MINERAL RESOURCES OF THE INYO AND WHITE MOUNTAINS, CALIFORNIA.

By Adolph Knopf.

INTRODUCTION.

The first chain of mountains east of the southern part of the Sierra Nevada is known as the White Mountain Range; the southern portion of it is termed the Inyo Mountains and the northern portion the White Mountains. Since 1860 mining has been in progress in this region, but the period from 1869 to 1877 comprises the years of greatest activity, for it was then that the mines of Cerro Gordo, in the Inyo Mountains, were yielding the great output of base bullion that made this locality the only notable producer of silver-lead ore in the State of California. Gold ores have also been important, and recently zinc carbonate ore has been developed on a commercial scale.

The previous knowledge of the geology and ore deposits of the range has been brought together by Spurr from various scattered sources of information,[1] and W. T. Lee, on the basis of his own work, has briefly described the geology of Owens Valley and the origin of the valley with reference to the confining mountain ranges.[2]

The present report is based on field work in progress from July 6 to October 18, 1912, during which time that portion of the White and Inyo mountains lying within the Bishop, Mount Whitney, and Ballarat quadrangles was geologically surveyed, special attention being given to the phenomena of mineralization and to the mining districts contained in the area. During this work the writer was efficiently assisted by Mr. Edwin Kirk, who devoted special attention to the stratigraphy and paleontology of the range.

The following pages present a short summary of the general geology of the range, followed by a description of the metalliferous mineral resources which is as detailed as the present mining developments warrant. The region with which this report is concerned covers essentially the southern 75 miles of the range.

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[1] Spurr, J. E., Descriptive geology of Nevada south of the fortieth parallel and adjacent portions of California, 2d ed.: Bull. U. S. Geol. Survey No. 208, 1905, pp. 206-212.

[2] Lee, W. T., Geology and water resources of Owens Valley, California: Water-Supply Paper U. S. Geol. Survey No. 181, 1906, 28 pp.

GEOGRAPHY.

The Inyo and White mountains form the east wall of Owens Valley in Inyo County, Cal. (See fig. 5.) Together they constitute a single continuous chain, 110 miles long, the Inyo Mountains forming the southern portion, and the White Mountains the northern portion. The line of demarkation has usually been placed along the Saline Valley road, which crosses the range east of Big Pine. The arbitrary character of this division was recognized by J. D. Whitney,[1] and his opinion has been concurred in by all subsequent observers. Local usage has tended in recent years to sanction the employment of "White Mountains" as a name for the entire range, although the extreme southern portion is by preference still known as the Inyo Range.

The range trends northwest and southeast; on the south it is separated from the Coso Mountains by a broad depression and on the north it terminates in White Mountain, whose white granite scarp is a prominent landmark visible for many miles. The average elevation of the range is 10,000 feet. Its western face slopes off abruptly toward Owens Valley, forming a scarp which is but little less pronounced than that of the Sierra Nevada, on the west side of the valley. The western border of the range is thus determined by the floor of Owens Valley, and is as a whole remarkably straight. The eastern border is not so sharply marked, and the boundary on this side is somewhat indefinite. Along the northern portion of the range Fish Lake Valley clearly determines the eastern limit, but between this valley and Saline Valley there is an irregular mountainous area not clearly separated from the White Mountains on the west or from the ranges on the east. Along the southern portion the deep elliptical depression known as Saline Valley, whose floor lies 2,500 feet lower than that of Owens Valley, sharply separates the Inyo Range from the Ubehebe Range to the east. The flank of the Inyo Range is here exceedingly steep and rugged, being comparable with the great escarpment of the high Sierra.

Owens Valley, separating the White Mountain Range from the Sierra Nevada on the west, is long and narrow. Its floor ranges from 2 to 8 miles in width, and the distance from crest to crest of the confining mountain chains ranges from 40 miles at the north end to 25 miles at Owens Lake near the south end, the minimum being 15 miles between Bishop and Big Pine.[2] The elevation of the floor of the valley decreases from about 8,000 feet above sea level at the north end to 3,600 feet at Keeler, on Owens Lake, the lowest point in the valley.

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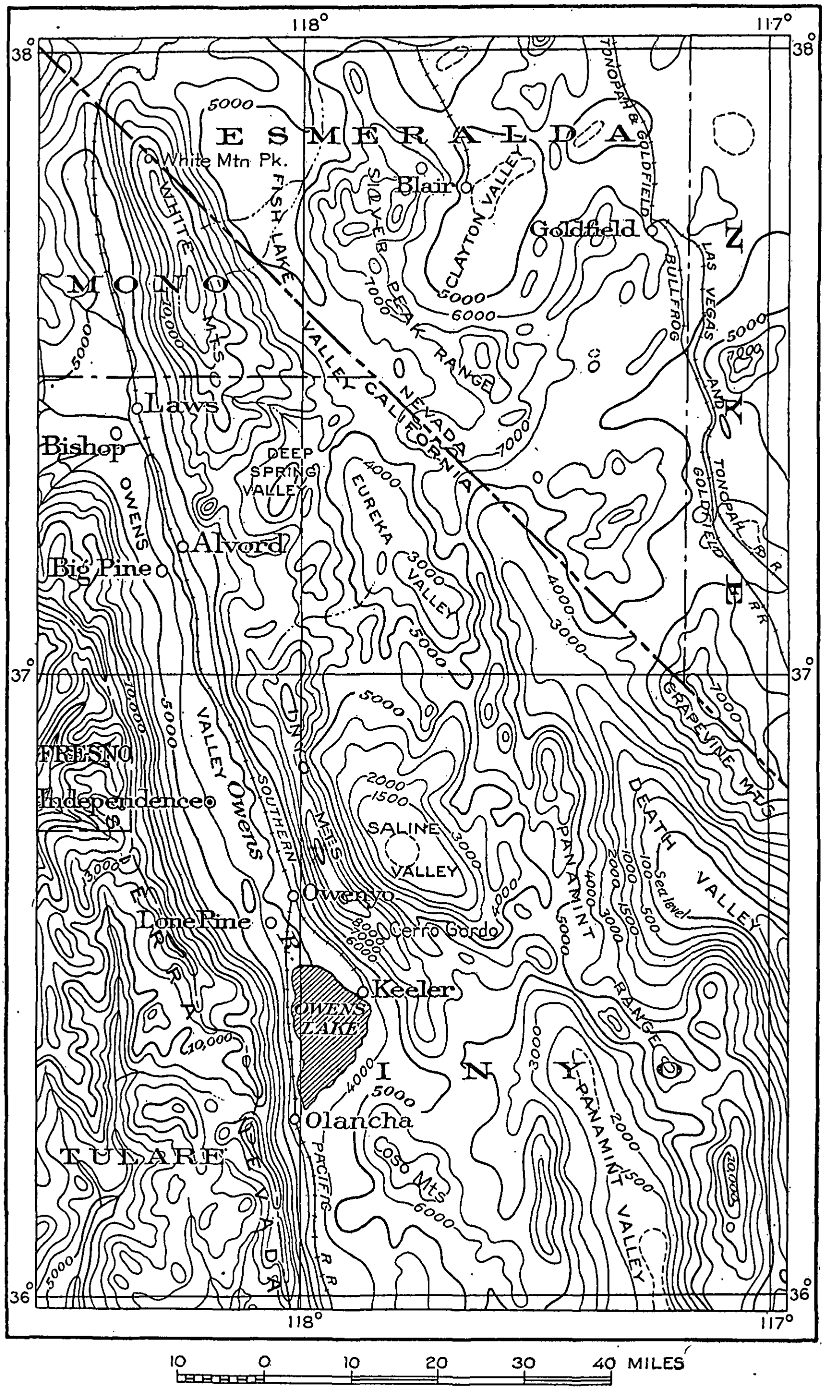
[1] Geol. Survey California, vol. 1, 1865, p. 456.

[2] Lee, C. H., An intensive study of the water resources of a part of Owens Valley, Cal.: Water-Supply Paper U. S. Geol. Survey No. 294, 1912, p. 9.



Contour interval 1,000 feet
Intermediate contours below 2000 feet altitude

FIGURE 5.—Map of White Mountain Range, Cal., and adjoining territory.

TRANSPORTATION AND MINING CONDITIONS.

The Nevada & California Railroad, a narrow-gage line, formerly the Carson & Colorado but now a part of the Southern Pacific system, traverses Owens Valley along the entire front of the White Mountain Range; it connects with the Tonopah branch at Mina, Nev., and its southern terminus in Owens Valley is Keeler. A broad-gage branch of the Southern Pacific has in recent years been built northward into the valley from Mohave, primarily to aid in the construction of the Los Angeles Aqueduct, and connects with the narrow-gage line at Owenyo. Mines situated on the western flank of the range are therefore favored by proximity to railroad transportation facilities. On account of the ruggedness of the mountains, roads are difficult to construct, and the few that have been made are characterized by excessive grades—a notable example being that to the Cerro Gordo mine, in which a rise of 4,500 feet is accomplished in 8 miles. Pack trails furnish the only feasible means of access to many mines and prospects, and in former days, before the rich surface ores had been exhausted, ores were commonly packed by mules to arrastres and mills situated at water, or to the valley for shipment to smelters. This is occasionally attempted at present.

Two roads cross the range, both of which start from Big Pine, in Owens Valley. One goes to Deep Spring Valley, the distance being 28 miles; the other goes to Saline Valley, 65 miles distant, and crosses three divides, the highest at an altitude of 7,500 feet. In addition to the handicap imposed on the mining industry by the difficulties of transportation, there is a scarcity of water, fuel, and forage. In places above 7,000 feet in altitude piñon is fairly abundant, but it is usually expensive to get out.

A favorable factor, especially for mines situated on the west flank of the range, is the abundant supply of hydroelectric power which is being developed on the west side of Owens Valley. Three companies are in the field. The transmission line of the Nevada-California Power Co., supplying power to Goldfield, Nev., crosses the White Mountains by way of Silver Canyon and Wyman Creek.

GENERAL GEOLOGY.

SUMMARY STATEMENT.

The White Mountain Range is built up of a thick series of sedimentary rocks, including bedded andesitic lavas, all of which are intruded by large masses of granite.

Sedimentary and igneous rocks occur in nearly equal volume and essentially form the bulk of the mountains. Locally, however, as on the west flank of the range, there are lake beds of early Pleistocene or Pliocene age, and northwest of Deep Spring Valley and at the south end of the range, southeast of Keeler, basalt sheets attain considerable prominence.

The pre-Pliocene sedimentary formations range in age from Lower Cambrian to Triassic. They are composed largely of limestone, sandstone, and shale; limestones predominate, and, because limestones of like appearance recur in the successive formations, it is difficult to discriminate the formations, and reliance must be placed mainly on the evidence of their fossil contents. In mapping the sedimentary rocks five broad subdivisions were employed—Cambrian, Ordovician, Devonian, Carboniferous, and Triassic.

The rocks are faulted and greatly folded—in places overturned—and are much metamorphosed by extensive intrusions; consequently the stratigraphic relations as a rule are obscure. The volcanic rocks, already referred to as making up part of the stratigraphic sequence, form a prominent belt along the west flank of the southern part of the range. They are of Triassic age.

The intrusive igneous rocks are predominantly of granite character, ranging from diorite to granite. Hornblende-rich varieties verging toward hornblendite are found in the precipitous slopes of the range southeast of New York Butte. Dikes of diorite porphyry are of common occurrence in the sedimentary rocks surrounding the granitic masses; and in the foothills east of Keeler dikes of dense-grained siliceous rock (felsite) are common, generally lying parallel to the stratification of the inclosing rocks.

