DEPARTMENT OF THE INTERIOR

HUBERT WORK, Secretary

UNITED STATES GEOLOGICAL SURVEY

GEORGE OTIS SMITH, Director

Bulletin 762

GEOLOGY AND ORE DEPOSITS

OF THE

ROCHESTER DISTRICT, NEVADA

BY

ADOLPH KNOPF

WASHINGTON
GOVERNMENT PRINTING OFFICE
1924

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15 CENTS PER COPY

CONTENTS

ILLUSTRATIONS

PREFACE

By F. L. Ransome

The modern development of the Rochester district dates from the later part of the year 1912. Early in 1913 F. C. Schrader was detailed by the United States Geological Survey to make a reconnaissance study of the district, and his brief examination was followed by an excellent report, which was published in 1915. The continued productivity of the Rochester mines and the interesting character of the ore deposits made it evident that more detailed geologic work was desirable, and after the completion of a topographic map, in 1916, Mr. Knopf was instructed to make a geologic study of the district early in 1917. The preparation of his report, like many other investigations by the Geological Survey then in progress, was interrupted by the urgent war demand for information in regard to particular mineral resources and was further delayed by Mr. Knopf's withdrawal from full-time participation in the work of the Survey and his acceptance of a professorship at Yale University. His new duties left only a small part of his time available for the investigation that he has now satisfactorily completed.

As Mr. Knopf shows, the ore deposits of the Rochester district are mineralogically of unusual character. Dumortierite, a rare aluminum borosilicate, is in some parts of this district extraordinarily abundant and is accompanied by tourmaline and andalusite minerals, which also are rather unusual in association with silver deposits. The boron-bearing minerals were evidently formed at high temperature, and Mr. Knopf concludes that there were three distinct stages in the deposition of these minerals. The principal silver-bearing veins were probably formed later and at lower temperature. The report shows that the original vein material was of too low grade to be ore. The district owes its economic development to downward enrichment, effected largely by the replacement of sphalerite by argentite—a process that is fully discussed in its appropriate place. It follows that the silver deposits of the Rochester district are not likely to extend to great depth. The same conclusion, based apparently on the observed decrease in tenor of the ore on the deeper mine levels, finds expression also in the annual report of the Rochester Silver Corporation for 1921. Mr. Knopf has given the explanation for the observed decrease.

The following report, although it deals with only a small area, throws considerable new light on the geology of the Humboldt Range. The range has long been noted as a collecting ground for Triassic fossils, but our knowledge of the beds in which these ancient marine shells are found left much to be desired. Mr. Knopf has not only supplied some of this deficiency but has shown that the light-colored felsitic rocks of the Humboldt Range, which in early reports were regarded as metamorphosed sediments and later were classed generally as rhyolites, include rocks belonging to the group of trachytes—a group that is rather sparsely represented in North America.

OUTLINE OF THE REPORT

Rochester is a silver-mining district in the Humboldt Range of western Nevada. Silver was discovered there in 1912, and to the end of 1922 the district produced 7,000,000 ounces of silver. It is second in yearly output among Nevada's many silver districts, but it ranks far below Tonopah, the leading district.

The prevailing rocks of the district are a thick series of Triassic volcanic rocks overlain by limestone of the same age. The volcanic rocks consist of felsitic trachyte and keratophyre, aggregating 10,000 feet in thickness, and an overlying series of rhyolite, 1,000 feet thick. Above the igneous rocks lies the limestone, of which only 2,000 feet is exposed in the district, although elsewhere in the Star Peak Range it apparently attains a far greater thickness.

At or near the end of the Jurassic period this series of volcanic rocks and limestone came within the influence of the great revolution and crustal disturbances that affected the western Cordilleran region at that time. A long train of events started then, which culminated in the formation of the ore deposits of the district. First the rocks were folded into a broad anticline, which constitutes one of the major structural features of the range. This arching of the rocks was followed by the intrusion of granitic magma, which within the district proper is represented by fine-grained white granite, or aplite. The bodies of aplite are comparatively large for rock of this kind, and their size implies, therefore, a notable amount of differentiation of the magma from which the aplite was derived. The last rocks to be intruded during this period of igneous activity are granite porphyry dikes. Thereupon began a period of active circulation of highly heated solutions, at first so hot as to be gaseous but later liquid. Doubtless these solutions were expelled from the cooling and consolidating magma in depth. The minerals produced by these solutions indicate three stages in these so-called post-intrusive processes—one in which dumortierite (an aluminum borosilicate) is the distinctive mineral that was formed, a second in which gold ores having tourmaline-bearing gangue were deposited, and a third in which silver protores having tourmalinic quartz gangue were deposited, which shade into silver protores without tourmalinic gangue. These three stages, which are interpreted as being successive in time and at temperatures successively lower, were discontinuous, as gradations between the deposits formed during the successive stages do not occur.

During the first stage a large body of trachyte on Lincoln Hill was shattered and interlaced with veinlets composed of pink dumortierite and quartz. The trachyte adjoining the veinlets was intensely altered and converted into an aggregate of andalusite and quartz. The dumortierite-bearing mass thus produced appears to exceed in size any other known. It is notable that no precious metals or sulphides were deposited during this stage; possibly the temperature of the solutions was too high to admit of their deposition. During the second and third stages the gold ores and the silver protores were deposited, and from the silver protores were later developed by supergene enrichment the most valuable deposits in the district. These will be considered later at greater length; only their relation to the post-Jurassic revolution and accompanying igneous activity is here emphasized.

A long period of erosion succeeded the post-Jurassic revolution. A deposit of bouldery alluvial-cone débris at least 600 feet thick records the next event in the history of the district. It is probably of Pliocene age and resulted from the initial uplift of the Star Peak Range, or northern subdivision of the Humboldt Range, and the consequent amassing of alluvial cones along the fault scarp of the newly formed range. Later this material was covered, in part at least, by flows of basalt. By the faulting and tilting of these basalt sheets the Humboldt Lake Range, or southern subdivision of the Humboldt Range, was produced, as has been so ably demonstrated by Louderback. The Star Peak Range was further uplifted, probably at this same time, and gradually attained its present altitude. Physiographically the fault-block origin of the range is shown by the clean-cut triangularly faceted escarpment along the west front and by the fact that the canyons, which are acutely V-shaped at the western front of the range, broaden widely upstream—a feature shown particularly well by Limerick Canyon. During the uplift of the range as a whole a certain amount of fragmentation took place, and the movement and readjustment of the minor blocks produced fault-trough valleys, the most notable example of which is the valley on the east flank of Nenzel Hill. The upward movement on the fault surfaces was slow enough to permit small streams to maintain their courses across the rising fault blocks. In this way were produced such remarkably anomalous stream conditions as those of American and South American canyons. South American Canyon cuts through the Black Range at right angles in a narrow V-canyon, 2,000 feet deep, and taps the broad, open longitudinal valley on the east side of Nenzel Hill. The physiographic conditions are similar to those shown in the rift valleys of the California Coast Ranges, though on a smaller scale and with more rugged relief.

The principal ore deposits of the Rochester district are silver-bearing quartz veins and stockworks. They belong to the relatively rare class in which the ore is valuable chiefly for its content of silver. The silver-bearing quartz veins furnish the greater part of the output of the district, and they are most numerous and productive on Nenzel Hill, at the head of Rochester Canyon. The stockworks are represented only by the deposits at Packard.

The silver-bearing quartz veins are inclosed in the Triassic rhyolite and trachyte. The ore consists of quartz that as a rule is exceedingly fine grained. The chief silver mineral is finely disseminated argentite. Other metallic minerals are pyrite, sphalerite, galena, tetrahedrite, covellite, and chalcopyrite, but in the aggregate the amount of all these minerals is small. Although quartz is the only gangue mineral in most of the veins, some contain noticeable quantities of the significant mineral tourmaline.

The average content of the ore now mined is from 10 to 12 ounces of silver to the ton. In early days, when the upper portions of the veins were being mined, the ore carried from 30 to 60 ounces to the ton. Although the higher grade of the ore then mined was in part due to sorting, nevertheless the silver content has greatly declined as greater depth has been attained, and the bottom of the ore has been reached. The extreme vertical range of ore is between 600 and 800 feet. Why the silver content has steadily decreased in the ore of the deeper levels has become clearly apparent during the course of the present investigation. The argentite, which determines the silver tenor of the ore, and hence its commercial value, is of supergene (secondary) origin, having been formed as the result of the reaction between the primary sphalerite of the unoxidized ore and silver sulphate that had been carried down by descending surface water from the outcrops of the oxidizing veins. The amount of argentite consequently diminishes steadily with increasing depth. The source of the silver by which the ore has thus been enriched is doubtless the sparse tetrahedrite of the primary vein filling. On oxidation this mineral yielded soluble compounds of silver and copper, and these substances trickling down in solution through veins reacted with the primary sulphides, chiefly the sphalerite, and produced the supergene argentite and the more abundant covellite.

The remarkable silver-bearing stockworks at Packard consist of Triassic rhyolite traversed by widely spaced, nearly imperceptible veinlets. The silver occurs as finely disseminated cerargyrite (horn silver), which has probably been formed at the expense of supergene argentite. The stockwork ore bodies are large shallow concentrations, nowhere extending more than 30 feet below the surface.

It is obvious from the preceding account that the silver ores are the result of the supergene enrichment of material originally containing so little silver as to be commercially valueless. This unenriched vein filling, too lean to be ore—the protore, to use Ransome's term—was formed largely by the replacement of sheeted and shattered zones in rhyolite and trachyte, a mode of origin which accounts for the prevailing fine-grained, in places nearly chalcedony-like character of the quartz gangue. In fact, this fine-grained quartz might readily suggest that the Rochester veins, though inclosed in Triassic rhyolite and trachyte, are of Tertiary age, like so many of Nevada's silver deposits. However, the tourmaline-bearing quartz gangue of certain typical silver veins, the remarkable faulting of certain veins by tourmaline lodes, and the profound tourmalinization produced by the aplite intrusions all combine to prove that the silver veins are genetically related to the aplite and were formed soon after its intrusion.

Economically, the most significant fact in connection with the origin of the silver ores is that their commercial value is dependent on their content of secondary argentite. The deep-level tunnels have cut the veins below the zone of enrichment and have thereby determined the maximum downward limit of the ground in which it is worth while to explore for ore. Future exploration will therefore be restricted to lateral work on the higher levels, in which considerable ground still remains to be tested.

