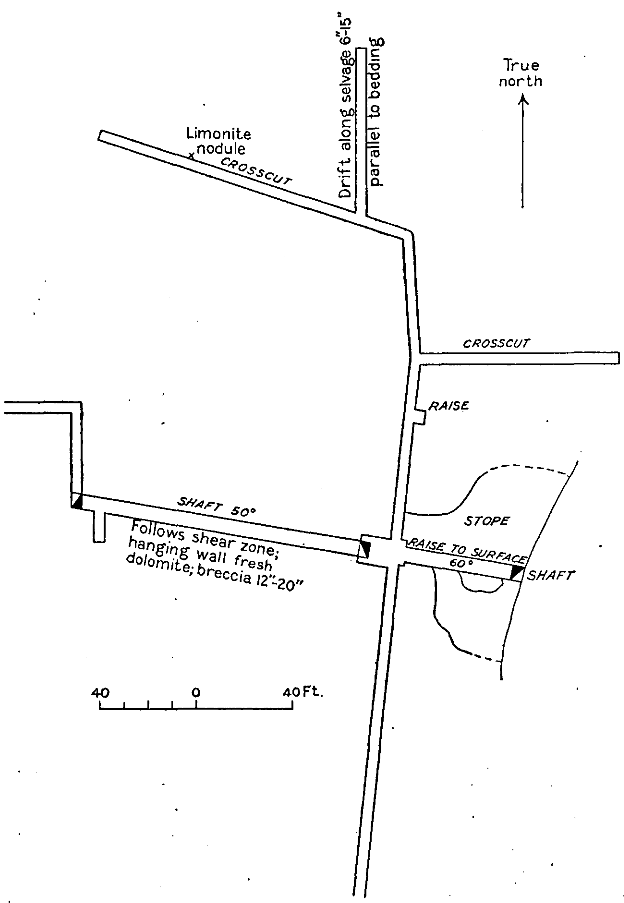


FIGURE 52.—Sketch map of Tam o' Shanter mine

TAM O' SHANTER MINE

The Tam o' Shanter mine (No. 69, pl. 30) lies a short distance south of the southern border of the Goodsprings quadrangle, in the SW. ¼ sec. 4, T. 26 S., R. 58 E. It was examined in connection with other near-by mines in the quadrangle, however, because it is the southernmost of the group and resembles other mines in the quadrangle.

The Tam o' Shanter claim was located in 1892 by Robert Puelz, Harry Spiller, and others, and the remaining claims—Calico and Fairview—in 1893 and 1906. Several years later, after a little work had been done, the property was sold to Jonas Taylor for $7,500 and in 1915 to J. R. Newberry, who now holds it. The principal working is a tunnel, about 700 feet long, which connects with a raise to the surface and a winze inclined 50° to a depth of 185 feet. (See fig. 52.) All the shipments have been made from stopes above the tunnel.

Production of Tam o' Shanter mine, 1908–1928

Year	Crude ore (tons)	Silver (ounces)	Copper (pounds)	Lead (pounds)	Zinc (pounds)
1908	7	83		8, 165	426
1916	167	1, 836	459	66, 304	40, 808
1917	429	5, 264		176, 954	72, 083
1918	5	62		4, 720	
1926	50	160		12, 015	17, 200
1928	15	43	146	20, 603	

The workings explore a bedded breccia zone near the base of the Bird Spring formation, a short distance west of the Tam o' Shanter thrust. The thrust trends N. 40° E., but the bedding and the mineralized breccia zone trend N. 10° E. and dip 50° to 60° W. Undoubtedly the breccia zone was formed at the same period as the thrust. The structural relations as well as the mineralogy of the deposit bear a resemblance to those at the Kirby mine.

To judge from the materials on the dump and left as pillars in the stopes, the ore was hard granular cerusite intimately associated with ferruginous chert. As at the Kirby mine, some of the ferruginous chert contains patches of straw-colored plumbojarosite. The stoped area above the tunnel level is irregular in shape, and the size is about 100 by 75 feet. The width of the stope ranges from 1 to 3 feet, and the average is about 1½ feet. It is especially noteworthy that the ferruginous chert lenses in the ore zone are thicker and more extensive in the upper 75 feet than below. In the workings below the tunnel the chert is only sporadically exposed. The commonest lead mineral in the winze is earthy plumbojarosite, which forms lenses from 5 to 15 inches thick.