SEDIMENTARY ROCKS.

CAMBRIAN SYSTEM.

The oldest rocks of the region are limestones, dolomites, quartzitic sandstones, and slaty shales of Lower Cambrian age. They are present principally in the White Mountains and extend southward along the east flank of the Inyo Mountains as far as Waucoba Mountain.

The stratigraphic column, determined by piecing together a number of incomplete sections, is, according to Edwin Kirk, as follows:

Section of Lower Cambrian rocks in White Mountain Range.

	Feet.
Arenaceous limestones and slates	1,300
Upper sandstone series	2,500
Coral limestone series	2,600
Lower sandstone series	3,000
Massive white limestone	2,000
	11,400

The massive white limestone is a notable member of the Cambrian section. It is best shown on Wyman Creek, where it is transsected by the stream gorge, which exposes a belt 4,100 feet wide, or approximately 2,000 feet thick. The basal member is a bluish dolomite marble carrying obscure circular fossil remains. The subjacent rocks, which are conformably below the marble, consist of alternating limestones and slates, highly folded and contorted and therefore not susceptible of measurement. The estimate of 11,400 feet as the thickness of the Cambrian rocks is for this reason regarded as a minimum.

The rocks overlying the massive limestone—the lower sandstone series—consist predominantly of dark fine-grained quartzite or highly indurated sandstone. Thin argillitic or phyllitic partings are common. Cross-bedding and extensive ripple-marked surfaces, as is well shown in Black Canyon, are characteristic features. In places, as in Black and Silver canyons, a pronounced slatiness has been imposed on the rocks, commonly at a considerable angle to the stratification.

The rocks above the lower quartzitic sandstone series consist of an alternation of limestones and shales, aggregating 2,600 feet in thickness. Certain of the limestone beds are crowded with the remains of Lower Cambrian corals (Archæocyathinæ).[1]

The upper sandstone series resembles the lower sandstone series; it is best shown on the summit of the range south of the Saline Valley road. It is overlain by black slates, which weather with a pronounced red tint, and by arenaceous limestones containing trilobite fragments.

ORDOVICIAN SYSTEM.

The Ordovician rocks overlie the Cambrian conformably and consist of a basal series of heavy-bedded limestones, aggregating 3,600 feet in thickness, succeeded by 800 feet of quartzite, shale, and limestone. They are best exposed along Mazourka Canyon, on the west flank of the Inyo Mountains, where their stratigraphic relations are partly determinable; thence they extend across the mountains, but along the east flank of the range south of Waucoba Mountain they are so folded, overturned, faulted, and brecciated and are so intruded by igneous rocks that their stratigraphy is probably impossible of determination.

In the upper portion of the Ordovician were found Hormotoma, Fusispira, Diplograptus, and Amphion. In addition to these there were a number of other gastropods, ostracodes, and brachiopods not yet identified by Mr. Kirk.

[1] Walcott, C. D., Am. Jour. Sci., 3d ser., vol. 49, 1895, p. 141.

DEVONIAN SYSTEM.

Above the Ordovician rocks are 1,400 feet of impure limestones, cherty in places, which are assigned to the Devonian. They are conglomeratic at the base of the section but rest in angular accordance on the subjacent Ordovician rocks. They are best exposed in the foothills east of Citrus.

The fossils found in these rocks include Striatopora, Cladopora, Ptychophyllum, and Chonetes. Concerning these Mr. Kirk reports: "This is an assemblage of fossils which strongly suggests Silurian but which I think may be more safely called Devonian. Fossils specifically identical with these have been found in the White Pine district of Nevada and have always been listed as Devonian by Walcott and others."

CARBONIFEROUS SYSTEM.

The Carboniferous is extensively developed in the southern part of the Inyo Mountains, attaining a thickness very roughly estimated at 5,000 feet. Portions of the section were measured carefully at several points in units aggregating 3,000 feet, but at no place was a complete section found.

The rocks comprise limestone, shale, and some quartzite, the limestone predominating. A conglomerate marks the base of the Carboniferous, indicating an unconformity between it and the underlying Devonian, but the strata rest in angular accordance on the subjacent rocks.

The lower portion of the Carboniferous section consists largely of heavy-bedded limestones; the upper portion consists of thinner-bedded limestones, ranging on the average from 6 inches to 2 feet. The upper 2,000 feet of the Carboniferous rocks, as exposed southwest of Cerro Gordo, weather in brilliant tints and resemble closely the overlying Triassic rocks, from which, however, they are readily distinguished by the presence of Fusulina.

The top of the Carboniferous section is characterized by the presence of a massive conglomerate composed largely of chert fragments, but at many places this conglomerate is faulted out, so that the contact of the Carboniferous and the Triassic is commonly a fault contact.

Locally the Carboniferous is fossiliferous, containing the following forms, among others: Fusulina, Productus, Derbya, Amplexus, and Goniatites.

TRIASSIC SYSTEM.

The Triassic rocks consist predominantly of thin-bedded limestones and calcareous slates, together with some hard, massive black shales occurring mainly north of Union Wash. The rocks weather as a rule in rather brilliant tints, buff and terra cotta prevailing.

The strata are faulted and closely folded and are overturned at many places; they were evidently far more susceptible to dynamic deformation than the older and more massive formations. Owing to this complex folding the thickness of the Triassic rocks could not be determined accurately, but 5,000 feet seems not an overestimate. The rocks form a belt extending southward from the Reward mine along the west flank of the Inyo Mountains.

Collections of fossils made by J. P. Smith show that this belt includes rocks of Lower Triassic and Middle Triassic age.[1]

QUATERNARY SYSTEM.

LAKE BEDS.

Along the foothills of the White Mountains east of Alvord there is exposed, especially as viewed from Owens Valley, an assemblage of beds strikingly different in aspect from the surrounding bedrock formations. The strata are brilliant white or light gray and are dissected by numerous gulches and sharp ravines, so that a sort of badland type of topography is produced.

The beds of this formation consist of shales, sandstones, conglomerates, thin limestones, and arkose grits. All of these, except the limestones and grits, are soft and loosely coherent. They are evenly and persistently stratified and dip westward at gentle angles. Locally the beds, including even the conglomeratic members, are crowded with fresh-water fossils. They were therefore laid down in a lake, and for this lake Walcott,[2] who first described the beds, has proposed the name Waucobi.

Beds possibly of lacustral origin occur east of Citrus and also southeast of Keeler. Along the Keeler-Darwin road, in the broad basin between the Inyo and Coso mountains, is an extensive exposure of what is very probably a series of lake beds. They consist of loose granitic detritus, as a rule rather coarse. Stratification is not well developed, though some beds of arkose grit, 1 to 2 inches thick, are firmly enough cemented to form distinct strata. Pumiceous rhyolite tuffs become prominent toward the top of the section, especially along the flanks of the Coso Mountains. The volcanic members are well shown east of the divide between Owens Lake and the drainage to the south. A breccia of rhyolite pumice forms beds ranging from a few inches to 30 feet in thickness. In the thicker beds the pumice

[1] Smith, J. P., Comparative stratigraphy of the marine Trias of western America: Proc. California Acad. Sci., 3d ser., vol. 1, 1904, pp. 350-351, 356-357.

[2] Walcott, C. D., The post-Pleistocene elevation of the Inyo Range and the lake beds of Waucobi embayment, Inyo County, Cal.: Jour. Geology, vol. 5, 1897, p. 340.

fragments attain a length of 6 inches. Slabs of coarsely crystalline gypsum an inch or so thick were noted but are not well enough exposed to show whether they are contemporaneous chemical precipitates. These rocks strike north and south and dip 10°–14° W.

Fossils found by Walcott in the lake beds east of Alvord were identified by W. H. Dall, who reported: "Any of them might be recent or Pliocene; my impression from the mass is that they are Pleistocene."[1] As the lake beds are unconformably overlain by indurated conglomerate, locally containing slabs of the underlying lake-bed grit, and as this conglomerate itself has been considerably dissected, it seems probable, from the length of the erosional history thus involved, that the lake beds are of early Pleistocene age or even of Pliocene age.[2]

ALLUVIAL DEPOSITS.

Deposits of gravels and sands occur throughout the White and Inyo mountains and on both flanks of the range. The most notable accumulation of this kind is afforded by the series of ancient alluvial cones best developed at Black and the adjoining canyons along the front of the White Mountains. The alluvial deposits here form the foothill portion of the range, extending up to an elevation of 6,600 feet, or 2,600 feet above the floor of Owens Valley.

As observed from a distance of a mile the alluvial deposits appear to be fairly well stratified, a feature that has led some observers to call them " lake beds," but actual examination at the outcrops shows that the seemingly even stratification is at best a rough, uneven, discontinuous layering.

By far the best developed of the old alluvial cones is that in Redding Canyon; it is, moreover, deeply dissected and the canyon affords a number of fine vertical sections that show the constitution and structure of the deposit. It consists of angular gravels, unshingled, unsorted, and rudely layered. A noteworthy characteristic is the large number of granite bowlders, 6 feet in diameter being a common size, though some attain a size of 12 feet. The deposit is semi-indurated, so that great masses spall off. A striking feature, also determined by the partial cementation of the gravels, is produced by the earth pillars or " toad stools " capped by granite bowlders. Near the mouth of the canyon, at an altitude of 4,500 feet, there occurs an intercalated bed of white rhyolite pumice breccia 2½ feet thick, which is rather well stratified. In appearance and composition this bed coincides with those found at the top of the lake-bed series along

[1] Walcott, C. D., op. cit., p. 342.

[2] See also Trowbridge, A. C., The terrestrial deposits of Owens Valley, California: Jour. Geology, vol. 19, 1911, p. 725.

the western flank of the Coso Mountains, and this lithologic resemblance suggests synchronous deposition. The pumice bed and the associated alluvial beds dip 7° W., but a short distance farther west the dip steepens to 16°, and this abrupt steepening indicates that the beds have been deformed since they were laid down.

Pumiceous rhyolite occurs in the sand beds or loose sandstones at McMurray Springs and forms a conspicuous white stratum in the alluvial gravels at Devils Gate, on the Saline Valley road. Along this road the old alluvial gravels extend continuously to the summit of the range at an altitude of 7,500 feet, and even across the divide down at least to 7,300 feet. Here, as noted along the June Smith cut-off, the gravels are cemented by a white matrix composed largely of particles of pumiceous rhyolite. Rhyolite tuff is also embedded in the coarse gravels, capped by basalt sheets, occurring on the east flank of the Inyo Mountains northwest of Willow Creek.

The gravels east of Alvord rest unconformably on the lake beds of the Waucobi embayment. Owing to the fact that the lake beds are poorly lithified few characteristic rock fragments derived from them occur in the overlying deposits, so that it is in many places difficult to determine that an unconformity actually exists. Furthermore, the lake beds, because of their loose and incoherent character were easily reworked, and the material thus derived was incorporated in the overlying deposits without essential change of appearance and now forms the matrix of the gravels. In this way deposits simulating littoral phases of the lake beds were formed, so that the discrimination of true lake beds from terrestrial deposits is no easy matter.

Well-rounded gravels, with which rhyolite tuff is commonly associated, occur generally below the basalt sheets that form cappings on the high summits in the eastern part of the White Mountains and in the Inyo Mountains southeast of Keeler. They occur at elevations as high as 8,300 feet. In places they cap the divides between such deep intermontane depressions as Deep Spring and Eureka Valley. From the fact that these gravels are thoroughly water worn and are locally auriferous it seems probable that they represent old river channels and may be older than the material of the alluvial-cone type.