GEOLOGY AND ORE DEPOSITS OF THE ROCHESTER DISTRICT, NEVADA

By Adolph Knopf

Part I. GENERAL FEATURES

GEOGRAPHY

SITUATION OF THE DISTRICT

The Rochester district as defined in this report is an area of 27 square miles in the southern part of the Star Peak Range, in western Nevada (fig. 1). It is in Pershing County, which was created from the southern portion of Humboldt County in 1919. The nearest railroad station and shipping point, Oreana, on the main line of the Southern Pacific system, is 12 miles distant. Formerly a railroad known as the Nevada Short Line extended from Oreana to the town of Rochester, but this line is now abandoned. Lovelock, the county seat, is the nearest large town and lies 25 miles southwest of the district.

Rochester, Lower Rochester, and Packard are the only settlements in the district. Rochester is at the head of Rochester Canyon, at an altitude of 6,300 feet, and is the chief settlement. The town is now little more than the place of residence of the employees of the Rochester mine. Lower Rochester is 2 miles farther down the canyon and consists of a few houses only. Packard is in the southern part of the district and consists of the dwellings of the employees of the Packard mine.

PHYSICAL FEATURES

The Star Peak Range, in which the Rochester district is situated, is the northern division of the West Humboldt Range. It is separated from the much lower southern division of that range—the division sometimes called the Humboldt Lake Mountains—by a broad depression trending obliquely to the course of the range. This depression is shown in detail in Plate I; in geologic publications it is referred to as Cole Canyon, but locally this name is given to the canyon transecting the Humboldt Lake Mountains a few miles farther south.

The West Humboldt Range was so termed to distinguish it from the East Humboldt Range, the loftiest mountain mass in Nevada, which lies south of Wells. The East Humboldt Range, however, is

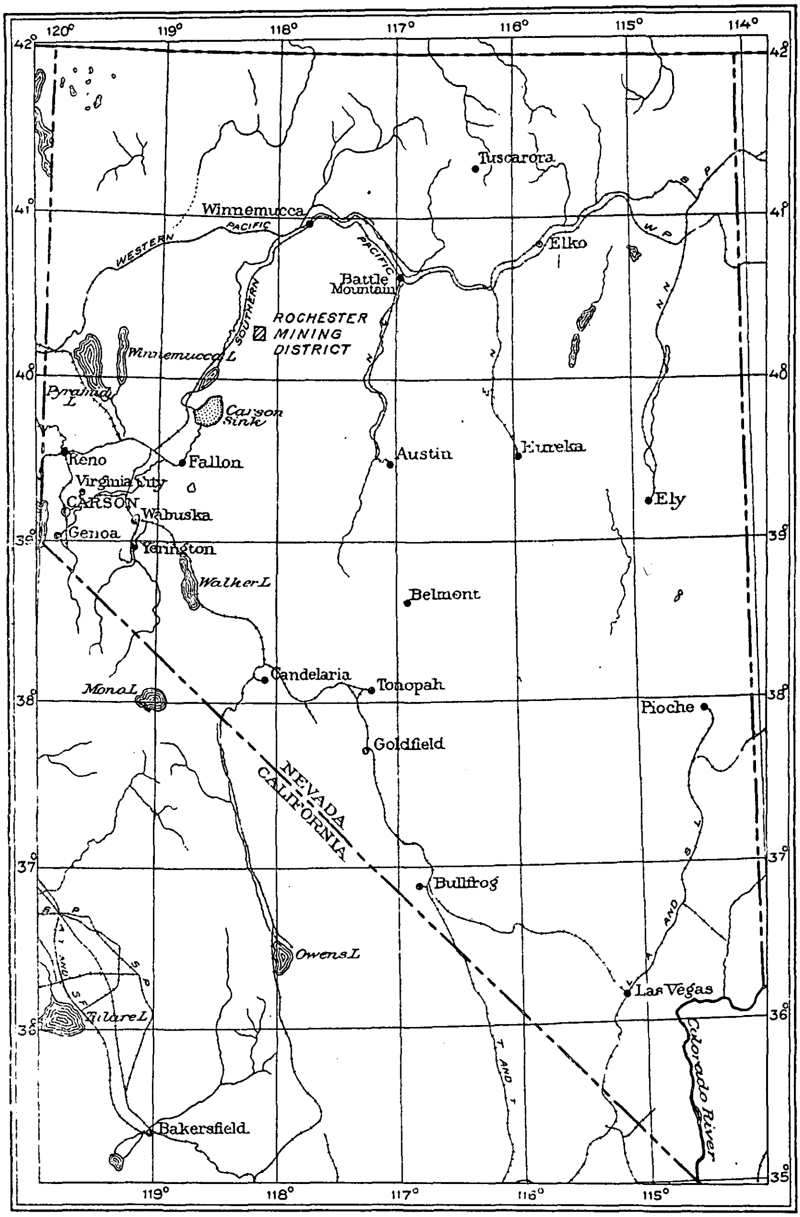

FIGURE 1.—Index map showing the location of the Rochester district

now generally known as the Ruby Range and the West Humboldt simply as the Humboldt Range. According to the Fortieth Parallel Survey, the Indian name for the range is Koipato.

The Star Peak Range is nearly 75 miles long and trends meridionally. It rises steeply along its regular western front from an altitude of 5,000 feet to an average of 8,000 feet and culminates in Stâr Peak, 10,000 feet above sea level. The southern prong of the range, which overlaps en échelon the north end of the Humboldt Lake Mountains, is called the Black Range; it culminates in Buffalo Peak, 8,400 feet above sea level.

In the latitude of the Rochester district the Star Peak Range is 15 miles wide. The district lies mainly on the western slope of the range. Limerick, Rochester, and Weaver canyons, opening upon the western front of the range, can be said to determine the main topographic features of the district. None of these canyons sustains a permanent stream, the only flowing water being that furnished by the melting of the snow during a few weeks in March and April. Limerick Canyon,[1] the northernmost, affords an easy grade across the range and is the site of the road from Lovelock to Unionville and other mining camps that lie on the east side of the range. At its mouth the canyon is deep, rugged, and sharply V-shaped, but headward it widens into a notably broad, open valley with gently sloping sides. Rochester Canyon is a fairly open valley, more open than perhaps is generally implied by the term canyon; it heads against Nenzel Hill, whose broad, flat summit stands at 7,200 feet above sea level. Weaver Canyon lies next south of Rochester Canyon. Both of these canyons have notably asymmetric cross sections, the north slopes being long and relatively gentle and the south slopes short and steep.

In general, the topography is of considerable and abrupt relief, but on the whole it can not be said to be rugged, as most of the ridge crests are smooth. The topographic features of the district are such as to favor mining by permitting the development of many of the veins in depth by means of adit tunnels. Plate I shows the topography excellently.

CLIMATE AND VEGETATION

Precipitation in the Rochester district is small and falls mainly during the winter as snow. It is insufficient to support any perennial streams, but farther north, where the Star Peak Range is higher, many of the canyons contain streams running the year round. The winters are cold and stormy but can not be said to be severe. Early in April the snow disappears from the hillsides, and soon countless flowers burst into bloom. In all too short a time the flowers vanish and the hillsides quickly take on the parched look of summer, re-

[1] Formerly known as Sacramento Canyon (so referred to in the reports of the Fortieth Parallel Survey), but that name has been transferred to the next canyon north.

lieved faintly, if at all, by the grayish-green stippling, as it were, of sagebrush and other desert bushes. The summer weather is warm and pleasant.

Mountain junipers, thinly scattered and of scraggly habit, are the only trees in the district, and they grow only above an altitude of 6,000 feet.

HISTORY OF MINING

During the early sixties of the last century the Star Peak Range was the scene of an intense silver excitement. One of the chief goals of the rush that took place at that time was Unionville, on the east foot of the range, and among those drawn to it was Mark Twain, who has vividly described, in that exuberant volume "Roughing It," the magnificent exaggeration concerning the wealth of Humboldt then current in the daily press, the great and blissful ignorance of mining, and the general disinclination of the stampeders to do any hard-rock work. It is a marvelously accurate picture that he has drawn, full of life and local color, such as rarely gets into the pages of the professed historian.

The earliest mention of the name Rochester appears in the more sedate volumes of Raymond's reports. In 1868 the Rochester Co. was intermittently working the south extension of the Montana ledge. The outcrops of the ledge, which were large and prominent, were in Limerick Canyon on the stage road between Lovelock and Unionville [2] and only 5 miles from the railroad. In 1869 the company prosecuted its work on the ledge "with great vigor." The Batavia Co. placed a steam hoisting works on the Rochester shaft in 1870, but as the drift from the shaft failed to cut any "paying quartz" work was discontinued.[3] In those early days a tunnel several hundred feet long was driven on the north slope of Limerick Canyon evidently to cut in depth some of the many quartz veins on the side of Lone Mountain. About 1881 gold was found in the gravel at the mouth of American Canyon; these placers are only a few miles east of the district—in fact, the stream heads at Nenzel Hill, the focal point of interest in the Rochester district. The placers were actively worked until 1895. The Americans, who were the first to work the placers, are said to have taken out $1,000,000, and the Chinese, who succeeded them, are credited with having taken out considerably more gold—as much as $10,000,000, according to some accounts, though this estimate severely strains one's credulity.[4]

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[2] Raymond, R. W., Mineral resources of the States and Territories west of the Rocky Mountains for 1868, p. 125, 1869.

[3] Idem for 1870, p. 137, 1872.

[4] Ransome, F. L., Notes on some mining districts in Humboldt County, Nev.: U. S. Geol. Survey Bull. 414, p. 12, 1909.

About 1905 an old prospector from the Black Hills, "Hutch" Stevens, located a large group of claims on the hill now known as Nenzel Hill, against which Rochester Canyon heads on the west and American Canyon on the east. His camp was at the head of American Canyon, and while returning to this camp from Spring Valley, on the east side of the range, he perished during a snowstorm of the winter of 1908–9. His claims thus came into the possession of his heirs, one of whom, a niece, was the wife of Joseph F. Nenzel.

Other prospectors were in the district at this time. In 1909 they drove some tunnels on the Plainview group of claims to prospect a gold-bearing silver vein in the rhyolite on the summit of the ridge forming the northward extension of Nenzel Hill and hardly a mile north of the locality where the great discovery was to be made in 1912. The Limerick group of claims on the northwest slope of Nenzel Hill also was located in 1909.

In June, 1912, Nenzel discovered rich silver ore on one of the many claims inherited from Stevens. The ore was found in a quartz vein, subsequenty called the West vein, which crops out at the head of Rochester Canyon in the prominent crags on the west brow of the mountain, since known as Nenzel Hill. The silver occurs in the ore in an inconspicuous form, as finely disseminated argentite, and it is doubtless due to this inconspicuousness that the value of the deposit remained so long unknown, although it occurs in a region that has been more or less continuously prospected since the sixties of the last century and is not far from a well-used route of travel.