Zinc minerals are uncommon underground, although several cars of zinc ore have been shipped. Fragments of banded smithsonite, such as generally forms along watercourses, were found on the dump. Aurichalcite and a green variety of calamine were noted on fractures near the bottom of the winze. Pyromorphite is common on fractures in ferruginous chert on the dump.

MILFORD MINE

The Milford and Addison are the principal claims of the Goodsprings Mining Co. The workings on the Milford claim (No. 70, pl. 30) lie on the north slope and those of the Addison claim on the south slope of a prominent ridge 9 miles in a direct line and 17 miles by road southwest of Goodsprings. The Milford claim had been located under several names as early as 1891, but the present name was given in 1904, when it was located by Jesse Jones. About 1906, when the old shaft was 90 feet deep, it was sold for $5,000. In 1910 it was bought for $12,000 by Jesse Knight and associates who formed the Goodsprings Mining Co. Most of the work since 1917 has been done by C. L. and J. A. Hyde. The Addison claim was located in 1899 by Addison Bybee, and after several transfers it was sold to Knight and his associates for $10,000.

The summary of the production of the Milford and Addison mines, as compiled from the records of the United States Geological Survey, is given below. If 840 tons of lead and zinc ores is assigned to the Addison mine (see p. 166) the indicated total for the Milford mine is 3,369 tons. Of 32 cars (1,243 tons) shipped by this mine since 1918 for which the record is accessible, only 10 cars (381 tons) was lead ore, containing 37 to 70 per cent of lead and 2 to 5 ounces of silver to the ton. The remainder, 710 tons, was mixed lead and zinc ore, containing 13 to 27 per cent of lead and 22 to 34 per cent of zinc, and 152 tons was zinc ore, containing 36 to 47 per cent of zinc.

Production of Milford and Addison mines, 1909–1928

Year	Crude ore (tons)	Gold (ounces)	Silver (ounces)	Copper (pounds)	Lead (pounds)	Zinc (pounds)
1909	105					67, 204
1910	382	1. 87	449	26, 104	248, 905	89, 249
1911	267		52		44, 651	168, 871
1912	204					154, 707
1913	144					106, 033
1914	127	. 04	46	26	12, 217	55, 516
1915	250		102		11, 775	155, 024
1916	520				72, 240	235, 872
1917	175		263		37, 754	82, 297
1918	525		860		209, 547	187, 362
1919	412		200		188, 020	171, 835
1920	650				228, 800	276, 250
1922	40				9, 888	17, 731
1923	295	1. 00	581	385	242, 688	41, 622
1924	120				21, 840	76, 800
1925	132		46		25, 198	64, 218
1926	35		12		6, 194	19, 741
1927	85		103		36, 649	15, 236
1928	50		42		19, 767	15, 480

The principal exploration on the Milford claim is an inclined shaft 380 feet deep on the slope, which has an inclination of 35° for 280 feet and of 29° for the lower 100 feet. There are four levels. (See fig. 53.) A wire-rope tramway delivers ore from the bins at the shaft to ore bins 500 feet below. There are several tunnels on the Addison claim, but only the longest, which was the source of the ore, is shown in Figure 54.