The present series of alluvial cones that form so prominent a feature along the east wall of Owens Valley were derived largely from the erosion of the older alluvial cones. They head in the deep canyons penetrating the west flank of the range and attain elevations ranging from 2,000 to 2,500 feet above the floor of the valley.

IGNEOUS ROCKS.

ANDESITES.

Andesitic rocks form a belt extending along the west flank of the Inyo Mountains from Union Wash to a point near the south end of the range. They are of volcanic origin and comprise a stratified series of lavas, breccias, and tuffs. Thick sheets of lava predominate at most places, so that as a rule it is difficult to ascertain the internal structure of the volcanic series.

East of Swansea the volcanic belt is approximately 10,000 feet wide. The general attitude of the beds is steep, the dip on the east side of the belt, where it is clearly determinable, being 70° W. If the belt represents a closely appressed syncline, as is indicated by the general structure of the range, then the probable thickness of the andesitic series is 4,500 feet. (See fig. 6.) This estimate doubtless gives a minimum thickness, for both contacts along the line of the measured section are fault contacts, although the amount of faulting that has taken place along them seems small.

The andesites are highly porphyritic, carrying numerous large phenocrysts of plagioclase feldspar. They are more or less thoroughly altered and are consequently of some dull, subdued color—grayish green, dull reddish, etc. They are well exposed on the Cerro Gordo road, where heavy sheets of conspicuously porphyritic andesite are shown, reddish on weathered surfaces and bluish gray on fresh fractures. A roughly schistose or sheared structure has been impressed on the volcanic rocks, especially on the tuffs and other pyroclastics.

Intrusive rocks have invaded the andesites—granites in the area northwest of the Burgess mine; aplite in dikes and as a large

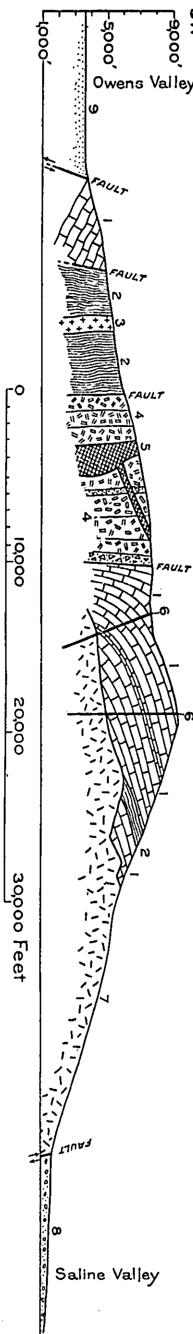


FIGURE 6.—Diagrammatic section across Inyo Mountains at Swansea, Cal. 1, Carboniferous limestone; 2, Carboniferous shales; 3, felsite; 4, Triassic andesite lavas, breccias, and tuffs; 5, aplite; 6, diorite porphyry; 7, quartz monzonite, diorite, and hornblendite; 8, alluvium; 9, lake beds.

mass east of Swansea, as shown in figure 6; and diorite porphyry in dikes intersecting them at several localities.

The age of the andesitic series is probably late Triassic. The evidence on which this determination is based was found in the ridge on the south side of Union Wash, where the basal portion of the volcanic series, consisting of andesitic breccias, interleaves with the underlying limestones of Middle Triassic age. Angular fragments of these limestones are common inclusions in the breccias. It is therefore certain that the andesitic series is younger than the Middle Triassic limestones, and the most probable interpretation of the facts at hand is that Middle Triassic sedimentation in this locality was terminated by a great outburst of volcanic activity.

GRANITIC ROCKS.

Granitic rocks occur in large volume in the White and Inyo mountains. Extensive areas are exposed on the east side of the White Mountains, but on the west flank only small masses occur, as that in Redding Canyon and those east of Alvord. About half of the Inyo Mountains shows granite at the surface, and it occurs in great amount on both sides of the range. Many unmistakable features indicate, moreover, that granite underlies the remainder of the range at no great depth. These features are the occurrence of aplite intrusions at considerable distances from surface exposures of granite; the prevalence of diorite porphyry dikes, many of which closely approach diorites in granularity; and the occurrence of masses of garnet rocks, which are ascribable to the metamorphic effects produced by underlying granitic intrusions.

The average granitic rock is a quartz monzonite composed of plagioclase, orthoclase, quartz, hornblende, and biotite. From this average the granitic rocks range on the one hand to varieties that may appropriately be termed granite, such as the mass east of Citrus, and on the other hand to quartz diorite, diorite, and hornblendite. The dark heavy hornblende-rich varieties are especially prevalent in Daisy Canyon, on the east flank of the Inyo Mountains, and along the crest of the range northward from New York Butte.

The intrusive character of the granites is made apparent most plainly by the extensive contact metamorphism that they have induced in the inclosing sedimentary rocks. This effect is displayed most notably, perhaps, in the great belt of chiastolite hornfels formed as a result of the recrystallization of a belt of shale occurring in the lower part of the Carboniferous section of Mazourka Canyon. The belt of chiastolite-bearing rock has a length of over 10 miles, extending from the foothills southeast of Citrus to and beyond Santa Rita Flat, and attains a width of over 1 mile at Barrel Springs.

The chiastolite, which is recognizable by its characteristic carbonaceous crosses, is present across the entire width of the belt, but toward the granitic contact the matrix in which the chiastolite prisms are embedded becomes more crystalline, and locally tourmaline becomes associated with the chiastolite as another visible constituent of the hornfels.

The age of the granitic intrusions, so far as it is determinable in the White Mountains, is post-Cambrian and pre-Pliocene. In the Inyo Mountains the age is determinable as post-Triassic and presumably pre-Pliocene. It is believed that all the intrusive masses are essentially of the same age, although this surmise is not susceptible of proof, and that they were probably intruded contemporaneously with those of the Sierra Nevada, which forms the opposite wall of Owens Valley. That successive intrusions did in fact take place within the Inyo Mountains was definitely determined at one locality at least. Southeast of Mount Whitney station a white granite, which is devoid of ferromagnesian minerals except rare flakes of biotite and is characterized by an abundance of subhedral quartz crystals, forms a prominent knob projecting out into Owens Valley as a spur from the main range, and a gray biotite-quartz monzonite forms the foothills of the main range. The two granitoids contrast strikingly, and the white granite proves to be the younger intrusive mass. The white granite carries considerable plagioclase and is therefore in all probability a salic differentiate of the quartz monzonite magma, genetically coordinate with aplite and intruded shortly after the main intrusion.

APLITE.

Dikes of fine-grained equigranular white rock termed aplite occur around the peripheries of the granitic intrusions, both in the granite itself and in the surrounding rock. They are composed almost wholly of feldspar and quartz. They were noted as particularly abundant in the zone of garnetization of the limestones adjacent to the granite mass north of Antelope Spring; these aplites show in places a small amount of purple fluorite. East of Swansea, as already mentioned, aplite intrudes andesitic rocks.

PORPHYRY INTRUSIONS.

Dikes and irregular masses of porphyry occur throughout the Inyo Mountains, cutting all the different formations of pre-Pliocene age, both igneous and sedimentary. They are particularly numerous in the vicinity of the large granitic masses and are there of obviously more crystalline texture. In the field most of the dikes would be designated diorite porphyry, because they show porphyritic plagioclase crystals embedded in a microcrystalline groundmass, but microscopic examination reveals the fact that some, such as that occurring northwest of Cerro Gordo, should be called monzonite porphyry. The distinction, however, is of no great importance. The dikes traversing the sedimentary rocks exhibit strongly chilled margins, which thereby take on an andesitic appearance.

The greater prevalence of the dikes and their more highly developed crystallinity in the neighborhood of the great granitic masses shows that they belong to the closing manifestations of the intrusive activity of the quartz monzonite magma.

FELSITE.

Felsite dikes were noted only in the southern part of the Inyo Mountains, more particularly in the lower slopes of the range east of Swansea and Keeler. They are dense-grained rocks containing minute inconspicuous phenocrysts of feldspar and resemble dense quartzite—a resemblance that is not diminished by the fact that they are generally intruded parallel to the stratification of the inclosing rocks. Under the microscope they show small sporadic orthoclase phenocrysts embedded in an extremely fine grained groundmass of quartz and orthoclase; ferromagnesian minerals are totally absent.

Some of the larger intrusions of felsite were slightly impregnated with pyrite, and the oxidation of this mineral has caused the outcrops to take on a rusty orange-colored tint.

RHYOLITE.

Breccia and tuff composed of pumiceous white rhyolite occur at many places throughout the region, as described in part in the section on the older alluvial deposits. The greatest thickness noted is 200 feet, as shown on the Saline Valley road 3 miles north of Rattlesnake Cabin, where the rhyolite tuffs are overlain by heavy flows of basalt.

The rhyolite is composed of a highly vesicular glass, silky in appearance on fresh fracture, holding phenocrysts of quartz, sanidine, and biotite. The quartz predominates, sanidine and probably other feldspars are common, but biotite is rare and is generally absent.

BASALT.

Basalts were erupted during two separate periods—the earlier in early Pleistocene time and the later in geologically very recent time.

The earlier basalts form a prominent part of the range southeast of Keeler, and the whole south end is buried under lavas. At an altitude of 6,300 feet the floor on which they were erupted—a nearly horizontal surface—is well shown. Beneath the basalt sheets as exposed here is a 10-foot stratum of tuff composed of pumice fragments of oxidized, highly vesicular basalt; the tuff itself rests on gravel deposited unconformably on the eroded edges of the Triassic. The horizontal lava sheets are step-faulted, as is graphically shown in the deep canyons eroded back into the basalt plateau, and it seems probable that the simulated appearance of a great lava flow descending from the plateau down to the level of the broad pass between the Inyo and Coso mountains is due to a great number of such step-faults.

Basalt sheets overlie the lake beds in places in the intermountain area between the Inyo and Coso mountains; they overlie ancient alluvial cones on the east side of the Inyo Range, and form a conspicuous series of plateaus sloping southeastward on the east side of the White Mountains at altitudes ranging from 5,500 to 10,500 feet. The thickness of these basalt cappings is about 125 feet.

The basalts are highly olivinitic varieties. A specimen from the head of South Fork of Crooked Creek is characterized by abundant phenocrysts of olivine and of augite in irregular stellate groups; feldspars do not occur among the porphyritic constituents but only in the groundmass, which is composed of augite, labradorite, and magnetite.

A large basalt flow of very recent origin was extruded at the base of the mountains northeast of Aberdeen, in Owens Valley. It flowed out over Recent alluvium and is exceedingly vesicular and scoriaceous. The basalt is an olivine-bearing variety, rather feldspathic, so that the holocrystalline form is dark gray. It is essentially similar in appearance to the earlier basalts. Ejection of cinders closed the eruption. This basaltic outburst was in all probability contemporaneous with the outpouring of lavas and the formation of cinder cones on the opposite side of Owens Valley, along the flank of the Sierra Nevada.

MINERAL RESOURCES.

PRINCIPAL ORES.

The metalliferous mineral resources of the Inyo and White mountains in the order of their present importance are zinc carbonate, argentiferous galena, gold-quartz, and copper ores. Formerly argentiferous galena ore was the principal resource, the famous mines at Cerro Gordo alone having yielded $7,000,000 in silver and lead.

HISTORICAL NOTE.