Soon after he had discovered ore Nenzel made a small shipment, mainly from talus or float, which gave surprisingly high returns. Some leases were granted, and the output for the year aggregated 144 tons of ore, averaging $32.67 a ton.[5] The favorable results becoming known, a great rush set in near the end of the year and the beginning of 1913. More than 2,000 people flocked to Rochester Canyon, and three towns were laid out—Rochester, at the head of the canyon, Lower Rochester, 2 miles down the canyon, and Central Rochester, between the two. Central Rochester soon disappeared, but the others have continued. At the present time the combined population does not exceed 200 or 300. The discovery of dry placers at the head of Limerick Canyon led to a stampede there and the founding of Panama, but this boom soon collapsed.

Development on Nenzel Hill proceeded rapidly, favored by the easy construction of adit tunnels, and in 1913 the output of the district jumped from the $4,704 of 1912 to $477,487.[6]

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[5] U. S. Geol. Survey Mineral Resources, 1912, pt. 1, p. 798, 1913.
[6] Idem, 1913, pt. 1, p. 827, 1914.

In this year a railroad, known as the Nevada Short Line, was extended from Oreana,[7] on the Southern Pacific system, up Rochester Canyon, terminating at the portal of the Rochester mine, the principal mine in the district. During the first two years of the life of the camp all the ore mined was shipped to the smelters for treatment. Under such conditions ore worth less than $22 a ton—that is, ore carrying less than 35 ounces of silver to the ton—could not be shipped with profit.[8] In 1915 the two principal producers—the Rochester Mines Co. and the Nevada Packard Mines Co.—built their own reduction plants, and thenceforth the bulk of the ore produced in the district has been treated locally. As a result ore containing much less than 35 ounces of silver to the ton could be worked profitably, and in fact ore carrying as little as 8 ounces to the ton has been treated at a profit. The decline of the boom and the building of the milling plants cut down the freight carried by the Nevada Short Line, and that road, which had become exceedingly unpopular on account of its unreliable service, became defunct toward the end of 1917. The same year saw a vigorous attempt to boom a town site at Packard, but this scheme failed. A fine silver-milling plant costing $300,000 was erected at this site by the Rochester Combined Mines Co. to treat the ore from a body publicly announced to be 130 feet wide and carrying $30 to the ton in silver. After operating a few weeks the mill was permanently shut, and in 1922 it was torn down and the material shipped to Candelaria, where it has been reassembled to treat the silver ore of that district.

Apex litigation threatened the principal producer, the Rochester Mines Co., in 1917, but fortunately was averted by compromise and consolidation, the eventual outcome being the formation of the Rochester Silver Corporation in 1920. The efficient management that came into control as the result of these changes soon succeeded in putting the mine on a profitable basis, and the amount of dividends disbursed since the reorganization has exceeded that of the entire previous history of the district.

OUTPUT OF SILVER AND GOLD

The Rochester district produced to the end of 1922 more than 7,000,000 ounces of silver and 60,000 ounces of gold of a total value of $7,000,000. The annual output of silver and gold is shown in the following table, which has been compiled from Mineral Resources

[7] Renamed for a time Nixon by the railroad company, renamed Nenzel at the time of the Rochester boom, and now called by its original name Oreana. The Post Office Department has steadfastly maintained the original name—Oreana.

[8] Schrader, F. C., The Rochester mining district, Nev.: U. S. Geol. Survey Bull. 580, p. 328, 1914.

of the United States. The sudden drop from the average value of $30 a ton of ore during the first three years of the life of the camp to the average of $10 a ton for the later years coincides with the beginning of operations by the two principal reduction plants in the district. After the plants began working little ore was shipped out of the district, and selective mining and sorting have been discontinued.

Silver and gold produced from deep mines in the Rochester district, Nev., 1912–1923

Year	Ore (short tons)	Silver (fine ounces)	Gold	Value	
				Average per ton	Total
1912	144	6,850	$491	$32.67	$4,704
1913	16,152	701,395	52,350	29.47	476,014
1914	14,499	621,833	71,769	28.69	416,045
1915	26,665	663,791	105,407	16.61	443,091
1916	67,992	816,620	81,228	9.12	620,151
1917	88,371	799,865	152,855	9.20	813,369
1918	95,747	810,974	177,120	10.36	992,154
1919	103,662	667,161	117,899	8.35	865,297
1920	75,048	620,046	130,715	10.75	807,043
1921	87,628	667,084	176,144	9.61	843,273
1922	116,455	800,238	107,033	7.79	907,271
1923	91,374	664,714	124,326	7.32	669,403

More detailed and homogeneous data are given in the subjoined table, which has been assembled from the annual reports for 1920 and 1921 of the chief producer, the Rochester Silver Corporation.

Output of the Rochester mine, 1918–1921

Year	Ore (short tons)	Content (ounces per ton)		Recovery (ounces)				Value of metals recovered	
				Per ton		Total			
		Silver	Gold	Silver	Gold	Silver	Gold	Average per ton	Total
1918		10.49	0.141	7.86	0.126				
1919		10.29	.105	7.85	.092				
1920	42,820	12.63	.139	10.37	.128	444,187	5,469	$13.90	$595,351
1921	55,181	11.63	.151	9.53	.138	526,023	7,701	12.42	685,246

GEOLOGIC INVESTIGATIONS OF THE DISTRICT

The earliest systematic geologic work in this region was that done by Arnold Hague and Clarence King, of the Fortieth Parallel Survey. They mapped the areal geology of the Star Peak Range on a scale of 4 miles to the inch and determined the structure. Although their conclusions have been considerably modified by subsequent studies, the large permanent result of their work is that they have shown that the range is built chiefly of a thick series of Triassic rocks flexed into a broad anticline. As one of the main traveled roads of the region crosses the range by way of Limerick Canyon, which is in the Rochester district as defined in the present report, they became somewhat familiar with the geology of this part of the range.

In 1902 G. D. Louderback intensively studied the Humboldt Range as an example of a fault-block range, devoting himself specially to the southern division, or Humboldt Lake Range. His work in the Star Peak Range, or northern division, established the significant fact that the so-called Archean granite nucleus of the range is in reality an intrusive mass of post-Triassic age, in all probability contemporaneous with the great intrusions in the Sierra Nevada—a conclusion, as is well known, that has since been found to apply to many other of the ranges of the Great Basin.

Important paleontologic investigations were made by J. P. Smith during five seasons from 1902 onward, at the remarkably prolific fossiliferous locality known as Fossil Hill, a few miles east of the Rochester district, and by J. C. Merriam, who exhaustively studied the ichthyosaurs entombed in the Middle Triassic limestone of that locality.

F. L. Ransome, in 1908, made a reconnaissance examination of the mining districts of the Star Peak Range, crossing the range by way of the road through Limerick Canyon. His report is the main source of information on the geology and ore deposits of the range. His brief investigation showed that the stratigraphy as determined by the Fortieth Parallel Survey was in need of drastic revision. He proved that the thick Koipato formation, of Triassic age, is not of sedimentary origin but is composed of volcanic rocks, chiefly rhyolites. As his work was not of detailed character, he naturally included among the rhyolites the felsitic trachyte of the present report.

In 1913, shortly after the discovery of the silver-bearing veins on Nenzel Hill, J. C. Jones briefly described the ore deposits and the geology of the new camp of Rochester, then at the height of its boom. In the spring of the same year F. C. Schrader examined the district in a reconnaissance way and prepared an excellent report, which appeared in 1915.

In 1916 T. P. Pendleton made the topographic map of the district that forms the base for Plate I. On the completion of this excellent base map a detailed examination of the district was made by the writer in the early part of 1917, from February 20 to May 30. Cold stormy weather, with frequent snowfall, and the unusual lateness of the advent of spring considerably hampered the work. A brief visit in August, 1919, allowed the writer to examine some of the newer developments in the district. During the war the preparation of this report was put aside for work connected with the Geological

Survey's activities on war minerals. Its subsequent completion has in part been delayed by the writer's withdrawal in 1920 from full-time Government service.

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GEOLOGY OF THE STAR PEAK RANGE

As the Rochester district is only a small fraction of the Star Peak Range, its geology will perhaps be more clearly understood if the broader features of the range are first sketched. Although the geology of the range as a whole has not yet been adequately determined, it is known well enough to give at least the geologic setting of the Rochester district.

The oldest rocks in the range form a bedded succession of lava, tuff, and breccia, more or less schistose and aggregating about 10,000 feet in thickness. They consist of light-colored felsitic trachyte, keratophyre of andesitic and greenstone appearance, and rhyolite. The rhyolites overlie the trachytes and keratophyres and as a rule are conspicuously porphyritic. This assemblage was named the Koipato group by the geologists of the Fortieth Parallel Survey, but they did not recognize its volcanic origin. It is in all probability of Middle Triassic age.

Overlying these volcanic rocks conformably is the Star Peak "group" as named by the Fortieth Parallel Survey. It was estimated to be 10,000 feet thick, and this appears to be its probable order of magnitude. The Star Peak formation, as it is now termed, was believed by King[9] to consist of "an alternation of three great limestone zones and three interposed quartzite zones," but the work of J. P. Smith and of the present writer has shown that the interposed zones consist mainly, if not wholly, of volcanic rocks.

Smith[10] gives the following columnar section of the West Humboldt Range, which, as just indicated, differs radically in lithology from the section of the Star Peak formation given in the Fortieth Parallel Survey report, and it differs equally in sequence.

Columnar section of the West Humboldt Range

Lower Jurassic (Lias).			Carries *Arietites*.
Unconformity—			
Upper Triassic.	Star Peak formation.	*Pseudomonotis* zone.	*Pseudomonotis subcircularis* zone (slates, with *Rhabdoceras* and *Halorites*). Thickness about 900 feet.
			Siliceous and tuffaceous beds, without fossils. Thickness unknown.
			Massive limestones, probably corresponding to the Hosselkus (Upper Triassic) limestone of the California section. Thickness about 2,000 feet.
			Siliceous and tuffaceous beds without fossils, partly rhyolites, and other volcanic flows. Thickness 1,000 to 2,000 feet.
Middle Triassic.		*Daonella* zone.	Slaty limestones and tuff beds, hard at the top and grading over into shaly limestones and calcareous shales at the bottom. Thickness 1,000 to 1,500 feet. The lower 200 feet contain nearly all the fossils, which belong to the fauna of *Ceratites trinodosus*.
Koipato formation.			Siliceous beds, tuffs, graywackes, and igneous rocks, of unknown thickness. Without fossils.

Smith was apparently unaware that Ransome[11] in 1909 had shown that the Koipato formation is dominantly of volcanic composition. The "siliceous beds" listed under the Koipato are consequently with little doubt the felsitic trachytes that make up the preponderant part of that formation. Ransome also showed that the "siliceous beds" of the Star Peak are in part, at least, volcanic rocks.