The structural conditions are rather simple on the west end of the Milford ridge, but they become progressively more complex eastward. Near the Milford mine beds are exposed that range from the base of the Monte Cristo limestone to a horizon several hundred feet above the base of the Bird Spring formation. They trend N. 50° to 65° W. and dip 25° to 35° SW. The shaly Arrowhead limestone crops out above the Addison mine workings as well as near the Ingomar mine, 800 feet higher, but was not noted southwest of the Milford mine. The ore bodies of the Milford mine closely follow the contact of the Bullion dolomite and underlying Anchor limestone. The line of contact of the dolomite and limestone may be readily examined westward for 1,000 feet until it passes under the wash. Although broadly the contact is parallel to the bedding, it locally departs 5 to 10 feet from a simple surface. Close examination of this contact shows that within 1,000 feet west of the Milford shaft it is broken by nine faults. These are separable into two groups according to their dip. The first group of six faults trend from north to N. 40° W. and dip steeply west, and along these the west or hanging walls have dropped 8 to 40 feet. These faults are marked by zones of breccia 2 to 10 feet wide, in which angular fragments of cream-colored dolomite are cemented by white dolomite. Most of these zones have been explored by pits and short tunnels for the galena which they contain. The second group of three faults trends N. 40° to 50° W., dips 45° to 60° NE., and contains no galena. Along these faults the northeast or hanging wall has dropped 4 to 75 feet. Wholly apart from the record of underground explorations, one would conclude that the westward-dipping group are premineral and the northeastward-dipping group postmineral.

Five rather distinct ore bodies have been found in the Milford mine. The two upper and most northeasterly bodies are not sufficiently accessible to permit their structural relations to be ascertained. The middle body is a vertical lens 3 to 6 feet wide and has been stoped as much as 25 feet above the 100-foot level. It follows a breccia zone that cuts across the bedding but does not extend west of a galena-bearing fracture (*A*, fig. 53) that appears in the shaft. A similar body was mined east of a winze below the 300-foot level—the Kirk stope. This stope is 1 to 2 feet wide and 10 to 20 feet high and yielded the 295 tons of lead ore shipped in 1923. The galena occurred in a breccia zone between walls of unaltered Anchor limestone and thus is one of the two bodies in the district not surrounded by dolomite. The lowest body in the mine is that stoped in badly broken ground above the 200-foot level and 240-foot sublevel (the Bullion stope). Above the 200-foot level the body lay almost parallel to the bedding, but below that level it pitched north across the bedding. Ore ceased westward against a fault (*B*, fig. 53) that bears galena on the 200 and 300 foot levels and is clearly premineral. West of fault *B* on the 200-foot level, a bedding-plane fracture contains a little galena.

The westernmost work on the 200, 300, and 400 foot levels is in a breccia zone (*C*) that trends northwest and dips steeply northeast. Locally this breccia is replaced by hydrozincite and smithsonite, but there is no evidence that the zinc was derived from sphalerite originally deposited in the breccia. In several places good striae and grooves on the walls of this zone pitch 65° NW. The fault zone is undoubtedly postmineral, and the northeast block has moved northwest and downward.

In addition to the common lead minerals and oxidized zinc minerals of the district, sphalerite was found on the 200-foot level east of fault *B*. Wulfenite is abundant here and there.

In the Milford mine it is hard to avoid the conclusion that the ore bodies are located where northeastward-trending breccia zones, locally parallel to the bedding, meet several premineral faults that trend slightly east of north and dip west.