Mining began in 1861, when the Russ mining district was established in that portion of the range east of Independence. From 1869 to 1877 the region enjoyed a period of great activity, for it was then that Cerro Gordo was yielding its great output of base bullion. The completion of the Colorado & Carson Railroad to Keeler in the early eighties served to stimulate the mining industry to some extent, although not as much as was expected, and the region never regained the prominence it held during the flush days of Cerro Gordo. About 1907 a revival of interest in the mineral deposits of the Inyo Mountains took place, the most notable result of which has been the development of zinc ore on a commercial basis. Mining and prospecting were not active in the White Mountain Range during 1912 except at Cerro Gordo, which yielded practically the entire output of metal of the region—zinc, lead, and silver.

OCCURRENCE.

The ore deposits occur most abundantly in the southern part of the range—that is, in the Inyo Mountains—and the preponderant part of the metallic output has come from that part of the range. This distribution of the mineral resources coincides with the distribution of intrusive granite, which, as already pointed out, is far more abundant in the southern part of the range than in the northern, or White Mountain, part. The zinc, lead, silver, and copper deposits occur as a rule in limestone; the gold deposits seem closely linked to the presence of granite, occurring chiefly in the marginal zone of the granite masses or in the country rock immediately adjacent to them. Ore deposits have not been found in the central portions of the larger granitic areas.

ZINC ORES.

OCCURRENCE AND ORIGIN.

Zinc ore composed essentially of the carbonate smithsonite occurs at Cerro Gordo; in fact it was the discovery of this ore, whose presence was previously unsuspected, that led to the recent revival of mining at that camp. It has been found nowhere else in the Inyo Mountains. The zinc ore forms pipes and irregular masses lying principally in the limestone footwall of the old galena stopes; it occurs immediately below the lead-ore bodies formerly worked and extends as far as 100 feet laterally from them.

The origin of the zinc ore is essentially as follows: The primary ore in the deposits formerly worked for lead and silver consisted of galena containing a small amount of admixed sphalerite; oxidation converted the sphalerite to the soluble zinc compound, zinc sulphate, which was then carried by downward-moving water into the footwall of the lead-ore body; here a reaction took place between the zinc-bearing solution and the limestone, and the zinc was precipitated as the carbonate smithsonite.

CERRO GORDO MINE.

LOCATION.

The property now known as the Cerro Gordo mine is a consolidation of the Union and Santa Maria mines, the two mines that furnished the bulk of the output of argentiferous lead ore to which Cerro Gordo owes its fame. Cerro Gordo has been the only notable producer of silver-lead ore in the State of California; its present importance, however, is due mainly to the discovery of bodies of zinc carbonate ore, which occur as footwall appendages to the lead chambers formerly worked.

The mine is situated near the summit of the Inyo Mountains, east of Owens Lake. At the Belshaw or principal shaft the altitude is 8,500 feet—nearly 5,000 feet above the town of Keeler, the terminus of the Nevada & California Railroad. In an air line the mine is 5½ miles northeast of Keeler; by wagon road it is 8 miles, and the grade from the valley is steep. The mine lies immediately below the bold scarp on the west flank of Cerro Gordo Peak, which rises to an elevation of 9,217 feet and is a prominent landmark as seen from Owens Valley.

HISTORY.

Cerro Gordo, according to Loew,[1] who visited the mines in 1875, was discovered in 1866 by Mexicans—Pablo Flores and his companions. By others the date of discovery is given as 1861. Be that as it may, the deposits were worked by the Mexicans on a small scale only, the ores being smelted in vasos, and the district did not become notably productive until its mines were taken over by Americans in 1869. The Union mine came into the possession of M. W. Belshaw and V. Beaudry; the Santa Maria and allied properties were shortly afterward acquired by the Owens Lake Silver Mining & Smelting Co., of New York. The ores were smelted at three reduction works. Those from the Union mine were treated at Belshaw & Judson's furnaces, situated above the portal of the Omega tunnel, and at Beaudry's furnace, just west of Cerro Gordo camp; those from the Santa Maria mine were smelted at the Owens Lake Silver Mining & Smelting Co.'s furnaces at Swansea, near the shore of Owens Lake.

Scarcity of water, scarcity of fuel, and high transportation charges made mining and reduction costs large; nevertheless the period from 1869 to 1876 was one of great activity. Water was piped to Cerro Gordo from a distance of 11 miles, the lift being 1,875 feet; charcoal burned from piñon and mountain mahogany, which grow in scattered stands in the higher portions of the Inyo Range, cost at the furnaces at Cerro Gordo 32½ cents a bushel; all freight

[1] Loew, Oscar, U. S. Geog. Surveys W. 100th Mer., 1876, p. 62.

had to be hauled across the desert from Los Angeles, a distance of 275 miles, at a cost of 3 to 6 cents a pound.

In 1871 the production of the district was $300,000, the recovery being only 50 to 55 per cent of the lead. In 1872 3,220 tons of base bullion carrying 140 to 150 ounces of silver a ton was produced, which, with silver at $1.2929 an ounce and lead at 6 cents a pound, aggregated $977,255 in value, or approximately $303 a ton.[1] Eilers, who visited Cerro Gordo in 1872 and described the metallurgical processes in use there, estimated that the ore of the Union mine, though the average content was not precisely ascertained at the works, contained about 34 per cent of lead, the slag carrying 15 per cent of lead.[2] Quartzose silver ores, obtained from the Ignacio, Belmont, and other mines in the vicinage of Cerro Gordo, were added in small quantity to the furnace charge for the purpose of concentrating their silver in the lead. Economy of fuel was obtained by means of "an almost unprecedented loss of lead." Eilers concluded that "the whole management of the works is rather calculated to create the suspicion that the proper composition of the charge is not understood. It is certain that either by an addition of iron oxide to the present charge, or by omitting the addition of the quartzose silver ores altogether, far better results might be obtained than at present."[3]

These suggestions seem to have borne some fruit, for the old slag dumps, as sampled by the present management of Cerro Gordo, show a content of not over $5 a ton in silver and lead; only by sorting out material containing unfused lumps of ore it is possible to obtain a product averaging $15 a ton.

It is recounted that at one time in 1873 $2,000,000 worth of bullion was corded up on the shores of Owens Lake awaiting transportation out of the valley, and bars of base bullion were even used to construct cabins as temporary shelter for the miners.

Litigation commenced at this time. The San Felipe Co., most of whose stock was owned by the Owens Lake Silver Mining & Smelting Co., claimed discovery title to the Union mine, and a verdict was rendered in its favor. The case was then appealed to the United States Supreme Court, where it lay for several years.

The maximum annual output—5,600 tons of base bullion—was made in 1874. From December 1, 1873, to November 1, 1874, the Union mine produced 12,171 tons of ore of an average assay content of 47 per cent of lead and 87 ounces of silver to the ton.

According to M. W. Belshaw,[4] for the period February 1 to October 1, 1876, the total cost per ton for mining and reduction was $19.96.

[1] Statistics of mines and mining in the States and Territories west of the Rocky Mountains, 1873, p. 26.
[2] Idem, p. 356.
[3] Idem, p. 355.
[4] Fourth Ann. Rept. California Min. Bur., 1884, p. 225.

The quantity of ore treated was 9,950 tons; the lead produced was 1,325 tons. The recovery was 64 per cent of the lead assay and 90 per cent of the silver assay. According to these figures the ore as mined carried 21 per cent of lead and was therefore of considerably lower grade than that mined a few years earlier.

It is impossible to give an accurate figure for the total output of Cerro Gordo during its most prosperous years. The figures now current in Owens Valley range around $20,000,000, but these estimates surely show the generous influence of time and tradition. The estimates given in contemporary or nearly contemporary reports range from $6,500,000 to $15,000,000. The total output of base bullion from 1869 to 1876, inclusive, obtained by summing up the yearly production given in Raymond's annual statistics of mines and mining in the States and Territories west of the Rocky Mountains, is approximately 22,500 tons. On the assumption that the average value was $300 a ton—as in 1872—the value of the total output of Cerro Gordo during its most prosperous period was $6,750,000, or, in round numbers, $7,000,000.

The mines, although consolidated after the settlement of the litigation, were shut down about 1877, mainly, it would appear, because the large bonanza bodies of argentiferous galena had been worked out. In the early eighties the Carson & Colorado Railroad, a narrow-gage line which connected with the Central Pacific Railroad at Reno, was completed to Keeler and was expected to revive the mining industry at Cerro Gordo. The mine, however, was worked spasmodically by lessees until it was acquired by the Great Western Ore Purchasing Co., in 1905. A small production was made by this corporation in 1907. Subsequently the property was taken over by the Four Metals Mining Co., which erected a 200-ton smelter just east of Keeler and built an aerial tramway from the mine to the smelter. This company attempted to smelt the old slags from Cerro Gordo and to work the mine, but went into insolvency. The present operators, who had obtained from the Four Metals Mining Co. a lease to extract the zinc ore of the mine, then took over the property by purchase of the bonds of the insolvent corporation. During 1912 litigation was in progress concerning the ownership of the property.

To whom belongs the credit of recognizing the occurrence of zinc ore at Cerro Gordo is not known. Its discovery in important quantities and its exploitation on a commercial base are due to L. D. Gordon, of the Cerro Gordo lease.

DEVELOPMENTS.

The underground workings are said to aggregate 20 miles in length. The Belshaw shaft, from which five levels have been driven, is 900 feet deep, and from the 900-foot level a winze extends down to the 1,150-foot level.

An aerial tram connects the mine with the smelter, which is situated half a mile east of Keeler. The nominal capacity of the tram is 50 tons a day, but this is frequently lowered by breakdowns. The difference in elevation between the terminals is approximately 4,500 feet; nevertheless the tram must be driven by a steam engine. Crude oil is at present employed as fuel in the operation of the hoist and the tram, but if developments warrant it electric power will be obtained from one of the hydroelectric power companies operating in Owens Valley.

Despite the considerable depth of the mine, the water level has not been reached. In the lower levels there was (in September, 1912) a slow trickling or "sweating" from the walls of the drifts.

GENERAL GEOLOGIC FEATURES.

The prevailing rock at the mine is a dense, fine-grained white marble; with this are associated some interstratified slate and a number of dikes of diorite and of monzonite porphyry which lie parallel or approximately parallel to the stratification of the inclosing beds.

The rocks in the immediate vicinity of the mine are part of a formation of Carboniferous age which is extensively developed in the surrounding area. This formation consists principally of limestone, with some interstratified shale or slate and quartzite. A belt of shale, probably 300 feet thick, lies northwest of the mine, and is underlain by fine-grained white quartzite, 100 feet thick. The strike is N. 30° W. and the dip 45° W. The shale is in places highly fossiliferous, carrying Derbya, Goniatites, pelecypods, and other forms, which fix its age as Carboniferous.

The intercalated beds of shale and quartzite prove useful horizon markers and show that faulting of a complicated character has taken place, centering particularly at the Cerro Gordo mine. If the attempt is made to trace the 100-foot quartzite member from the northwest toward the mine, it is found that near the mine the quartzite is cut out by a fault, trending northeastward. The displacement of the fault is of large and unknown magnitude, and the details are obscured by talus covering the rocks. The fault zone appears to be made up of a number of diversely oriented blocks. For example, some 600 feet north of the shaft house there is an outcrop of blue crinoidal limestones interbedded with quartzitic strata, striking east and west and dipping 50° S.; 50 feet southwest of this exposure the rocks strike N. 15° W. and dip vertically, and other similarly discrepant measurements can be obtained—facts indicating that the fault zone is probably made up of a mosaic of small blocks.