The Middle Triassic limestones have yielded the remains of remarkable huge Ichthyosauria (marine "fish-lizards"), which were

[9] King, Clarence, Systematic geology: U. S. Geol. Expl. 40th Par. Rept., vol. 1, pp. 268–278, 347, 1878.

[10] Smith, J. P., The Middle Triassic marine invertebrate faunas of North America: U. S. Geol. Survey Prof. Paper 83, pp. 8–9, 1914. Smith's presentation of the stratigraphic results of his important work is unfortunately all too brief.

[11] Ransome, F. L., Notes on some mining districts in Humboldt County, Nev.: U. S. Geol. Survey Bull. 414, p. 32, 1909.

obtained at Saurian Hill and Fossil Hill,[12] on the east flank of Black Range, on the divide between South American Canyon and Troy Canyon, 3 or 4 miles east of the Rochester district. At the same locality Smith collected 111 species of ammonites and 19 species of other organisms.

The Jurassic appears to consist mainly of slates, which exceed 2,000 feet in thickness.[13] King thought that the Jurassic rests on the Triassic with "perfect conformity," but Louderback and Smith say that it overlies the Triassic unconformably. The unconformity is apparently not very great, for, according to Louderback, "some deformation and erosion probably took place at the end of the Triassic, but of comparatively limited magnitude, for the Jurassic is distributed to about the same extent that the Triassic is." [14]

The Triassic and Jurassic rocks have been folded into a broad anticline whose axis strikes north and plunges southward, thus causing the west limb of the anticline to strike at an angle of 30° with the meridional trend of the range itself. As has long been recognized and generally accepted, this folding took place in post-Jurassic time, most probably at the end of the Jurassic, contemporaneously with the revolution that affected the Sierra Nevada region at this time—the great crustal disturbance that will here be termed the Jurasside revolution.[15] In the Star Peak Range, as in many of the ranges of the Great Basin and the Sierra Nevada, this revolution was accompanied by the intrusion of granite and related rocks. Unlike some of the other ranges, the Star Peak Range shows but a small amount of granite so far exposed by erosion. This igneous activity, according to Ransome,[16] was followed by the deposition of a series of antimonial silver ore bodies—a conclusion that admittedly rested on slender evidence. However, the evidence at Rochester is convincingly clear that there the mineralization took place soon after the intrusion of the granitic rocks. The lean silver-bearing veins that were then formed have subsequently been enriched to workable grade by the action of descending surface waters during the long erosion to which the region was subjected in post-Jurassic time.

The broader geologic features of the Star Peak Range are shown in generalized form in Figure 2.

The next younger formation in the range is a coarse bouldery deposit, which evidently represents a series of ancient alluvial cones

[12] Merriam, J. C., Triassic Ichthyosauria: California Univ. Mem., vol. 1, pp. 18–19, 1908.
[13] King, Clarence, op. cit., pp. 269, 294–295.
[14] Geol. Soc. America Bull., vol. 15, p. 335, 1904.
[15] This usage conforms to that employed by R. T. Chamberlin to denote the folding or strong diastrophic movements that took place either at or near the end of a geologic period (Diastrophism and the formative processes: Jour. Geology, vol. 22, p. 317, 1914).
[16] Ransome, F. L., U. S. Geol. Survey Bull. 414, p. 46, 1909.

that were amassed in front of a young growing range. They are Pliocene in age or possibly Quaternary. They were partly covered by flows of basalt, as is well shown in the north end of the Humboldt Lake Mountains. Although these basalt sheets are most extensive in the Humboldt Lake Range, where in fact they form a widespread capping, they also occur in the Star Peak Range, but only in small areas on its east flank bordering the valley. The basalt sheets of the Humboldt Lake Range were broken by longitudinal normal faults and tilted eastward. By this faulting and tilting, as proved by Louderback,[17] the range was given its relief and topographic expression; it was blocked out essentially in the form we now see it. The surface of the main north-south fault forms the abrupt westward-facing escarpment, and the surface of the basalt sheets, which at the north end of the range dip 12° E., forms the gentle east

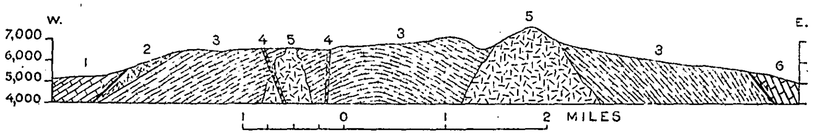

FIGURE 2.—Diagrammatic section through the south end of the Star Peak Range. 1, Triassic limestone, probably Middle Triassic; 2, Weaver rhyolite; 3, trachytic and keratophyric lava, breccia, and tuff; 4, granite porphyry; 5, aplite; 6, massive Triassic limestone, probably Upper Triassic

slope of the range. The physiographic evidence fully supports this conclusion concerning the origin of the range. In regard to the origin of the Star Peak Range we are limited to physiographic criteria, because of the absence of the basalt sheets, but the evidence of the land forms in support of its fault-block origin is so strong as to be compulsory. The second and major uplift of the Star Peak Range, which is thus indicated by the physiographic evidence, doubtless took place contemporaneously with the faulting that blocked out the Humboldt Lake Mountains. In Recent time faulting has recurred along the west front of the range and has produced the fresh scarp that traverses the alluvium at the base of the range. This fault extends continuously for more than 100 miles, and the scarp is from 10 to 29 feet or more high.[18]

[17] Louderback, G. D., Basin Range structure of the Humboldt region: Geol. Soc. America Bull., vol. 15, pp. 312–316, 1904.

[18] Russell, I. C., Geological history of Lake Lahontan: U. S. Geol. Survey Mon. 11, p. 277, 1885.

PART II. GENERAL GEOLOGY OF THE DISTRICT

TRIASSIC ROCKS

INTRODUCTORY OUTLINE

Triassic rocks, chiefly of volcanic origin, make up the larger part of the bedrock of the Rochester district.

The oldest rocks are felsitic trachytes, comprising lavas, breccias, and tuffs, here named the Rochester trachyte. They aggregate 5,000 feet in thickness. With them are associated keratophyres, partly as a thick series of flows and pyroclastic rocks and partly in such intimate association with the trachytes as to form belts of alternating trachyte and keratophyre.

Conformably overlying the trachytes and keratophyres is another volcanic series, which is essentially of rhyolitic composition. The lowest member of this sequence is the Nenzel rhyolite breccia, of variable thickness but 600 feet thick at a maximum. It is of main economic interest, because the most productive silver veins crop out in it. Rhyolite tuffs, of sandstone-like appearance but in reality composed of shards of glass, overlie the Nenzel rhyolite breccia conformably but being of lenticular habit are not everywhere present. Above the Nenzel rhyolite breccia and the tuffs lies the Weaver rhyolite, consisting chiefly of flows that aggregate 720 feet in thickness. The rhyolite lavas of this formation have highly distinctive characters, such as abundant prominent phenocrysts of quartz and a widely prevalent content of quartz nodules and geodes resulting from the filling of spherulites that originally were hollow. Some lenses of tuffaceous shale are intercalated between the flows of Weaver rhyolite.

The assemblage of trachytes, keratophyres, and rhyolites, with their breccias and tuffs, makes up the Koipato group of the Fortieth Parallel Survey—in fact, it was recognized by the geologists of that Survey that in Limerick Canyon this "group" attains its greatest thickness.[19] It is of Middle Triassic age at least, but it may be older, though this is regarded as highly improbable.

Limestones overlie the volcanic rocks in the western part of the district. They have been faulted down against the Weaver rhyolite. They are part of the Star Peak group of the Fortieth Parallel Survey, but as neither Koipato nor Star Peak is a secure stratigraphic term and as not enough work justifying their redefinition has been

[19] U. S. Geol. Expl. 40th Par. Rept., vol. 1, p. 270, 1878.

done, those terms are not employed in this report. The limestone in the western part of the Rochester district contains marine fossils, which indicate that it is of Middle or Upper Triassic age. Comparison with the columnar section given by Smith suggests that it is of Middle Triassic age.

ROCHESTER TRACHYTE

GENERAL FEATURES

A light-colored felsite carrying small inconspicuous phenocrysts of microcline is the prevailing rock in Rochester Canyon. It is well exposed on the ridges inclosing the canyon and forms the lower slope of Nenzel Hill, where it is penetrated by extensive mine workings. It extends northward to Gold Mountain and eastward far beyond the boundaries of the area mapped. It is the most widespread of the Triassic volcanic rocks.

This volcanic formation comprises lavas, breccias, and tuffs. As a whole they are remarkably similar and monotonously alike. More than half of the assemblage, as shown by a detailed study of the excellent sections along the ridges bordering Rochester Canyon, consists of breccias and tuffs. As the fine-textured tuffs are extraordinarily difficult to distinguish from the massive felsite, it is probable that the pyroclastic portion of the formation considerably exceeds the massive portion. In places the tuff beds are clearly lenticular and are intercalated in the breccias and thus supply a means for determining the strike and dip of the formation. At many places they fail, however, and the monotonous similarity of the formation as a whole and the absence of key layers of breccia or of distinctive lava sheets makes it impossible to determine the local structure. None of the breccias are coarse, for the fragments of which they are composed are rarely as much as 6 inches in diameter and are generally less than an inch.

The lava sheets are commonly unfoliated, but the breccias and tuffs are distinctly though roughly schistose, with more or less sericitic gloss on the foliation surfaces.

PETROGRAPHY

Felsite is a highly appropriate field name for these volcanic rocks. They are exceedingly fine grained, and the phenocrysts they contain are as a rule sparse, small, and not readily discerned. Feldspar. which is commonly striated but which under the microscope proves to be microcline, doubtless derived from sanidine as the result of the dynamic metamorphism the rocks have undergone, is the only porphyritic constitutent in the great bulk of the series. A few minute sporadic phenocrysts of quartz occur in some of the upper members, but they hardly affect the generalization that this thick pile of volcanic rocks consists of felsites that carry inconspicuous phenocrysts of microcline only. It is the absence of quartz phenocrysts that specially contrasts the trachytes with the overlying Nenzel rhyolite breccia and Weaver rhyolite.

The breccias and tuffs consist of angular fragments of felsite of the same kind as that of the lava sheets. The lack of variety in the constituent material enhances the essential uniformity of the series. Dark minerals, such as biotite or hornblende, or vestiges of dark minerals have not been found in any of the lavas, breccias, and tuffs. In color the felsites on fresh fracture are generally a rather pure white. Rarely they are blackish or bluish gray. On weathered surfaces the felsites—lavas, breccias, and tuffs alike—are characteristically buff or brownish yellow, owing to the oxidation of the finely disseminated pyrite introduced into them during the mineralization of the district.