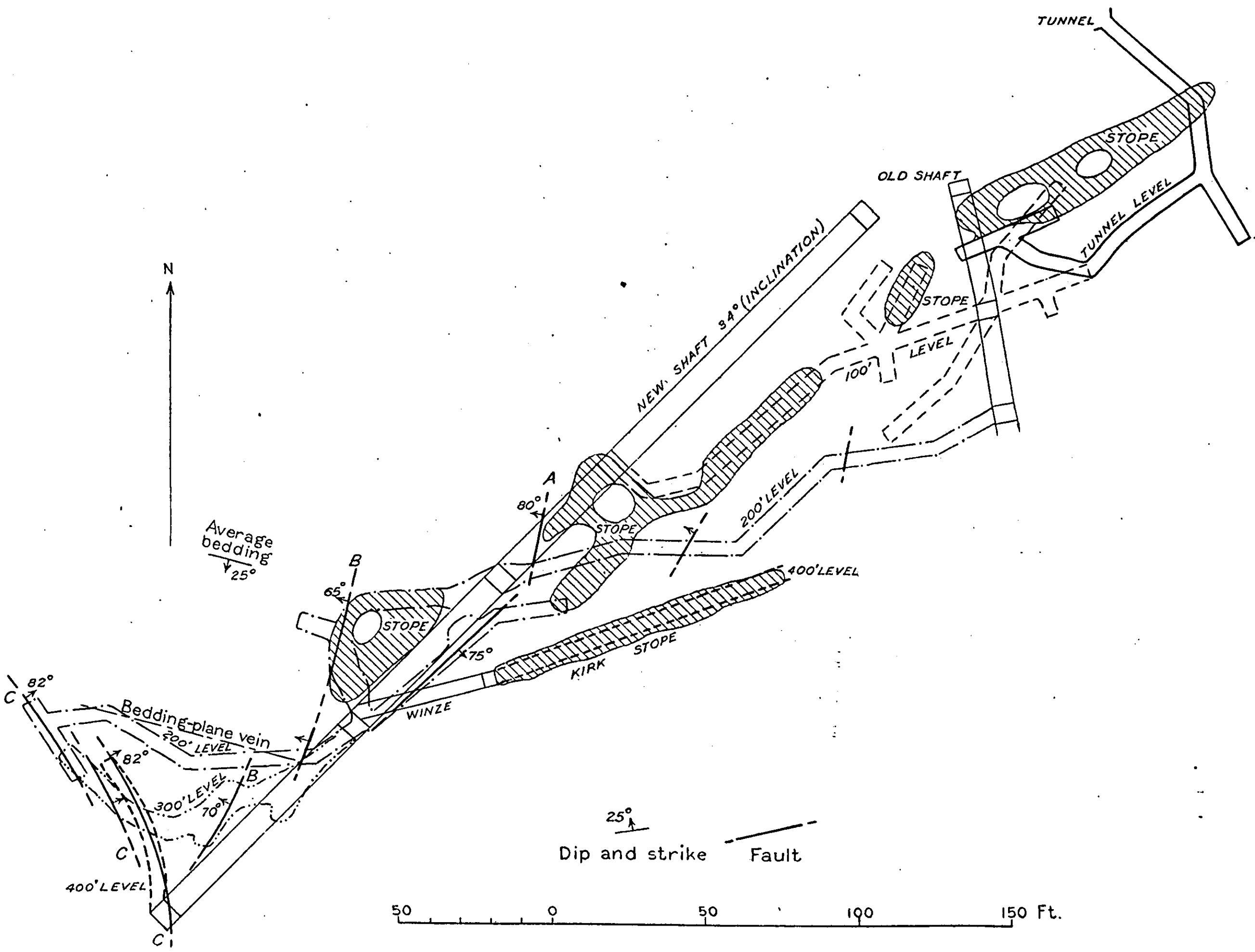


FIGURE 53.—Map of Milford mine. *A*, Galena-bearing fracture; *B*, premineral fault; *C*, breccia zone. (See text.)

ADDISON MINE

The workings of the Addison mine (No. 73, pl. 30) explore a zone of dolomitized limestone 150 feet thick which underlies the shaly Arrowhead limestone. The beds trend N. 60° to 70° W. and dip 45° to 50° SW. The Arrowhead limestone crops out above the main tunnel, and it is broken by several small faults that trend northwest and dip southwest. Along these faults the hanging-wall beds have dropped 5 to 25 feet. They may be premineral faults, but none contain ore and none are conspicuous underground. (See fig. 54.)

According to local report the workings have yielded 15 or 20 cars (about 700 tons) of good-grade zinc ore and 4 cars (140 tons) of lead ore. Most of the ore has come from two stopes at the northeastern part of the lower tunnel. These follow walls that trend northwest and dip northeast and therefore cut across the bedding. There are several minor postmineral faults that trend northeast.

INGOMAR AND MILFORD NO. 2 MINES

The Ingomar and Milford No. 2 claims cover areas high on the crest of the ridge east of the Milford mine. Most of the workings are on or near the crest, 800 to 1,000 feet above the near-by valleys. They are accessible only by rugged trails, and on both sides of the ridge aerial tramways have been constructed from the principal tunnels to ore bins in the valleys. The distance from the ore bins of each mine to Goodsprings is about 18 miles. The Ingomar claim (No. 72, pl. 30) was first located about 1884 by Jonas Taylor and was relocated several times before 1904, when D. W. Johnson undertook to mine ore. Johnson and Fayle did all the work between 1905 and 1915, when they sold it to S. S. Arentz and W. A. Perkins at a price reported to be $8,500. These owners worked the property until February, 1919, and it was idle until May, 1923, when L. M. Benson leased it. The Milford No. 2 claim (No. 71, pl. 30) was located in 1904 by Jesse Jones, but most of the present work was done after it was bought by Arentz and Perkins in 1917. Recently it has been worked under lease by G. L. McIntyre.