East of the mine the limestones as a rule dip eastward, the dip averaging 45° E. on Cerro Gordo Peak and flattening farther east, being practically horizontal near the Newtown mine. At this locality a remarkably fine example of a bedding fault breccia is shown. The breccia, lying between two beds of limestone, consists of long slabs of dark-gray limestone and a light-buff variety held in a matrix of very coarse white calc spar, individuals of which show cleavage surfaces 6 to 8 inches broad. The breccia is locally 4 feet thick. On the face of the cliff southwest of the Newtown shaft house a reverse fault of 10 feet displacement is well shown. The value of quartzite beds as indicators of faulting is illustrated effectively on the slopes behind the Newtown mine. Here within a length of a few hundred feet the rocks are intersected by four faults, marked by fault breccias, with displacements, as measured on the interstratified beds of quartzite, that range from a few feet to 75 feet. One of these fault breccias carries numerous fragments of gossany iron oxide.

The examination of the geologic structure around Cerro Gordo therefore shows that the rocks have been subjected to severe faulting. Some of this faulting took place prior to the formation of the ore bodies and some after the ore bodies had been formed, but the post-mineral faults are probably of much smaller magnitude than those of premineral origin. Underground examination in the Cerro Gordo mine is confirmatory of the facts shown by the study of the surface geology, for many faults are exposed in the workings. The correct elucidation of the faulting may prove to be a matter of highest practical importance, for a possibility exists that valuable ore bodies may have been cut off by faults and that the faulted segments were not found by the former operators. In working out the character and amount of displacement along the faults, the diorite porphyry and other dikes should prove of great help.

Northwest of Cerro Gordo monzonite porphyry forms a small mass intrusive into the surrounding shale. The porphyry is characterized by an abundance of feldspar phenocrysts and hornblende prisms, the phenocrysts being in certain parts of the mass so closely crowded as to give the rock a granitic appearance. The specimen examined microscopically was found to show essentially these features: Plagioclase ($Ab_{62}An_{38}$) forms the predominant phenocryst and is associated with phenocrysts of orthoclase and hornblende; the porphyritic constituents are inclosed in a groundmass composed of orthoclase and quartz and forming but a small proportion of the whole rock. Titanite, which is rather abundant, apatite, and magnetite are the accessory minerals.

This intrusive mass of monzonite porphyry is in all probability an unroofed upward extension of the granitic mass that underlies the whole Inyo Range at no great depth. Although along the crest granite is not encountered for a distance of 10 miles north of Cerro Gordo, yet toward the east, where the range drops off abruptly toward Saline Valley, 7,000 feet below, great quantities of granitic rock are exposed. Furthermore, masses of garnetized limestone occur at several mines and prospects west and southwest of Cerro Gordo, as at the Ignacio, Ventura, and others—a fact which indicates that the rocks at Cerro Gordo at the time of the intrusion of a granitic mass, now unexposed, were situated near the outermost limit of the zone of metamorphism produced by the invasion.

In the mine occur dikes which appear to have been originally similar to the monzonite porphyry northwest of Cerro Gordo. They have, however, been altered by three distinct kinds of metamorphism, successively applied—(1) alteration by shearing, (2) alteration accompanying the primary mineralization, and (3) alteration by oxidation and by the downward percolation of sulphate solutions. Any one of the alterations produced by these processes might be sufficient to obliterate the original features of the dikes; it follows, therefore,

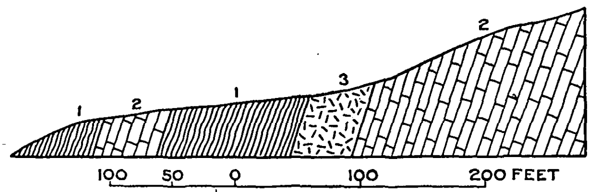


FIGURE 7.—Diagrammatic section along the line of the Union tunnel, Cerro Gordo, Cal. 1, Slate; 2, marble; 3, monzonite porphyry.

that the precise identification of some of these rocks is impossible; in fact, certain narrow dikes, which are considerably sheared, are difficult to distinguish from slate.

One of the most prominent dikes in the mine is that cut in the Union tunnel, in the footwall crosscut of the Santa Maria pit, where it is 50 feet wide, and in the Zero level. The dike apparently conforms in the main with the strike and dip of the bedding of the inclosing rocks. (See fig. 7.) In the Union tunnel, however, the contacts are much shattered. The west contact strikes N. 15° W. and the east contact N. 35° W., both being nearly vertical. The dike is overlain by a shale belt 105 feet wide and is underlain by massive white marble. In the Zero level, which is several hundred feet south of the Union tunnel, the dike lies within the shale belt and therefore probably cuts across the trend of the formation at a narrow angle. The dike is of conspicuously porphyritic appearance, owing to the prevalence of large tabular feldspar crystals; it is considerably sheared and is deeply stained by oxides of iron and manganese. Specimens from this dike are unsuitable for precise determination; some material from the 400-foot level, taken near the intersection by the San Felipe quartz vein, was found to be a porphyry much altered by carbonatization.

Other dikes differing considerably from the monzonite porphyry were noted in the underground workings. They range in different dikes from 4 to 25 feet in thickness; on the 900-foot level one of these dikes was found to be intrusive into the monzonite porphyry. They are gray, fine-grained granular diorites carrying numerous small black prisms of hornblende; a characteristic feature is the presence of corroded phenocrysts of quartz, although these are rare and widely scattered. One of the best-preserved dikes is that shown on the 400-foot level, 200 feet north of the shaft. Under the microscope, however, even this proved to be highly altered and to consist of epidote, chlorite, feldspar, and sericite.

LEAD ORE BODIES.

The lead ore bodies of Cerro Gordo consist of lenticular masses distributed through a zone 2,000 feet long and several hundred feet wide. The predominant rock of the ore-bearing zone is a white, finely saccharoidal marble, essentially a pure calcite rock, which on freshly fractured surfaces shows a slight bluish tint. Slate and igneous rock—the dikes of diorite and porphyry—as already described, occur also within the ore-bearing zone, but the ore bodies are inclosed principally in the marble. Certain important ore bodies, however, rested on a footwall of slate, as, for example, that taken out from the Santa Maria pit.

The rocks of the ore-bearing zone strike in a north to northwesterly direction and dip on the average 70° SW.; the ore bodies conform to the trend of the inclosing rocks. To cite an example, the Jefferson stope—the stope farthest southeast—strikes N. 35° W. and dips 75° SW.

The lead ore bodies formerly worked attained thicknesses of 40 feet. The Jefferson stope is from 3 to 20 feet wide and averaged 70 feet in length; the Union stope, from which $3,000,000 worth of silver and lead is supposed to have been extracted, extended down to the 550-foot level. According to Raymond[1]—

> The Union, the highest on the mountain side, has undergone considerable development during the past year. On the surface the ore body strikes about S. 30° E. and dips steeply to the southwest, but at the level of the main working tunnel, which strikes the Union at a depth of about 175 feet from the surface, the ore body begins to stand nearly perpendicularly and continues so for a depth below this level of 165 feet, the lowest point reached in September, 1872. At a depth of 200 feet below the tunnel a branch leaves the main ore body toward the west. Its dip is very flat, and it has been followed over 100 feet, always in very excellent ore, the greater part of which is galena. This

[1] Raymond, R. W., Statistics of mines and mining in the States and Territories west of the Rocky Mountains, 1873, pp. 18–19.

branch is about 3 feet thick. It is thought and hoped by the owners of the Union that it will eventually run into the Santa Maria, and as the Union has the older title the independent existence of the Santa Maria would in that case be endangered. The longest level on the vein in the whole mine is the one driven at a depth of 200 feet below the tunnel, and even this one is little over 100 feet long. But the ore deposit, as developed by this level and the work done in the 65 feet below, is of extraordinary extent, being in many places 40 feet wide and nowhere less than 15. At the same time the ore is very solid, being either reddish-yellow carbonate or pure gray carbonate, lying in great blodges in the former. The masses of the latter kind have frequently a diameter of from 3 to 6 feet and always show a concentric arrangement—that is, every mass of this kind which has been cut through by the excavations shows concentric rings around an interior nucleus (generally a small lump of unaltered galena), the rings being somewhat darker than the main mass. This arrangement presents a beautiful aspect and, though common with gray carbonate of lead when lying in a ferruginous gangue, it is not often seen on as large a scale as exposed in the Union. The carbonate ores of the Union, on account of their friability termed "fuse ores" by the miners, average, as delivered to the furnace, about 25 ounces of silver per ton, and the galena from 50 to 80 ounces.

During 1912 lead ore was being mined on the 700-foot level, where it formed a shoot as much as 5 feet wide. It consisted largely of galena, though considerably oxidized, so that cerusite was common, forming a yellowish ocher mixed with anglesite. A small quantity of chrysocolla occurred here also; in fact, chrysocolla is persistent throughout the mine, though nowhere abundant. Linarite, the deep azure-blue double sulphate of lead and copper, and brochantite, a basic sulphate of copper, are found here occasionally. The massive galena contains a small amount of dark-brown or black sphalerite—a fact of great importance in connection with the origin of the zinc carbonate ore.

A shoot of lead ore recently uncovered at the surface, averaging 1 foot or so in width, consists predominantly of galena but contains also some tetrahedrite, sphalerite, and pyrite. The galena has a distinct sheared structure, which is circumfluent around the sphalerite and tetrahedrite. This structure was evidently produced by the crushing of galena into small flat lenticles lying in parallel orientation. Oxidation products, among which bindheimite was the most notable, occur to a small extent associated with the primary lead ore, though not so abundantly as on the 700-foot level. Completeness of oxidation at Cerro Gordo was obviously not determined wholly by depth but was dependent largely on the perviousness of individual ore shoots to oxidizing solutions. Adjoining the lead ore is several feet of zinc carbonate that has replaced the marble wall rock.

The predominant primary mineral in the ore bodies of Cerro Gordo is galena; as minor constituents occur sphalerite, tetrahedrite, and pyrite. By oxidation a multitude of secondary minerals have formed—cerusite, anglesite, bindheimite, smithsonite, calamine, hydrozincite, aurichalcite, chrysocolla, linarite, brochantite, caledonite, limonite, and others. Cerusite and smithsonite are of economic importance; the others are of mineralogic interest only. Linarite deserves mention because of its striking beauty, and Cerro Gordo is in fact a locality well known for this rare mineral; aurichalcite, another comparatively rare mineral, is also noteworthy because it occurs locally in some abundance as small veinlets traversing zinciferous limonite; it is of delicate blue and bluish-green color, though fading on continued exposure to light, and characteristically forms rosettes and fanlike groups of pearly luster.

SAN FELIPE VEIN.

The San Felipe vein cuts diagonally across the silver-lead ore-bearing zone, trending N. 45° W. and dipping 70°–80° SW. It traverses both marble and porphyry and ranges from a fraction of an inch to 18 inches in thickness. The main ore mineral noted is tetrahedrite, with its oxidation products, azurite and malachite, inclosed in a gangue of barite and quartz. The ore is said to carry $100 a ton in silver.

ZINC ORE BODIES.

Occurrence and character.—The zinc ore forms irregular masses and pipes occurring in the limestone walls of the old lead stopes, principally in the footwall. The form of the ore bodies is determined partly by structural features, such as stratification, jointing, and the fracturing that took place after the formation of the lead ore masses. The zinc ore is frozen tightly to the limestone, but there is no gradation between them, although the ore originated clearly by replacement of the limestone.