The felsitic trachyte of the belt extending from Nenzel Hill north to Gold Hill is distinguished for its remarkable streakiness and flow banding. Some of the most highly flow-banded felsite consists of an alternation of bluish-black and cream-colored bands, a fourth to half an inch thick, more or less curly and contorted. Spherulitic structure also is common and has become strikingly accentuated in the mineralized areas by the processes of alteration accompanying the mineralization. In places the trachyte is vuggy from the prevalence of gas cavities, and in the area of mineralization these cavities have been filled or lined with zinc blende, galena, pyrite, chalcopyrite, and quartz, as is well shown in the Pitt and Friedman tunnels. In addition to the streakiness and flow banding, many of the lavas are flow layered, breaking up into thin layers, an inch or so thick, which were produced by flowage.

The flowage structure is most conspicuous in the belt extending from Sunflower and Nenzel hills to Gold Mountain, but it can be found throughout the areal extent of the Rochester trachyte, although elsewhere generally far less pronounced.

The best-preserved material of this formation occurs on Gold Mountain, in the northern part of the district. It is nearly normal rock without a trace of foliation and without the secondary sericite and pyrite so commonly developed in the trachyte throughout most of the district. It is regarded as representative of the formation as a whole in so far as a single specimen is likely to be, and the remainder of the formation probably does not depart widely from it in composition. It is clearly the unmineralized, unaltered equivalent of the flow-banded felsite on the lower western slope of Nenzel Hill, into which the productive silver veins extend in depth and which is deeply penetrated by the Pitt and Friedman tunnels.

The trachyte from Gold Mountain selected for chemical analysis was obtained from the upper spherulitic portion of a streaky, highly flow-banded lava sheet. It is a dark-gray rock carrying numerous slender phenocrysts of microcline, not over a millimeter or two in length, many of which have a fairly glassy luster. The groundmass consists of spherulites about 3 millimeters in diameter, some of which are obscurely banded. Under the microscope phenocrysts of microcline are seen scattered through a matrix composed wholly of spherulites. Crystals of microcline generally form nuclei around which the spherulites have grown. The spherulites are dusted with minute black particles, doubtless oxide of iron, and it is due to this pigmentation that the trachyte is darker than the great bulk of allied rocks in the district. The spherulites are only feebly birefringent, the interference tints being generally not higher than iron-grays, and in many the birefringence is barely perceptible. They are evidently composed of feldspar, as the index of refraction is markedly less than that of Canada balsam. They are built of fibers that give parallel extinction, some of which have positive and others negative elongation, although the predominant effect on inserting the gypsum plate is that of positive elongation; manifestly the feeble birefringence of the spherulites is due in part to the compensatory effect of superposed fibers of opposite optical elongations. As the following chemical analysis of the rock indicates, the spherulites must consist almost wholly of potassium feldspar. They are concentrically banded, though as a rule there are not more than two zones. The accessory minerals are abundant oxides of iron (apparently hematite and magnetite) and minor amounts of apatite, titanite, and zircon. No ferromagnesian minerals or traces of them are recognizable. The only alteration product is quartz, occurring in a few minute veinlets and as local, incomplete replacements of some of the microcline phenocrysts.

Analysis of trachyte from Gold Mountain, Rochester district

[R. C. Wells, analyst]

SiO_2	67.01
Al_2O_3	15.97
Fe_2O_3	2.54
FeO	.44
MgO	Trace.
CaO	.19
Na_2O	1.92
K_2O	11.42
H_2O- / H_2O+	.28
TiO_2	.39
	100.16

The immediately striking feature of the analysis is the high percentage of K_2O—nearly three times that of the average rhyolite, which is 4.09 per cent.[20] There are in Washington's tables[21] but four analyses of rocks termed rhyolite, quartz porphyry, or felsite that contain as much K_2O as this trachyte. The silica content is slightly higher than it would be in the absolutely fresh rock, on account of the presence of a small quantity of secondary quartz.

In view of the absence of quartz phenocrysts in the rock from Gold Mountain, the extremely high content of K_2O, and the relatively low SiO_2—that is, low for a rhyolite—it will be termed a trachyte. In the norm system of classification it falls into class I, order 5, rang 1, subrang 2. This subrang, which is unnamed, is represented by only one analysis—that of a pegmatite from Broken Hill, Australia,[22] which, however, should be excluded, as it is an altered mineralized rock.

THICKNESS AND AGE

The thickness of the Rochester trachyte exposed in the Rochester district is of the order of 5,000 feet. Roughly one-half of this thickness, as already mentioned, consists of breccias and tuffs.

The most favorable section for measuring the thickness of the formation is that extending westward from Sunflower Hill along the ridge crest on the south side of Rochester Canyon. It crosses the belt of trachyte approximately at right angles; the strike of the formation is N. 30° W., and the dip averages 30° W. From the measured width of the belt, the thickness of the formation is calculated to be about 5,000 feet. This calculation is subject to correction for faulting, but how much correction can not be determined, because the amount of faulting is not ascertainable, owing to the lack of key horizons. That 5,000 feet represents the order of magnitude of the thickness, however, is indicated by the following consideration. The trachyte in the measured section is part of the western limb of the great anticline of the Star Peak Range, and the eastern limb, which is best exposed in the ridges extending eastward from Gold Mountain (east of the mapped area), displays a thickness of trachyte of the same order of magnitude. That this agreement is a mere coincidence appears improbable.

The apparent thickness of the trachyte along the ridge bounding the north side of Rochester Canyon is 6,000 feet. In neither section is the base of the trachyte exposed, nor has it been found elsewhere, so that 5,000 feet appears to be a conservative estimate for the thickness of the formation.

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[20] Daly, R. A., Igneous rocks and their origin, p. 19, 1913.
[21] Washington, H. S., U. S. Geol. Survey Prof. Paper 99, pp. 108-109, 1917.
[22] Idem, p. 269.

The Rochester trachyte is the preponderant element in the Koipato group as defined by King, of the Fortieth Parallel Survey. It was considered to be of Lower Triassic age but, as will be shown subsequently, is most probably Middle Triassic.

DUMORTIERITIZED TRACHYTE

Dumortierite, an aluminum borosilicate ($Al_8HBSi_3O_{20}$), occurs in extraordinary abundance on the west flank of Lincoln Hill. In the amount of this comparatively rare mineral that it contains this area, so far as is now known, is without a peer anywhere. The dumortierite is prevailingly pink and lavender, the blue color usually thought to be characteristic of the mineral being very rare. Rich cobalt-blue dumortierite occurs in places with the deep-pink variety, and the combination produces a gorgeously colored rock. The dumortierite-bearing area is underlain largely by felsitic trachyte breccias, which strike N. 20° W. and dip 25° W. The dumortierite is distributed through these rocks in brilliantly colored splotches of red, pink, and lavender, but more commonly it occurs as a close-spaced network of pink veinlets. The area that contains this dumortieritic rock is outlined in Plate I; its boundary is, of course, not hard and fast, for the amount of dumortierite fades out gradually toward the borders. In much of this area hardly a cubic yard of the rock is without a veinlet of dumortierite, and in many places the veinlets are so abundant that they average an inch apart. They range in thickness from a small fraction of an inch up to 6 inches. They appear to follow no system or systems, though perhaps they are more commonly normal to the bedding.

The thinner veinlets consist chiefly of pink dumortierite with some quartz; in places they contain also a little brown tourmaline. The thicker veinlets consist more largely of quartz than the thinner ones, and some of this quartz is noteworthy because of its fine rose color. Between the rose quartz and the pink dumortierite all stages of gradation due to intergrowth of the two minerals can be followed in hand specimens. Under the microscope the transition can be seen more readily and what appears to be clear rose quartz to the unaided eye is found to inclose numerous hairlike fibers of dumortierite, many of which have the ultra-microscopic diameters of the thinnest sillimanite needles, which, indeed, they resemble indistinguishably. Where the dumortierite needles become too numerous the rose quartz loses its translucence. This new variety of rose quartz thus certainly owes its color to inclosure of capillary fibers of pink dumortierite.[23] The lavender-colored dumortierite, according to W. T. Schaller, gives a decided test for titanium. The titanium is thought to be present as Ti_2O_3, replacing Al_2O_3.

That the development of the dumortierite in the felsite was accompanied by other profound changes is evident in the field, but to determine what these changes are requires the aid of the microscope. Some silvery-white mica in small scales is in places apparent to the unaided eye, as well as a light-colored vitreous mineral that has a fairly good cleavage. Under the microscope the dumortieritized felsites are seen to have undergone a drastic alteration: all volcanic textures have been completely obliterated, and the rocks consist of four minerals in variable proportions—quartz, andalusite, dumortierite, and sericite. The quartz is the most abundant constituent and forms a fine-grained mosaic. The andalusite is generally second in abundance; it forms anhedrons as much as half an inch in length, many of which are markedly skeletal and inclose much quartz. The dumortierite is commonly in radiate groups of sillimanite-like needles or of fibers that have brushlike ends resembling sillimanite brushes. The thicker needles show a red, lavender, or blue pleochroism parallel to the *c*-axis and paler tones transverse to it. Where both dumortierite and tourmaline occur together, as in some of the veinlets, they contrast in pleochroism and absorption very markedly. The fine-grained micaceous mineral generally present in subordinate quantity is believed to be sericite, though some may be pyrophyllite ($HAlSi_2O_6$), which has indistinguishably similar optical properties. It has in part grown at the expense of the andalusite.

The extensive development of dumortierite and associated minerals is clearly due to the action of boron-bearing gases, which have undoubtedly escaped from an underlying granite magma and permeated the trachytes as they traveled upward through a closely spaced network of fractures. These emanations were evidently rich in silicon, aluminum, and boron and deficient in alkalies and sulphides. The development of andalusite by this pneumatolysis is noteworthy, though perhaps not surprising in view of the close resemblance of andalusite and dumortierite, especially in composition.[24] The metasomatic origin of andalusite appears to be rare. A

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[23] A preliminary account of the occurrence of the dumortierite in the Rochester district and the possible utilization of the rose quartz as a semiprecious stone was given by the writer in Schaller, W. T., Gems and precious stones: U. S. Geol. Survey Mineral Resources 1916, pt. 2, p. 893, 1919. J. C. Jones had earlier (Geology of Rochester, Nev.: Min. and Sci. Press, vol. 106, p. 737, 1913) identified the dumortierite as pink tourmaline (rubellite). Dumortierite is most easily distinguished from tourmaline by its cleavage and by its absorption, which is strongest parallel to its elongation.