The combined production of the Ingomar and Milford No. 2 mines is shown in the following table, which has been compiled from the records of the United States Geological Survey. As there is no record of production from the Milford No. 2 mine prior to 1918, and there was none from the Ingomar between February, 1919, and May, 1923, the total production of the Milford No. 2 is estimated at about 450 tons, probably largely lead ore, whereas that of the Ingomar mine is about 4,030 tons, largely zinc and mixed lead and zinc ore. The records of 12 cars shipped in 1918 show the zinc ore to contain 42 to 46 per cent of zinc and the mixed ore 23 to 30 per cent of zinc and 17 to 25 per cent of lead. One car of lead ore contained 72 per cent of lead and 3.3 ounces of silver to the ton.

Production of Ingomar and Milford No. 2 mines, 1919–1926

Year	Crude ore (tons)	Gold (ounce)	Silver (ounces)	Copper (pounds)	Lead (pounds)	Zinc (pounds)
1909 [a]	49		132	208	23, 562	23, 000
1910	41		65		21, 208	17, 600
1911	27				7, 674	15, 074
1912	37	0. 05	5, 630		12, 344	17, 527
1913	22					15, 446
1914	40					26, 410
1915	46					34, 252
1916	731		621		257, 504	444, 933
1917	1, 970		1, 362		383, 700	1, 095, 490
1918	1, 208		270		187, 156	724, 924
1919	94		17		13, 840	58, 650
1920	173		288	249	200, 021	
1921	50		91		57, 718	
1922	45				15, 012	9, 707
1923	200	. 14	74	81	49, 374	98, 266
1924	300		1, 830		178, 000	119, 000
1925	338		497		363, 475	37, 258
1926	118		64		85, 621	31, 069

[a] According to local report, four cars of ore, about 100 tons, were shipped in 1905.

The principal workings on the Ingomar claim are three tunnels whose total length is about 1,000 feet. (See fig. 55.) The principal tunnel on the Milford No. 2 claim is 450 feet long, but recently ore has been mined at another tunnel farther east on the ridge.

The ridge in which these mines are located presents a complicated structural problem, and close study would be necessary to unravel it thoroughly. The entire ridge forms part of a block that has been thrust forward and upward about 1,000 feet along the Milford thrust. Two minor thrust faults overlie this thrust and probably merge with it in depth. The mine workings on this ridge, however, all lie west of a northwestward-trending normal fault that dips steeply west and passes slightly east of the Milford No. 2 workings. Along this fault the upper or western block, that which contains the ore deposits, has dropped

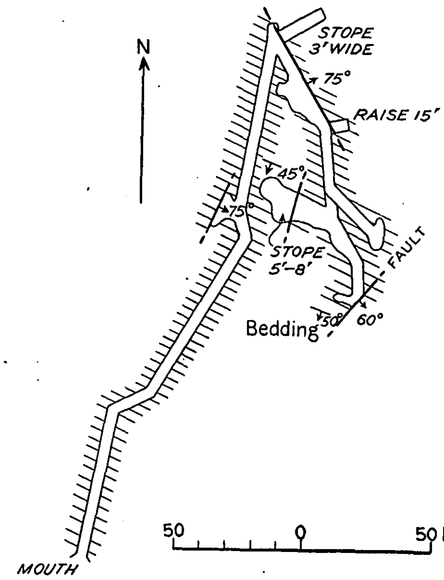


FIGURE 54.—Sketch map of Addison main tunnel

about 300 feet. Another fault of the same type lies west of the Addison mine and therefore about 2,000 feet west of the Milford No. 2 workings. The Ingomar and Milford No. 2 mine workings again lie in a block of rocks that is limited downward by a flat fault that trends northwest and dips 20° NE. This fault is well shown at the mouth of the Ingomar lower tunnel as well as both east and west of it for 1,000 feet. The upper block has moved northeastward 100 feet or more with reference to the base. Galena was found in the breccia 200 feet west of the Ingomar tunnel, but it can not be stated with assurance that the fault was premineral. Finally, the Ingomar mine workings explore three northeastward-trending faults that dip northwest. Considerable ore has been stoped from two of these, so that they are undoubtedly premineral,