The first zinc ore taken out was that found in the footwall of the old Union stope; from this 5,000 tons were extracted. On the 400-foot level a pipe 5 feet in dameter and 150 feet long was discovered that averaged more than 40 per cent in metallic zinc. As the zinc mineral in the ore is mainly smithsonite, whose theoretic percentage of zinc is 52, the ore is very pure; considerable quantities have actually contained as much as 50 per cent. The pipe headed toward the Union stope, and with increasing proximity to the old stope there was a notable increase in limonite and kaolin. Near the head of the pipe extensive masses of limonite, including bodies of pure white kaolin as much as 4 feet in thickness, were found. The same phenomenon occurs throughout the mine; the zinc ore becomes, by progressive disappearance of the iron, increasingly purer with increasing distance from the old lead ore bodies. Bodies of zinc ore extend in places at least 100 feet laterally from the lead ore.

The zinc ore consists essentially of the carbonate smithsonite; the impurities with it are limonite and calcite. The ore is of fine-grained texture and dead-white color and hence is known as "dry bone." It is characteristically laminated; the laminæ range from nearly imperceptible thickness to one-half inch and are curiously convoluted, the convolutions being governed by no discernible law. Vugs are common, and are lined with crystalline smithsonite and calamine. Calamine also occurs to some extent in the form of laminæ, and these show a radial fibrous structure. Hydrozincite occurs rarely, chiefly as small botryoidal groups implanted on crystalline smithsonite.

The ore as shipped averages 35 per cent of zinc, the gangue consisting of calcium carbonate and hydrated iron oxide. The ore carries neither silver nor gold. The total production of zinc ore to January 1, 1913, was 10,000 tons.

Origin.—The primary ore bodies as a rule have undergone extensive oxidation. During this process sulphates of lead, zinc, iron, and copper were formed, together with sulphuric acid, which, acting on shale or porphyry, took alumina and silica into solution. The lead sulphate, being insoluble, remained in place and was later transformed into cerusite; the copper also did not travel far, but was precipitated as chrysocolla or as a basic sulphate. Thus in the first stage the zinc and iron were separated from the other metals and, being contained in a solution acting under the influence of gravity, naturally tended to sink into the footwall of the lead ore bodies. Here the solution came into contact with the calcitic wall rock and a further separation took place. The free sulphuric acid present was immediately neutralized and the ferric iron was precipitated as hydroxide according to the equation—

$$Fe_2(SO_4)_3+3CaCO_3+3H_2O=2Fe(OH)_3+3CaSO_4+3CO_2.$$

This reaction has been studied by Meigen, who finds that ferric iron is, even at 15° C., rapidly and completely precipitated as hydroxide from its solutions by calcite.[1] He finds further that ferrous iron and zinc are precipitated more slowly. According, then, to the extent that the iron contained in the solution was in the ferric state, the zinc, which is later precipitated as carbonate, will be proportionately free from iron.

At Cerro Gordo the zinc ore is as a rule remarkably free from iron, indicating, as one possibility, that the iron in the downward-percolating solutions was mainly in the ferric condition. This would be so, if during oxidation there had been available an excess of

[1] Meigen, W., Beiträge zur Kenntnis des Kohlensauren Kalkes: Ber. Naturforsch. Gesell. Freiburg i. Br., vol. 13, 1903, p. 76.

oxygen—a condition likely to arise, among others, owing to the comparatively small amount of pyrite that underwent oxidation in the primary deposits.

After the precipitation of the ferric iron the ferrous iron and the zinc would be precipitated as carbonates. At Wiesloch, Baden, for example, ferrous carbonate is mingled with zinc carbonate in all proportions up to 50 per cent, although the main ore bodies are relatively pure zinc carbonate.[1] By subsequent oxidation the ferrous carbonate may be converted to limonite, and in this way iron-stained zinc carbonate ores would be produced. The separation of the zinc from ferrous iron would be determined by two factors—the concentration of the solutions in zinc and ferrous iron and the relative precipitability of the carbonates of zinc and ferrous iron. The solubility of zinc carbonates and of ferrous carbonate, measured in gram-equivalents per liter,[2] is respectively 1.7×10^{-4} and 6.2×10^{-5}. From these figures it can be inferred that the iron is more easily precipitable and that this favors the segregation of the zinc from the iron. When, however, the concentration of the zinc becomes high relatively to the iron, both metals must come down together. No experimental data are available concerning the fractional precipitation of a mixture of sulphates of zinc and ferrous iron by means of calcium carbonate, but the geologic evidence seems to show that the fractionation as carried out in nature is very complete, provided, as already pointed out, that the thorough separation of the zinc and iron is not due to the previous complete precipitation of the iron as ferric hydroxide.

One of the most striking features of the ore deposits of Cerro Gordo is the localization of the zinc as carbonate in high-grade bodies in comparison with the small proportion of zinc blende contained in the primary ore. The zinc carbonate, as shown in the preceding paragraphs, was derived from the blende by a process involving oxidation, solution, migration, and precipitation; nevertheless the proportion of blende in the unoxidized lead ore now encountered in the mine is extremely small, ranging perhaps from 1 to 2 per cent. The lead ore bodies formerly worked may have been more highly sphalerite-bearing than any ore now visible, but this seems unlikely because in no account hitherto published concerning Cerro Gordo is the presence of sphalerite recorded. It is believed, therefore, that the primary ore found now is an index of the primary ore occurring formerly in the mine. In the shoot of primary ore recently uncovered at the surface the galena contains only a small quantity of sphalerite; nevertheless the galena is bordered by a layer of smithsonite several feet thick. From a consideration of the foregoing

[1] Schmidt, A., Die Zinkerz-Lagerstätten von Wiesloch, Baden: Verhandl. Naturh.-Med. Ver zu Heidelberg, neue Folge, vol. 2, 1880, p. 399.

[2] Data supplied by R. C. Wells, U. S. Geological Survey.

facts it would appear that the zinc, sparsely distributed throughout the primary lead ore, was effectively segregated and concentrated to a remarkable extent during the formation of the secondary ore.

PRACTICAL DEDUCTIONS.

Some deductions of practical importance follow almost obviously from a recognition of the principles governing the formation and origin of the zinc carbonate ore bodies. Certain of these deductions had been recognized at Cerro Gordo as criteria for the search for undiscovered bodies of ore, although the theoretic foundations on which they were based were not known. These deductions are, stated summarily:

1. The zinc carbonate bodies can occur only in the marble, most likely in the footwall zones of primary lead ore deposits. The largest zinc deposits will therefore be found most probably in the footwall country rock of the old lead stopes.

2. Zinc ore is especially likely to occur below bodies of hydrated iron oxide situated along the periphery of the primary ore masses—the iron oxide bodies marking the heads of the channels along which the sulphate solutions commenced to migrate into the limestone wall rock. The zinc ore will not necessarily be situated vertically below these masses of iron oxide but may occur diagonally or otherwise as governed by the structural features of the wall rock.

3. Conversely, bodies of lead ore, if not already mined out, may be found on the upward extension of zinc ore deposits, above the iron oxide masses.

4. Zinc ore is likely to be found as far down as the downward limit of the zone of oxidation, the bottom of which has not yet been reached.

The discovery of zinc carbonate ore at Cerro Gordo is another striking illustration of what has been happening in recent years at many of the other silver-lead mining camps in the Western States. Oxidized zinc ores were formerly unsought or were thrown over the dumps unrecognized; only in recent years have they been recognized or their value appreciated. At Leadville the zinc carbonate ores were long unrecognized, but Leadville is now the largest producer of oxidized zinc ore in Colorado; in the Kelly or Magdalena district, in New Mexico, the zinc carbonate ores were long unrecognized, but the Kelly district is now the largest producer of zinc ore in New Mexico; Yellow Pine illustrates the same fact for Nevada; Cerro Gordo illustrates it for California; and according to recent report the abundance of zinc ore in the old stopes at Tintic, Utah, is proving a surprise to the operators there.

These facts render it highly probable that other valuable deposits of zinc carbonate will be discovered in association with galena ore bodies inclosed in limestone, which were formerly worked for their lead and silver. As shown by the occurrence of zinc ore at Cerro Gordo, a fact pointed out in the discussion of the origin of the ore (pp. 106–108), the primary ore bodies need not have contained a large proportion of sphalerite in order to have given rise to commercially important deposits of zinc carbonate.

LEAD-SILVER ORES.

GENERAL CHARACTER.

Argentiferous galena ores occur at a number of localities scattered throughout the region, but only at Cerro Gordo and vicinity has there been a notable production. The ore bodies form irregular lenticular masses inclosed, as a rule, in limestone country rock; in fact, the important productive ore bodies are all inclosed in rock of that kind. Oxidation has partly altered the galena to the carbonate cerusite, and if the ore originally contained zinc blende, the possibility exists that bodies of zinc carbonate ore were formed during the process of alteration, as already discussed in detail under the description of the Cerro Gordo mine.

MINES AND PROSPECTS.

GIBRALTAR PROSPECT.

The Gibraltar prospect is situated 3 miles north of Antelope Spring, in Deep Spring Valley. The prospect was located in 1886, and it is stated that a number of years ago 10 tons of ore was sent to the Selbey smelter; this ore carried $34 to the ton in lead and silver. The country rock at the prospect is a tremolite-bearing white fine-grained marble. The lode trends N. 85° E. and stands vertical. The large open cut on the property exposes a zone about 4 feet wide carrying the small irregular stringers of ore; and 100 feet above is a short tunnel in which the lode ranges from 6 inches to 1 foot in thickness. The ore consists of galena, sphalerite, and tetrahedrite. The oxidized ore shows a little azurite stain, but this is exceedingly rare.

MONTEZUMA MINE.

The Montezuma Mining & Smelting Co.'s property lies near the foot of the White Mountains, 9 miles by road southeast of Big Pine. The Montezuma is one of the old mines of the region and is described in the report of the Director of the Mint for 1883. At that time there was exposed at or near the surface a large amount of argentiferous galena lying almost horizontal. The ore contained 30 ounces of silver to the ton and 38 per cent of lead. A smelter had been built on the railroad at Elna and the ore was hauled there for treatment. This smelter has since been abandoned. It was found later that the ore is difficult to treat on account of its low grade and considerable admixture of zinc blende. The mine was idle during 1912.

Buff-weathering and gray-weathering limestones of dense texture, which on fresh fracture are white with a bluish cast, constitute the prevailing country rock in the vicinity of the upper tunnel. As seen within the tunnel the rocks are intensely shattered and broken, and in one drift a porphyry dike, which seems to have been originally a diorite porphyry, was, because of the intensity of dynamic disturbance, kneaded to a putty-like mass and powerfully slickensided. The ore seen on the dump carries finely disseminated galena, sphalerite, and pyrite, together with a few coarse particles of tetrahedrite; the galena and sphalerite occur in approximately equal amounts and are in part intimately intergrown. The gangue in which these minerals are inclosed consists largely of dolomite with which some quartz is associated. The oxidized ore shows azurite, lead carbonate, and iron oxide.

ESTELLE MINING CO.'S CLAIMS.