[24] Schaller, W. T., Dumortierite: U. S. Geol. Survey Bull. 262, p. 110, 1905. The occurrence of dumortierite in Washington described by Schaller has the same mineral association as that in Nevada—namely, quartz, andalusite, dumortiertie, and muscovite—but its genesis is unknown.

remarkable example from the Inyo Range, Calif., has been described, where andalusite has formed in enormous quantity, making up a mass more than 300 feet wide, which has resulted from the replacement of a volcanic porphyry.[25] Andalusitic alteration of Tertiary lavas, an alteration that evidently took place under conditions somewhat different from those indicated for the Inyo and Rochester occurrences, has been described by Butler,[26] who pointed out that alteration of this kind had not previously been recorded.

KERATOPHYRES

OCCURRENCE AND CHARACTER

The slopes of Limerick Canyon consist largely of a series of altered volcanic rocks of keratophyric composition. They comprise tuffs, breccias, and lava flows, some of which are amygdaloidal. As a rule they are porphyritic, owing to the presence of phenocrysts of white striated feldspar, and as these feldspars are embedded in a darkish groundmass, the rocks wholly resemble andesite. Inasmuch as under the microscope the porphyritic crystals invariably prove to be albite, the rocks are termed keratophyres.

The dip of the keratophyre flows and breccias is prevailingly 30° W., though locally they stand vertical. The apparent thickness of the keratophyres on the north slope of Limerick Canyon, possible duplication by faulting being disregarded, is 4,500 feet. Southward they thin abruptly, so that on the ridge between Limerick and Rochester canyons they are much thinner. It must be pointed out that although boundaries are drawn on the geologic map (Pl. I) delimiting the keratophyre belt, yet a few sheets of keratophyre are intercalated in the adjacent trachyte, both east and west of the main belt where it crosses the divide between Limerick and Rochester canyons.

Smaller areas of keratophyre occur in the Black Range, east and southeast of Nenzel Hill.

PETROGRAPHIC FEATURES

The keratophyres contain numerous phenocrysts of albite, which are set in a fine-grained groundmass of rather dark color. A few have also phenocrysts of quartz, and such varieties may be termed quartz keratophyres. Crystals of albite as much as half an inch in length have been etched in relief on the weathered surfaces of some of the pyroclastic members. Most of the keratophyres are

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[25] Knopf, Adolph, An andalusite mass in the pre-Cambrian of the Inyo Range, Calif.: Washington Acad. Sci. Jour., vol. 7, pp. 549–552, 1917.

[26] Butler, B. S., Geology and ore deposits of the San Francisco and adjacent districts, Utah: U. S. Geol. Survey Prof. Paper 80, pp. 78–82, 1913.

roughly or even rather thoroughly schistose, and this is especially true of the tuffs and breccias. The considerable alteration, both dynamic and pneumatolytic, that these rocks have undergone interposes an insuperable obstacle to their satisfactory petrographic study.

However, of the many specimens examined microscopically all but a few contain albite phenocrysts only, so that they fall readily into the class of keratophyres. The phenocrysts of albite evidently resisted metamorphism more effectually than the other constituents and have survived both the dynamic disturbance (though some are cracked and broken) and the Jurasside pneumatolysis, even though the groundmass has been drastically altered. But under intense pneumatolytic attack some of the albite phenocrysts have been replaced by aggregates of biotite and calcite. What ferromagnesian minerals were originally present was determinable in only one rock examined—a quartz keratophyre from the summit of the 6,648-foot peak at the east margin of the district. It is the best-preserved keratophyre found and is massive and of grayish-green color. It is a porphyritic rock of dacitic aspect, containing phenocrysts of feldspar and quartz and chloritic pseudomorphs. Under the microscope the porphyritic minerals are seen to be albite ($Ab_{90}An_{10}$), microcline, and quartz. Chlorite pseudomorphs are abundant, some of which clearly are after pyroxene, for square sections with truncated corners are common.[27] The groundmass is fine grained and obscured by alteration products. This keratophyre is the only one found that contains phenocrysts of potassium feldspar along with those of albite and is therefore not typical of the series as a whole. The groundmasses of the keratophyre are generally indeterminable, but in a fragment inclosed in one of the pyroclastic breccias it could be seen that the groundmass is salic, consisting largely of albite in faint fluidal arrangement.

The keratophyres were richer in ferromagnesian constituents than the trachytes; hence their darker color and andesitic appearance. During dynamic metamorphism the ferromagnesian minerals were altered to chlorite, especially in the pyroclastic keratophyres, which thereby became chloritic schists, and subsequently by pneumatolysis the chorite was altered to biotite and concomitantly biotite was developed more or less promiscuously throughout the rock, even replacing the albite phenocrysts.

In many places pneumatolytic action has been particularly intense. Tourmaline is extremely common in such places, rather evenly scattered as innumerable black needles through the rocks thus affected, and biotite is unusually abundant.

[27] It is interesting to recall that Rosenbusch (Elemente der Gesteinslehre, 3d ed., p. 345, 1910), in defining the keratophyres, gives diopside as the characteristic ferromagnesian phenocryst.

RELATION OF KERATOPHYRES TO THE ROCHESTER TRACHYTE

The keratophyre contains in places some intercalated trachyte and banded trachyte tuff, proving that these different volcanic rocks were erupted contemporaneously. Where the two kinds are associated, as near Limerick Pass, the keratophyre is more highly schistose than the trachyte. Farther west in Limerick Canyon the keratophyre and trachyte form a distinct belt in which they alternate so regularly that it was desirable to map the belt as a separate entity. (See Pl. I.) The belt is not of uniform width but widens northward; the thickness of the alternating series is 900 feet on the summit of the ridge on the north side of Limerick Canyon, where the volcanic rocks stand practically vertical. Single sheets of keratophyre are as much as 100 feet thick. Near the top of the succession at this place is a keratophyre amygdaloid which is spotted white with numerous phenocrysts of albite and amygdules of quartz; it is fairly schistose, and its foliation planes shimmer from innumerable tiny flakes of biotite.

There are a few narrow belts at various places in the Rochester trachyte that appear to be of mixed origin, being due to a commingling of trachyte and keratophyre tuff. Through subsequent shearing and the development of secondary minerals it is impossible to determine certainly the origin of these rocks. They are darker than the felsites and somewhat lighter in color than the keratophyres, but their difference from either is not sharply defined.

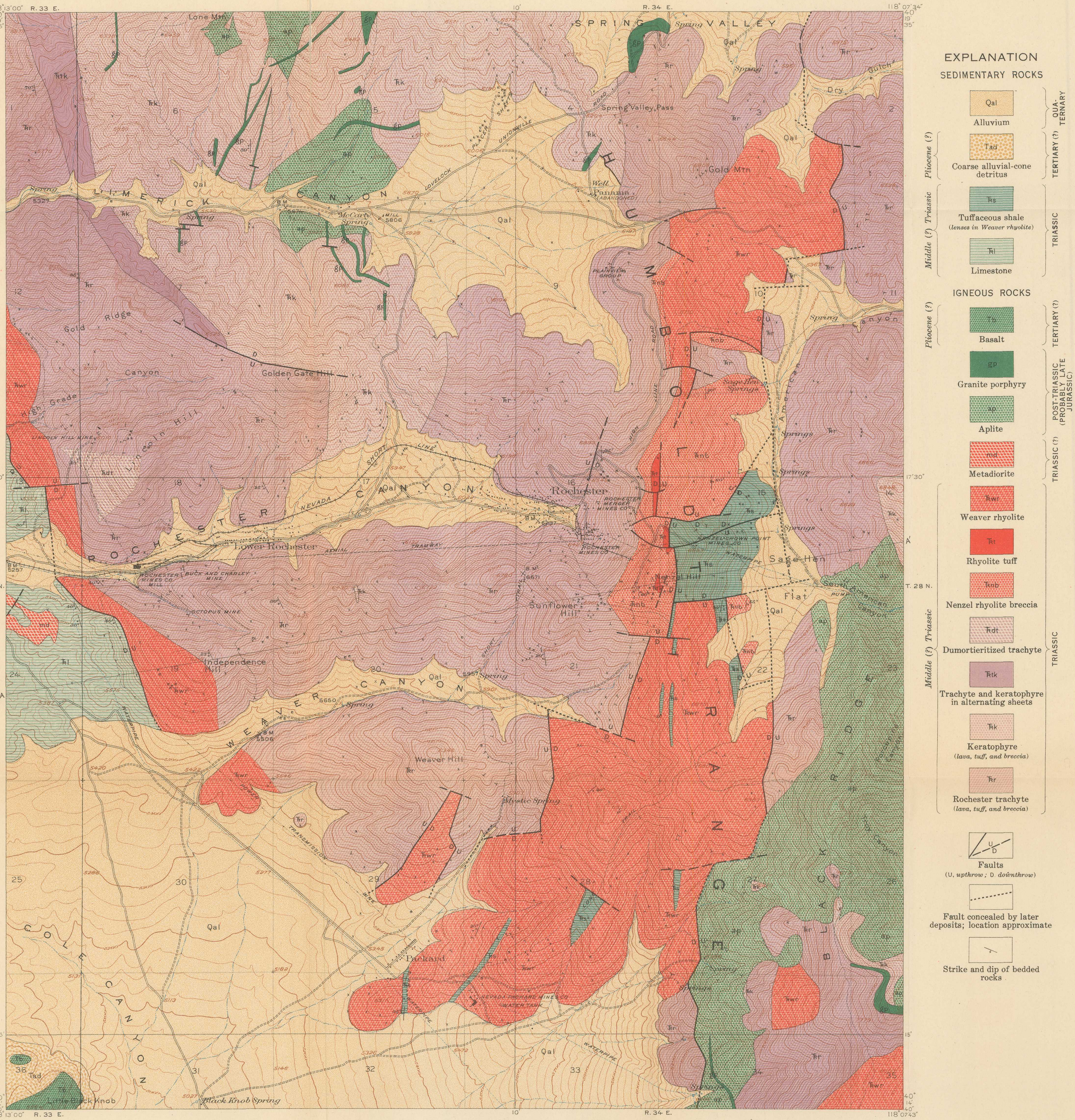
AGE AND CORRELATION

The keratophyre eruptions were clearly contemporaneous with those of the trachytes, and the keratophyres are therefore of Triassic age. The close association of these two varieties appears to imply a very notable magmatic differentiation during the Triassic volcanism, whereby the potassa was largely concentrated in one magma and the soda in another.

Keratophyres occur in other Triassic areas of Nevada. They are abundant in the Yerington copper district, where they are light-colored felsites with inconspicuous phenocrysts of albite.[28] Curiously enough, these rocks at Yerington do not in the least resemble in appearance the keratophyres of the Rochester district but they do resemble exactly the trachytes. In the Simon silver-lead district of Cedar Mountain, north of Tonopah, highly porphyritic quartz keratophyre is associated with limestone of Middle Triassic age.[29]

[28] Knopf, Adolph, Geology and ore deposits of the Yerington district, Nev.: U. S. Geol. Survey Prof. Paper 114, pp. 13–16, 1918.