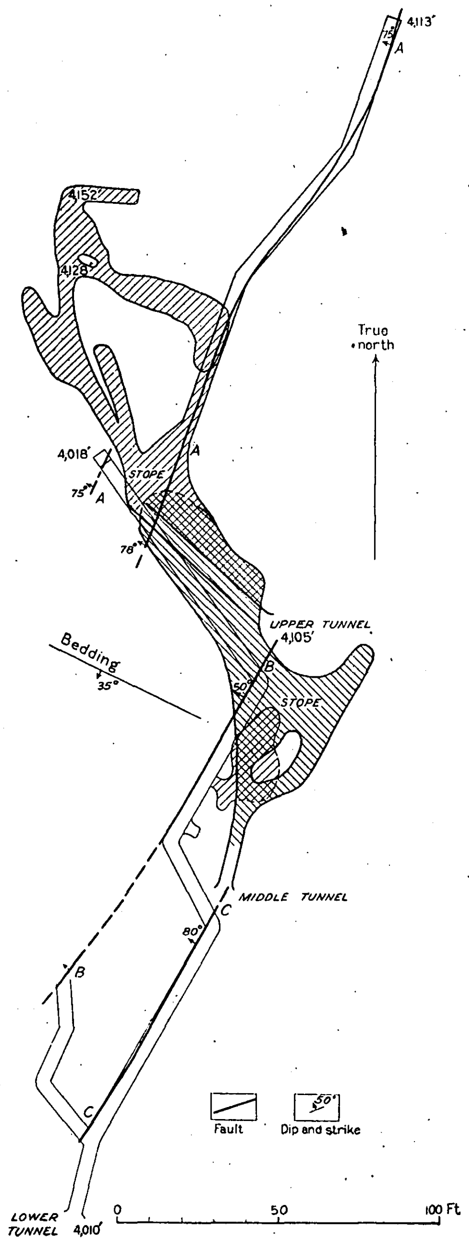


FIGURE 55.—Map of Ingomar mine

but they terminate downward against the flat fault described above. The beds exposed on this ridge range from the Anchor limestone to the thin limestones near the base of the Bird Spring formation. They strike northwest and dip 35° to 40° SW. All the ore in these claims is derived from dolomitized parts of the Yellowpine limestone.

Most of the ore shipped from the Ingomar mine prior to 1919 came from two stopes that follow the northeast faults. One of these stopes is above the lower tunnel on fault B, is roughly 40 by 50 feet and 2 to 6 feet wide, and extends to the surface. The other lies largely along fault A and extends irregularly from the intermediate tunnel to and above the upper tunnel. The only ore now visible in these stopes consists of hydrozincite and smithsonite, and though they may have yielded some lead, zinc minerals were greatly in excess. As some of the zinc carbonate was very pure it seems probable that these bodies may have been enriched by downward circulation of zinc from bodies now eroded. The principal sources of high-grade lead ore in this mine have been two stopes that do not lie along the faults shown but along bedding planes where they are cut by minor fractures. One lies west of fault B in the lower tunnel, and the other west of fault A in the upper tunnel. Although galena was present, most of the lead occurred as carbonate and sulphate.

The principal working on the Milford No. 2 claim is a tunnel 450 feet long from which ore has been mined in three small stopes. The largest stope is near the inner end and is roughly 20 by 40 feet by 3 to 5 feet wide. It follows a wall that trends N. 30° E. and dips southeast. Another stope 25 by 25 feet follows a wall that trends north and dips west. As the local beds trend N. 70° W. and dip 35° S., the structural relations of the shoots closely resemble those found in the Ingomar mine.

During 1924 and 1925 G. L. McIntyre mined mixed lead and zinc ore from a tunnel 700 feet southeast of the tunnel described above.

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