The Estelle Mining Co., organized in August, 1902, owns 29 claims situated south and southwest of the Cerro Gordo mine. During the last four years the energies of the company have been devoted to driving a crosscut tunnel, now 4,400 feet long, with the intention of undercutting the iron oxide cropping on the Morning Star claim, which is situated 1,700 feet above the portal of the tunnel. The tunnel, known as the Dellaphene, intersects Carboniferous rocks consisting mainly of limestones. A considerable number of fault zones have been encountered, the most extensive being 200 feet in width. At 3,750 feet from the portal drifts have been turned off both north and south for several hundred feet along one of these fault zones. This fault zone is traversed by a number of quartz veins of irregular size and description. Locally the quartz contains tetrahedrite, galena, sphalerite, and pyrite in amounts in the order named. The ore is said to carry 20 ounces to the ton in silver. The outcrop on the Morning Star claim, which the Dellaphene tunnel is projected to undercut, is said to assay $14 in gold and 17 ounces in silver to the ton across a width of 45 feet. The developments on the Morning Star claim consist of a tunnel 420 feet long, from which a winze has been sunk 225 feet, giving a total depth of 500 feet below the apex. From this winze levels have been run at depths of 35, 70, 120, and 220 feet. A crosscut tunnel traverses what may be called the ore-bearing zone, exposing 35 feet of hydrous iron oxide and limestone, 60 feet of limestone, and then 20 feet more of limestone stained with iron oxide. The iron oxide contains a few small lumps of galena.

MONSTER MINE.

The Monster mine, discovered in 1907, is situated on the east flank of the Inyo Range northwest of Saline Valley. It is reached either by a trail over the summit of the mountains from Mazourka Canyon or by the Saline Valley road from Alvord. The principal developments consist of two tunnels and a number of open cuts.

The general country rock consists of a stratified series of limestones, probably of Ordovician age, striking N. 75° E. and dipping steeply to the north. Several hundred yards south of the mine occur dark knotted schists, representing thermally metamorphosed argillaceous sediments, intruded by granite.

The ore body at the point of discovery was an irregular lens of nearly solid galena 3½ feet wide and approximately 40 feet long. The general trend of the body of ore as seen in the upper tunnel, which is 75 feet long, is northwest. The galena has been nearly completely removed, but at the far end of the tunnel some galena remains embedded in quartz veinlets reticulating through the limestone. The ore makes in bunches in the limestone but is everywhere associated with quartz, although the galena tends to segregate and form pure masses. A new tunnel was driven below the upper tunnel and is approximately 150 feet long, but not much ore was encountered in it. At the portal of the lower tunnel the country rock is a mottled blackish limestone transfixed by tremolite fibers; the rock is coarsely brecciated throughout the length of the tunnel. The limestone in the ore-bearing zone is a buff-weathering variety which is white with a slight yellowish cast on fresh fracture; it is severely brecciated.

The ore seen on the dumps consists almost entirely of galena. It contains a very subordinate proportion of pyrite and even less tetrahedrite, which is to be found only on close search; no sphalerite or other zinc mineral was noted. The oxidized ore consists largely of cerusite, in places finely crystallized, but shows also a little chrysocolla and blue and green basic sulphates of lead and copper—linarite and caledonite.

The ore was taken on pack animals over the Inyo Mountains to Mazourka Canyon, where it was hauled by team to the railroad at Citrus. It was carefully sorted and is reported to have carried $100 a ton in silver and lead. The property was not worked in 1912.

GOLD ORES.

GENERAL CHARACTER AND OCCURRENCE.

The gold deposits of the Inyo and White mountains are mainly small, narrow quartz veins. The greatest depth attained on any of the veins, so far as known to the writer, is 300 feet. The surface ores are thoroughly oxidized and are of comparatively high grade, ranging from a few dollars up to $100 a ton. The mineralogic features are simple; the primary ores carry a small amount of sulphides, commonly pyrite or galena, with subordinate sphalerite and chalcopyrite, inclosed in a coarse white quart gangue. Primary barite was noted in one ore.

The veins occur either in the borders of the granite intrusions or in the surrounding country rock at no great distance from the granite This is so uniformly true that it suggests strongly a genetic connection between the veins and the granite.

A large number of veins have been found and developed, have contributed their quota to the output of the region, and are now exhausted. During 1912 opportunities were not favorable for the study of this class of deposits; consequently a more extended treatment of them here is not advisable, and the details concerning the mines and prospects that were accessible must be sought under the special descriptions.

Many of the deposits were discovered by Mexicans in the sixties and worked by means of arrastres during the succeeding decades. The most important gold-producing area was probably the Beveridge district, on the summit of the Inyo Mountains northeast of Lone Pine. The Keynote, situated at an altitude of 10,000 feet at a point accessible only by a mule trail, was the most productive mine; for a time its output exceeded $10,000 a month.[1] Much ore was taken out from other mines, but records of production are not available.

As a whole the veins have not, however, given rise to a steady gold-quartz mining industry, and during 1912 the exploitation of this kind of ore was nearly at a standstill. The Reward, the largest gold-quartz mine in the range, was idle during the year, pending change of ownership.

Placers, especially those of Mazourka Canyon, were formerly of some importance.[2] The gold was separated by passing the gravel through dry washers. The best ground has been exhausted, and in 1912 a few men working on the rims of the auriferous channels and at the heads of the gullies were able to make only bare wages by dry washing.

MINES AND PROSPECTS.

GOLDEN SIREN PROSPECT.

The Golden Siren prospect is situated in the White Mountains at an altitude of 10,500 feet, near the head of North Fork of Crooked Creek. The main shaft is reported to be 90 feet deep, intersecting

[1] Rept. Director of the Mint upon the production of the precious metals in the United States for the calendar year 1883, 1884, p. 159.

[2] Thirteenth Ann. Rept. California State Mineralogist, 1896, p. 182.

the vein at 45 feet. The country rock is a white marble of Cambrian age, which is intruded by the granite outcropping a few hundred feet east of the shaft. The ore is of two kinds—quartz and iron oxide. The vein sampled over a width of 5 feet is said to average from $14 to $18 a ton in gold.

BLIZZARD EXTENSION PROSPECT.

The Blizzard Extension prospect, which is a scant 3 miles south of the Golden Siren, is situated on the north flank of Mount Blanco at an altitude of 10,800 feet. The developments consist of an incline and a few small open cuts; the incline is 60 feet long, and a drift, 26 feet long, was driven at a depth of 45 feet. The geologic features are essentially like those at the Golden Siren. The country rock is a white marble of Cambrian age, and a large mass of intrusive granite lies a few hundred yards north of the property. The vein strikes N. 80° E. and dips steeply south. It consists, as seen at the surface, of 3 to 6 inches of quartz carrying oxidized sulphides, but it is said to be 2 feet wide in the drift and to average $13 a ton in gold. On the dump considerable gossany iron oxide has accumulated; much of this material was doubtless formed by the reaction of iron-bearing solutions (derived from the oxidation of the primary sulphides originally inclosed in the quartz) on the limstone wall rocks.

During 1912 a road 5 miles long was being constructed to Roberts's ranch, on Wyman Creek, at an altitude of 8,200 feet. Here a small stamp-milling outfit, to be driven by an overshot wheel, was being installed.

WATERFALL PROSPECT.

The geologic features at the Waterfall prospect are unlike those seen anywhere else in the White and Inyo mountains. This prospect, located in 1906, is situated at an altitude of 7,400 feet, 3 miles north of Antelope Spring, in Deep Spring Valley. The general limestone country rock lies within the zone of contact metamorphism of the near-by intrusive mass of granite, and as a result has been considerably altered, chiefly by marmarization and the development of tremolite and other minerals. The gold-bearing deposit, as shown by open-cut workings, consists of a belt of tremolitic white marble traversed by fluoritic veinlets. The fluorite is of pronounced purple color and imparts to the gold ore an unusual and striking appearance. The veinlets range from a fraction of an inch to several inches in thickness. The larger veinlets are quartzose and contain coarse orthoclase, muscovite, and fluorite, and are therefore pegmatitic in composition and appearance. The belt or zone traversed by these veinlets trends north and south and is between 10 and 20 feet thick. The hanging wall is a stratum of black micaceous hornfels. The purple fluoritic ore is said to assay $18 a ton in gold. Neither gold nor other metallic mineral is visible, except rare specks of pyrite. The proportion of fluoritic veinlets to the whole mass of limestone traversed by them is small, and at one point only are the veinlets possibly numerous enough to bring the whole mass up to ore grade.

GRAY EAGLE PROSPECT.

The Gray Eagle prospect is situated on the south side of Redding Canyon, on the west flank of the White Mountains, at an altitude of 7,000 feet. The vein, which occurs at the contact of the granite and limestone, lies nearly horizontal and has a maximum thickness of 8 inches. The quartz carries considerable iron oxide; the sulphide ore shows some chalcopyrite and pyrite associated with iron oxide in a quartz gangue. At the immediate contact a small mass of oxidized ore was found carrying some galena. In the underground workings massive garnet rock is found at the contact, and also rock showing columnar epidote several inches long. These contact rocks are traversed by small quartz stringers carrying a minor quantity of chalcopyrite.

GOLDEN MIRAGE PROSPECT.

The Golden Mirage prospect lies west of the Gray Eagle at an altitude of 6,450 feet. It comprises a number of workings opened on a quartz vein inclosed in the granite. At the lower open cut is shown 2½ feet of solid milk-white quartz, and the vein is seen to strike N. 20° E. and to dip 40° E. Leached cavities in the quartz indicate the presence of former sulphides, which consisted principally of large cubic crystals of iron pyrite. The vein is irregular in thickness; 2½ feet is the maximum and 1 foot is probably a generous average. The gold content is spotted and is generally highest in the honeycombed rock; it is reported to average perhaps $5 a ton for the whole vein.

X-RAY MINE.

The X-Ray mine is an old property, having been worked by the Mexicans in the sixties. The present owners obtained it by relocation after its abandonment by the former owners. This mine is situated on the west side of Redding Canyon, near the Gray Eagle and Golden Mirage prospects, all of which are now under the same ownership. The vein is inclosed in granite and on the south end, which is near the contact of granite and sandstone, ranges from a fraction of an inch to 8 inches in thickness. In the incline driven on the vein it dips 16° N. and trends N. 70° E. Toward the north end the vein is as much as 1 foot thick, but 3 inches is probably the average thickness. The walls are well defined. In view of its narrowness, the vein is remarkably persistent and continuous. The shoot of ore on the south end is said to be nearly 600 feet long. During 1912 five carloads of ore were shipped from this and the other two claims under the same ownership.

EUREKA MINE.

The Eureka mine is situated on the east side of Owens Valley at the foot of the Inyo Mountains, 9 miles northeast of Independence. The California & Nevada Railroad (Southern Pacific system) passes the mine. The property consists of four patented claims, which were located in 1862, the year following the Kearsarge Pass mining excitement. About 1864 a 20-stamp mill was erected on Owens River, which flows near the property; the river was dammed and a water wheel set up, but within a year the mill burned down. The settlement that sprang up here was known as Chrysopolis, but it has long been obliterated.

The principal developments at the Eureka mine consist of a shaft and a tunnel undercutting the deposit at a depth of 100 feet. The prevailing country rock is a fairly coarse hornblende-biotite granite, which is intersected by a number of dikes of dark fine-grained diorite porphyry. These dikes as a rule are highly schistose, whereas the granite is massive. The dike intersected in the tunnel is 15 feet wide; it is roughly schistose and the inclosing granite is somewhat sheared along the contacts. The dikes in general consist of black fine-grained rock which, owing to the presence of small white feldspars, exhibit an obscure porphyritic texture. Under the microscope the porphyritic feldspars are found to consist of plagioclase and the groundmass to be made up of a fine intergrowth of feldspar, finely flaked biotite, and sericite. A specimen of granite, or, more precisely, quartz monzonite, taken from the bottom of the winze at a depth of 140 feet, was determined microscopically to be composed of plagioclase, microcline, quartz, and biotite, with which are associated considerable secondary epidote and calcite.