[29] Knopf, Adolph, Ore deposits of Cedar Mountain, Mineral County, Nev.: U. S. Geol. Survey Bull. 725, pp. 363–364, 1921.



Topography by T. P. Pendleton
Surveyed in 1916

GEOLOGIC MAP AND SECTION OF THE ROCHESTER DISTRICT, PERSHING COUNTY, NEV.

Geology by Adolph Knopf
Surveyed in 1917

Scale 1/24000

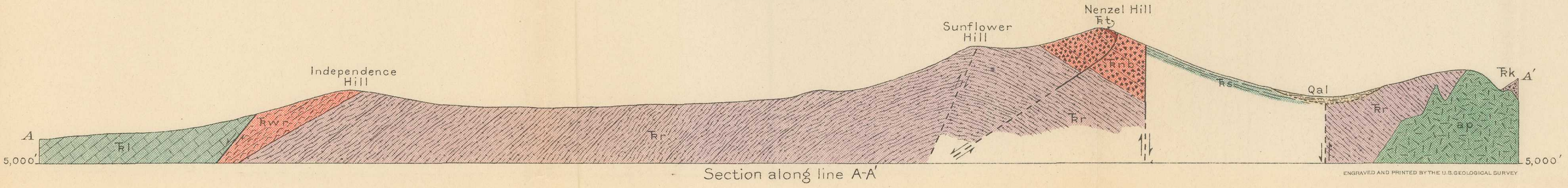
1 Mile

2000 1000 0 2000 4000 6000 8000 Feet

1 Kilometer

Contour interval 25 feet
Datum is mean sea level

APPROXIMATE MEAN DECLINATION 1916



Section along line A-A'

ENGRAVED AND PRINTED BY THE U.S. GEOLOGICAL SURVEY

In conclusion, it appears that the Middle and Upper Triassic were times of great igneous activity in Nevada, during which large volumes of widely diverse volcanic rocks were erupted. Andesite, dacite, trachyte, rhyolite, keratophyre, and quartz keratophyre are the principal kinds. The maximum aggregate thickness of these rocks is of the order of 10,000 or 15,000 feet.

NENZEL RHYOLITE BRECCIA

OCCURRENCE AND CHARACTER

The rock whose bold craggy outcrops form the summit of Nenzel Hill is here termed the Nenzel rhyolite breccia. It is of particular interest because the silver veins first discovered crop out in it, and these veins have yielded the bulk of the silver that the district has produced.

The most prominent member of the formation is generally devoid of bedding, though in a few places it contains fine-grained banded layers a few inches thick, which in the best exposure were seen to represent lenticular tuff beds pinching out within a length of 40 feet along the strike. Because of its massive outcrops the Nenzel rhyolite breccia closely resembles a lava, and this resemblance is enhanced by the fact that quartz and feldspar crystals are distributed evenly through it, like phenocrysts in a porphyry. That it is made up of ejected volcanic fragments, however, is indicated by the angular pieces of felsite scattered through it, though the breccia nature is generally obscure because the fragments resemble the matrix in which they are embedded.

The Nenzel breccia is generally stained from the oxidation of the secondary pyrite contained in it, but where it is absolutely unoxidized it is pure white. The component fragments are generally under an inch in diameter, though in places blocks as much as 16 inches in diameter occur. The microscope confirms the conclusions drawn from the field evidence as to the pyroclastic origin of the rock and its rhyolitic composition. The feldspar crystals and fragments prove without exception to be the potassium variety and somewhat perthitic. The rock fragments comprise felsites of various kinds—microspherulitic trachyte and so on—and rhyolite carrying quartz phenocrysts.

STRATIGRAPHY AND STRUCTURE

The best section of the Nenzel rhyolite breccia is that on the north end of Nenzel Hill; it is clearly exposed and displays a greater lithologic diversity than any other, and the stratigraphic relations are fairly well shown. (See fig. 3.) The lowermost member of the formation consists of a series of well-stratified breccias carrying as a notable feature an abundance of euhedral quartz crystals; these beds strike north and dip 35° E. They are 50 feet thick, but their full thickness is not shown here, as they are faulted against the underlying felsite along a north-south fault dipping 75° E. The breccia beds are turned up so that they dip 55° or more to the east adjacent to the fault, which is therefore clearly a normal fault. Farther south along the strike of the beds, south of the Boughton & Hackley tunnel, the indicated thickness is approximately 250 feet, although the base of the series is not satisfactorily exposed. The uppermost bed of breccia is rather coarse, containing boulders as much as 15 inches in diameter.

Above the stratified breccias lies a highly distinctive bed, a conglomeratic breccia or subangular conglomerate, which is 10 feet thick. It consists largely of felsite detritus plus white rhyolite that is dotted with quartz phenocrysts; much of this material is sharply

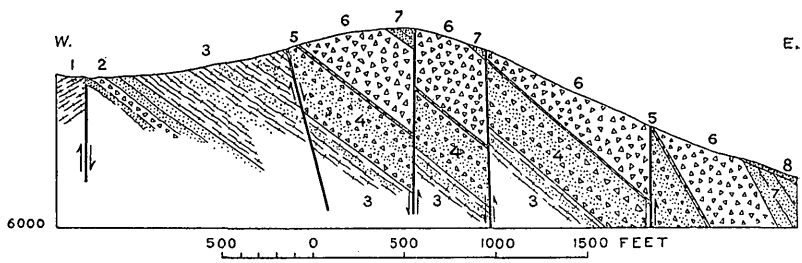


FIGURE 3.—Geologic section through the north end of Nenzel Hill. 1, Trachyte, roughly schistose; 2, trachyte tuffs and breccias; 3, trachyte flows with subordinate tuff; 4, bedded rhyolite breccia; 5, conglomerate; 6, rhyolite breccia, essentially without bedding; 7, well-bedded tuffs, resembling sandstones; 8, alluvium

angular, but some is well rounded. This characteristic bed can be traced only a short distance southward, nearly to the Transportation tunnel of the Rochester mine, but it extends northward for a mile, to the Plainview prospect. It appears locally on the east flank of the ridge also, as at Sage Hen Spring, where its presence is due to a number of strike faults that would not be detectable but for this bed.

Above the conglomerate is 25 feet of stratified tuff and breccia in beds ranging from 3 inches to 3 feet in thickness. Some of the beds are identical in appearance with the massive facies of the formation; others consist of white microcrystalline rocks devoid of the quartz crystals that are characteristic of the formation in general.

The massive member of the formation, whose outcrops form the crags on Nenzel Hill, rests on the bedded tuffs and breccias. It is without a trace of bedding, but its fragmental origin is here obvious, especially of the basal part. Fragments 16 inches in diameter are the largest that were seen. The total thickness of breccia above the conglomerate in the section shown in Figure 3 is 350 feet. The breccia is overlain by a well-stratified tuff that to the eye resembles a sandstone. The contact is a locus of weak mineralization and is doubtless a minor fault. Elsewhere the normal superposition of the sandstone-like tuff on the massive breccia is excellently shown, as on the summit of Nenzel Hill and on its south slope below the C P X shaft.

In summary, the Nenzel rhyolite breccia at its best exposure is 350 feet thick and incloses a conglomerate bed near the middle of the section. If allowance is made for the portion faulted out near the base of the section, the total thickness may be estimated at 600 feet.

As the formation is traced away from the type section marked changes in its lithology become apparent. Toward the south the conglomerate disappears, as already mentioned, and furthermore it becomes impossible to discriminate the bedded breccias that lie below the horizon of the conglomerate from the massive breccia above that horizon. The result is that the massive member has apparently increased greatly in thickness, and this increased thickness of resistant breccia has produced the unusually bold outcrops on the southern brow of Nenzel Hill. Toward the north the formation thins progressively: under the summit of the 6,893-foot peak it is not more than 30 feet thick and the intercalated conglomerate bed is only 3 inches thick. One of the flows of the Weaver rhyolite, a vuggy lava that is sporadically spherulitic, directly overlies the Nenzel rhyolite breccia here, the sandstone-like tuff that caps the breccia on Nenzel Hill having pinched out. There is some flow breccia at the contact of the lava with the underlying explosion breccia, so that it is difficult to distinguish the two rocks. Farther north the formation thicknes again, and at the Plainview prospect the conglomerate member is once more 10 feet thick.

The apparent great thickness of the Nenzel rhyolite breccia northeast of Nenzel Hill, on the east flank of the ridge—more than 1,000 feet—is due to repetition by faulting. At least three strike faults were detected, but these have not been shown on the map.

The Nenzel rhyolite breccia is somewhat unsatisfactory as a key rock, owing to the fact that breccias of similar appearance are intercalated at various horizons in the succession of lavas that make up the Weaver rhyolite. None of these other breccias, however, was found to inclose the characteristic conglomerate. Nevertheless, faults can not be invoked offhand to explain what at first thought might appear to be anomalous occurrences of breccias; but in the areas shown on Plate I the faults demanded by the stratigraphy to account for the distribution of the breccias, as those at the south end of Sage Hen Flat, are clearly exposed in prospect pits.

In conformity with the extensive faulting that the formation has undergone, the dip is highly variant: it is 35° E. in the type section at the north end of Nenzel Hill, horizontal in the Rochester mine above the Transportation tunnel, 30° E. on the summit of Nenzel Hill, 15° E. between the C P X shaft and the portal of the C P X tunnel, and 70° E. at the foot of the east slope of Nenzel Hill.

RHYOLITE TUFFS

Resting conformably on the Nenzel rhyolite breccia is a series of tuffs whose even, regular, sharply defined bedding is their most prominent feature. This clearly marked bedding has in fact led them locally to be called sandstones.

They are well exposed at various places on the summit of Nenzel Hill. At the Crawford shaft on this hill they exceed 70 feet in thickness, but as they are cut off on the east by a fault their full thickness is not known. The tuffs, as already shown in the description of the Nenzel rhyolite breccia, evidently accumulated as lenticular deposits; consequently the Nenzel breccia is not everywhere overlain by these well-stratified tuffs but in places is covered by the basal flow of the Weaver rhyolite.

The beds range in thickness from an inch to a foot or two. In grain the tuffs range from those so fine as to have a conchoidal fracture resembling that of argillite to those that might be termed fine-grained breccias.

Material from some of the thin beds that are particularly suggestive of sandstone was examined under the microscope. It is a white rock which is faintly but distinctly laminated or banded. It proves to consist largely of shards of glass now silicified, filaments of pumice, and angular bits of orthoclase and quartz. The crescentic and pronglike sections of the glass shards and the striated, drawn-out structure of the pumice fragments (like bits of pulled candy) unmistakably prove that this rock is an old rhyolitic ash. Despite the geologic vicissitudes through which this ancient ash has passed the vitroclastic texture has been strikingly well preserved.