The ore body consists of a mass of granite interlaced with quartz stringers lying between two dikes of diorite porphyry, which converge at a narrow angle toward the south. The surface ore is highly oxidized, containing much red and brown iron oxide and showing in places some blue copper silicate, chrysocolla. Coarse gold is not uncommon and is readily panned from the oxidized ore. The ore is sorted and shipped to the smelter; recent shipments are reported to have averaged $77 a ton in gold.

On the present small scale of working necessarily the richer ore alone is taken out. Single stringers are followed, and because of their irregular and discontinuous character this makes mining expensive. Investigations with a view to determining the practicability of mining the whole mass of granite and its included quartz stringers are reported to have been undertaken.

BLACK EAGLE MINE.

The Black Eagle mine is situated on the west flank of the Inyo Mountains at an altitude of 8,300 feet, 4 miles in an air line east of Citrus. The developments consist of a shaft 310 feet deep and a number of levels. The ore body is a narrow quartz vein situated at the contact of granite and limestone but is inclosed principally in the granite. The vein trends N. 70° E. and dips nearly vertical but with a slight inclination to the south. On the third level the total length is 400 feet.

The vein material is quartzose, though carrying a little barite intergrown with the quartz and undoubtedly of primary origin; pyrite is the only sulphide noted and its oxidation has given rise to earthy hematite, limonite, and ferruginous jasper. The ore is usually of high grade; by sorting, a product can be obtained that carries $100 a ton in gold. During the operation of the mine the ore was packed on mules at a cost of $4 a ton to a small steam-driven stamp mill at Willow Springs, 2,800 feet lower down on the flank of the range.

REWARD AND BROWN MONSTER MINES.

The Reward and Brown Monster mines, usually spoken of together as the Reward mine, are the property of the Reward Consolidated Gold Mining Co. The Brown Monster was formerly known as the Eclipse, and the Eclipse mill of six stamps was built in 1870. After change of ownership a 30-stamp mill was erected, which was driven by water power generated by water diverted from Owens River. The mill is reported to have produced $200,000, when the property became involved and was sold under an execution.[1] Subsequently this mill was dismantled and the present mill of 20 stamps was built, situated near the mine openings and connected with them by a gravity tram.

In 1911 the mine and plant were overhauled and an electric transmission line 4½ miles long was constructed across Owens Valley to furnish power. After a short run the mine was closed in the spring of 1912, pending change of ownership.

The Reward mine is favorably situated, being on the east side of Owens Valley and less than 2 miles from Manzanar station on the California & Nevada Railroad.

The working tunnel of the Reward mine, which opens on Reward Gulch, intersects the vein at 750 feet from the portal; from the inter-

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[1] Rept. Director of the Mint upon the production of the precious metals in the United States during the calendar year 1883, 1884, p. 160.

section a level, known as the seventh, follows the vein for a distance of 300 feet. Above the seventh level, which is the lowermost in the mine, are six others, ranging from 300 to 500 feet in length. The workings on the Reward vein are all on the south side of Reward Gulch; those on the Brown Monster vein are on the north side and a short tunnel has been driven to connect them with the main working tunnel of the Reward mine. The Brown Monster vein is developed by an incline on the vein several hundred feet long and by several short drifts to the north.

The country rock in the vicinity of the Reward mine consists of a stratified series of limestones of Carboniferous age; to the southwest of the mine Triassic rocks appear, forming the low hills projecting through the alluvium of Owens Valley. The strata strike in a generally northwesterly direction, but as they have been intensely folded the dips are extremely variable. The folded structure is displayed in diagrammatic perfection on the north side of Reward Gulch; in the bottom of the gulch the strata stand vertically, but near the level of the Brown Monster outcrop they are sharply bent and dip west at an angle of a few degrees.

A few hundred yards east of the mine, at an altitude of 5,000 feet, is exposed intrusive diorite which is part of the great granitic mass making up the western flank of the Inyo Mountains for a considerable distance northward from this locality. In consequence of the intrusion the limestones in the vicinity of the mine have been considerably metmorphosed and are either tremolite-bearing marbles or dense-textured lime-silicate hornstones. Dikes and sills have been injected, one of which is particularly noteworthy because, being easily traceable on the surface, it furnishes an index of the character and amount of the faulting that the Reward vein has undergone; this sill is 10 feet thick and is approximately 50 feet above the vein. A limestone bed 1 foot thick, lying above the diorite sill, has as a result of metamorphism been recrystallized to a coarse-grained aggregate of diopside, tremolite, and calcite.

The Reward vein is approximately conformable to the bedding of the inclosing rocks. The hanging wall, as seen above the outcrop, is a stratum of dark-blue siliceous limestone 5 feet thick; locally it is considerably brecciated. The outcrop of the vein can be traced for a distance of 400 feet south of the gulch; here the vein forks and the branches pinch out abruptly. Near the surface the vein lies nearly flat, but as measured at the face of the lowermost drift it dips 40° NE.; the strike here is N. 40° W. The vein swells and pinches abruptly, ranging from a few inches to 10 feet in thickness; the average thickness is 4 feet.

The ore is a coarse white quartz generally devoid of sulphides. On some of the levels the Reward vein shows large solid bunches of coarsely crystalline galena; other sulphides noted were pyrite, chalcopyrite, and sphalerite, but these are extremely rare, and the total quantity of sulphides constitutes a small fraction of 1 per cent of the ore. Oxidation products occur to some extent—limonite, ferruginous jasper, chrysocolla, cerusite, anglesite, the deep azure-blue linarite, and the bluish-green caledonite, the last two of which are rare basic sulphates of lead and copper.

The Brown Monster vein can be traced more or less continuously for a distance of 1,000 feet northwestward from Reward Gulch. In the underground workings the vein displays the same general features that it shows along the outcrop; in places it is a solid and well-defined quartz vein and in others it is mixed with country rock. In the upper levels the vein dips 25° E., but in depth it steepens and near the bottom of the incline the dip increases abruptly to 50°. The vertical depth attained on the vein is 200 feet.

The ore is a quartz practically barren of sulphides. Locally the quartz carries blebs of pyrite and, rarely, chalcopyrite, galena, and sphalerite. Minerals resulting from the oxidation of sulphides originally present are limonite, which is by far the most abundant, calamine, chrysocolla, and wulfenite, but their amount is small. Well-formed crystals of orange-yellow wulfenite occur in vugs in the quartz at the north incline. In the face of the fifth level the secondary minerals are well shown, constituting replacement products of country rock inclosed in the vein. They comprise calamine in fine radial groups, some of which attain half an inch in diameter, hydrous iron oxides, ferruginous jasper, chrysocolla, and wulfenite.

The underground workings of the Reward and Brown Monster mines are dry and oxidation has extended down to the lowest levels, although the larger masses of sulphides, occurring on the upper levels, such as the bunches of galena in the Reward vein, have escaped alteration.

Considerable ore is exposed in the workings of the Reward mine and is stated to average $12 a ton in gold and silver.

Reward Gulch is eroded along a shear zone 40 to 50 feet wide, the crushed and broken character of the country rock being excellently shown in the main working tunnel of the Reward mine. It is therefore a matter of importance whether the Reward and Brown Monster veins are two distinct veins or are the faulted segments of a single vein displaced about 200 feet horizontally along the line of Reward Gulch. The limestone strata or groups of strata match on opposite sides of the gulch, and the diorite sill previously mentioned, which serves as a more easily recognizable indicator than the limestones, crosses the gulch without essential displacement. The powerfully slickensided country rock encountered in the Reward tunnel is therefore the product of oscillatory movement, and as a further consequence it follows that the Reward and Brown Monster veins are two distinct and independent veins. Faults along which displacement has occurred have, however, affected the veins, as shown along the outcrop of the Brown Monster vein and in the workings of the Reward vein, the dislocations ranging from 1 foot to 6 feet. The faulted blocks have been invariably downthrown on the south side. On the north side of Reward Gulch the diorite sill is cut by two faults, both of which displace the sill 15 feet vertically and produce a fault segment 20 feet long.

Several hundred feet stratigraphically above the Reward vein is a bedded quartz vein 2 feet thick; the hanging wall is limestone and the footwall is a diorite sill. The vein carries a moderate quantity of galena and some chrysocolla. In the main mass of diorite near its contact with the invaded limestone is a quartz ledge 6 inches thick carrying galena. The ore is of similar character to that of the Reward vein and is of interest as establishing the fact that the mineralization took place after the intrusion of the diorite.

BURGESS MINE.

The Burgess mine is situated on the summit of the Inyo Range at an altitude of 9,200 feet. It is reached by a trail from Mount Whitney station and by wagon road from Swansea, but supplies are usually brought in by pack train over the trail. In the mine the rocks strike N. 30° W. and dip 65° W. The vein conforms in strike and dip with the inclosing rocks. These are mainly limestones of Triassic age, and crushed specimens of ammonites are readily found in the limestones north of the shaft. Dikes of diorite porphyry are common in the vicinity of the mine.

The ore is a milky-white quartz carrying galena; by sorting, a product high in gold is obtained. The developments consist of two shallow inclines, the principal one of which was operated by a gasoline hoist. During 1912, however, the mine was idle, though it is said that the owners intend to reopen it.

COPPER ORES.

OCCURRENCE AND CHARACTER.

Cupriferous contact-metamorphic rock occurs in limestone at a number of places where the limestone abuts upon the margin of the intrusive granite west of Mazourka Canyon. In the unoxidized condition this material consists essentially of garnet carrying a small quantity of chalcopyrite, but because of the prevalent oxidation the copper is now present mainly as films and thin veinlets of chrysocolla.

On account of the small extent of garnetization and the trivial quantities of copper contained in them, most of the deposits of this type in this region are not of economic importance.

GREEN MONSTER MINE.

The most notable deposit of contact-metamorphic copper ore is that exploited at the Green Monster mine, situated 1½ miles north of Citrus. The total production of this property, it is reported, is 300 tons of 12 per cent copper ore, carrying $4.50 a ton in gold and silver. In 1912 the property changed ownership, and it was the intention of the new owners to develop it systematically. The developments so far made (1912) consist of a number of open cuts, short tunnels, and drifts.

Geologically the mine is situated at the contact of intrusive aplite and limestone that is probably of Carboniferous age. The aplite, which is a white, even-grained rock of fine texture composed of feldspar and quartz, penetrates the limestone in irregular fashion and has produced considerable metamorphism in the invaded rock, as shown by the formation of garnet masses. At the upper workings of the mine the buckled arch of an anticline is exposed; the west limb, which is the more regular, strikes N. 10° E. and dips 30° W.; the east limb stands vertical.

The copper ore occurs in the garnetized zone; it is highly oxidized, so that the facts concerning its origin and distribution are much obscured. It is associated with iron oxides and occurs in such a form that its presence must be determined by chemical means. Chrysocolla, which is found subordinately, is the only copper mineral definitely recognizable. In the outcrop there is much yellowish-green mineral, to whose prevalence the mine doubtless owes its designation. This mineral is in part earthy in texture, and in part shows a fibrous, woody structure. Some of this fibrous material was investigated chemically by W. T. Schaller and proved to be a hydrous ferric silicate analogous to chloropal.