WEAVER RHYOLITE

OCCURRENCE AND CHARACTER

The Weaver rhyolite consists chiefly of lava flows. Intercalated tuffs and breccias are small in volume, contrasting in this respect with the great thickness of pyroclastic rocks associated with the Rochester trachyte. The main area of the rhyolite forms a broad, continuous belt extending from Nenzel Hill to Packard, and as the formation is well exposed at the head of Weaver Canyon, it is named the Weaver rhyolite. At Packard the rhyolite is of economic significance, because the ore bodies of the Packard mine are inclosed in it. Another belt extends along the west slopes of Independence Hill and Lincoln Hill, where it is much more schistose than elsewhere.

The successive flows of the Weaver rhyolite are much alike, the consequence of which is to emphasize the unity of the formation. Certain features that are distinctive of the formation as a whole are widely prevalent—conspicuous phenocrysts of quartz and feldspar, spherulitic structure, and quartz nodules and geodes, which have been produced by the partial filling of gas cavities or of hollow spherulites with quartz. The variable development of these different features in one and the same flow gives rise to highly differing facies. For example, the quartz nodules due to the filling of hollow spherulites may locally be so abundant that the rhyolite containing them resembles a conglomerate made up largely of quartz pebbles.

The fresh rhyolite is white, but stained reddish-yellow varieties are most common. A botryoidal fracture is typical and under the microscope is found to be due to the spherulitic structure. Quartz phenocrysts are prominent in some flows, and pearly-white feldspar phenocrysts in others, but biotite or other dark minerals do not occur, nor do they appear ever to have been present, except in negligible quantity in some flows. The obviously porphyritic habit of these rocks and especially their prominent phenocrysts of quartz distinguish them from the Rochester trachyte.

The thickness of the Weaver rhyolite is at least 700 feet, but its full measure is unknown, for the original top of the formation was nowhere seen. The tuffs and breccias that occur in small volume in the formation closely resemble the Nenzel rhyolite breccia. North of Nenzel Hill the Weaver rhyolite rests directly on the Nenzel rhyolite breccia. Undoubtedly this breccia is the material ejected by the initial explosive outbursts that immediately preceded the outpouring of the succession of flows that make up the Weaver rhyoite.

PETROGRAPHY

The Weaver rhyolite, where fresh, is a pure-white rock, but in the mineralized areas it is generally stained yellowish, reddish, or buff from the oxidation of the pyrite. In structure it ranges from massive—that is, without a trace of foliation—to conspicuously though roughly schistose, with the foliation surfaces heavily plated, as it were, with silvery sericite. The rhyolites on the west flank of Independence Hill and Lincoln Hill are particularly strongly foliated, and their marked foliation is attributable to their being situated well down on the western limb of the anticline. In contrast, those occupying the main ridge, which are situated at the crown of the anticline, as a rule are entirely massive.

The spherulitic crystallization so common in most of the flows has given rise, where the spherulites radiate from widely spaced centers, to a botryoidal fracture, or, where the spherulites were originally hollow and have later been filled with quartz, to quartz nodules or spheroids, or to geodes where the filling has been incomplete. Geodes of this kind are in places as large as a hen's egg. Both features—the botryoidal fracture and the quartz-filled hollow spherulites—may, of course, occur together. The quartz filling is coarse, granular, and glassy; and although it forms nodules that may be as much as 1½ inches in diameter, the smaller nodules, averaging half an inch, are more common. In places they are so abundant as to make up half the bulk of the inclosing rhyolite. Schistose facies of such rocks closely resemble sheared quartz conglomerate. Where the quartz filling is in irregular masses it simulates inclusions of quartzite in the rhyolite.

Spherulitic structure, then, is a particularly noteworthy feature of the Weaver rhyolite. In fact, certain flows consist entirely of a closely packed aggregate of spheroids and ellipsoids of spherulitic origin. The spherulites rarely exceed half an inch in diameter. Under the microscope most of them are seen to be composed of radiating fibers of orthoclase, which show negative elongation. Others are made up of radiating fibers of orthoclase and quartz, the orthoclase as before showing negative elongation and the quartz positive elongation, higher birefringence, and index exceeding 1.54. Some spherulites consist of both positively and negatively elongated fibers of feldspar. Some of them are concentrically banded, and where contiguous spherulites have mutually interfered the outer bands have coalesced, producing in thin section lemniscate patterns.

The phenocrysts comprise quartz and microcline, both showing marked magmatic corrosion. Biotite is extremely rare and is invariably completely altered. The microcline, which does not show pronounced plaid twinning, is perthitic, the albite having separated out as well-defined lamellae in some of the phenocrysts. This perthitic microcline evidently represents ancient phenocrysts of sanidine that have become "unmixed"—that is, the original homogeneous solid solution has broken up into microcline and albite. The groundmass, as a rule, is microspherulitic.

In summary, the petrography of the Weaver flows shows them to be rhyolites of normal composition.

TUFFACEOUS SHALES

Lentils of tuff and shale occur in the Weaver rhyolite intercalated between successive flows. They are generally from 50 to 100 feet thick and exceed 1,000 feet in length. The most extensive area of these rocks is that on the east slope of Nenzel Hill, but their apparent considerable thickness here is doubtless due to duplication by faulting.

The tuff is white where unweathered; in degree of metamorphism it varies widely from sericitic phyllite to massive rock of almost felsitic aspect. The shale, or argillite, as some of it may be termed, is dark-colored. Some of the shale is slightly calcareous. Both tuff and shale are in places notably banded—a useful feature, as it allows the attitude of the inclosing rhyolite flows to be determined. One of the most instructive exposures of such an intercalated mass of banded shale is that in the hill southwest of Packard. It is best displayed on the southeast side of the hill; the sedimentary bedding is plainly apparent, dipping 35° W., and the cleavage cutting the bedding at high angles is excellently shown, as is also its refraction from bed to bed.

The long, narrow belt of tuff and shale at the Packard mine, a belt that is of particular economic significance, is bounded on both sides by parallel normal faults. Neither the presence of these faults nor the extent of the belt would have been determinable, except for the numerous exposures made during the course of mining.

LIMESTONE

GENERAL FEATURES

Limestone occurs in the western part of the district, forming the foothill slopes of the Star Peak Range. It is a dark-gray rock, which is stratified in beds averaging 3 inches in thickness, those as much as 1 foot thick being rare. One or two thin layers of shale are intercalated in the limestone and are notable for the innumerable prisms of tourmaline they contain. The limestone strikes N. 35° W. and dips 25°–40° W. It conforms thus to the strike and dip of the underlying Weaver rhyolite, from which, however, it is separated by a fault that strikes northwest and dips west, probably at an angle of 45°. The limestone shows considerable internal disturbance, and in places it has been buckled into small folds that cause local eastward dips.

The apparent thickness of the limestone exposed is 2,000 feet, but there may possibly be some repetition by faulting, and neither the top nor the bottom of the section is observable.

AGE

The limestone along the flank of Independence Hill is shown on the map of the Fortieth Parallel Survey as the southernmost extension of the Star Peak formation. It contains many fossils of ammonites and belemnites, but as a rule they are poorly preserved. A small lot of fossils recently collected from this area was submitted to T. W. Stanton, who reports as follows:

10078. Western part of Rochester district, Humboldt Range, Nev., in the Star Peak limestone of the Triassic. Only two fossils are recognizable in the limestone, one a small ammonite not well enough preserved for generic determination, the other a small slender belemnoid probably belonging to the genus *Atractites*. These fossils doubtless belong to the Triassic fauna, but I am unable to determine from them whether the rocks are Middle or Upper Triassic.

RELATION OF LIMESTONE AND VOLCANIC ROCKS

Within the mapped area (Pl. I) the formation mapped as limestone contains practically nothing but calcareous beds, but just south of the area it contains thick intercalations of volcanic rocks at several horizons. This assemblage of alternating limestone and igneous material is excellently exposed on the west flank and summit of the Black Range. Rhyolite tuff and breccia are interbedded with limestone, and thick belts of roughly schistose, coarse andesite breccia [30] and andesite amygdaloid [30] nearly half of the bulk of which consists of amygdules are intercalated in the limestone. From this locality Star Peak fossils were obtained by the Fortieth Parallel Survey.[31] It is thus apparent that the limestone and volcanic rocks are essentially contemporaneous and that Star Peak time was therefore a period of active volcanism.

The bedded rocks of the West Humboldt Range were divided by King and Hague into two groups—a lower group termed the Koipato, 4,000 to 6,000 feet thick, consisting of argillite and quartzite, which in places "remarkably resemble an erupted felsite porphyry," and an upper group, termed the Star Peak, 10,000 feet thick, consisting of "an alternation of three great limestone zones and three interposed quartzite zones."[32] In 1909 Ransome,[33] as a result of a rapid reconnaissance of the Humboldt Range, showed that the Koipato group, which he called the Koipato formation, consists predominantly of rhyolite and associated tuffaceous rocks and that the Star Peak greatly needed revision of its stratigraphy and lithology. These conclusions have been amply confirmed. The argillites, quartzites, and porphyroids of the Fortieth Parallel Survey are the rocks

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[30] Field determination; it may possibly be keratophyre.

[31] King, Clarence, Systematic geology: U. S. Geol. Expl. 40th Par. Rept., vol. 1, pp. 277–278, 1878.

[32] Idem, pp 268–278, 347, 1878. (Hague's usage differs from that of King; he refers to the Koipato as a "series" and to the Star Peak both as a formation and as a series. Idem, vol. 2, pp. 727, 729, 1877.)

[33] Ransome, F. L., Notes on some mining districts in Humboldt County, Nev.: U. S. Geol. Survey Bull. 414, pp. 31–46, 1909.

now termed trachytes, keratophyres, and rhyolites. Furthermore, much of the so-called quartzite in the Star Peak formation has likewise proved to be rock of volcanic origin.

The Koipato formation was regarded by King and Hague as of Lower Triassic age, and in considering it Triassic they have been followed by Ransome, Jones, and Schrader. What is actually known bearing on its age is that it lies conformably beneath the *Daonella* zone, of Middle Triassic age, as shown in the columnar section given by Smith (p. 10), who is noncommittal as to the age of the Koipato. Two considerations point to the conclusion that the formation is of Middle Triassic age: (1) The *Daonella* zone consists of limestone interbedded with tuff and may therefore represent the less active and waning stage of the volcanism that began during Koipato time; (2) volcanism did not break out in the Cordilleran region during the Mesozoic until Middle Triassic time. Where the Lower Triassic is present, as in the Inyo Range of eastern California, it is free from volcanic rocks, but during the Middle and Upper Triassic great volumes of volcanic rock were erupted.[34] Moreover, the volcanic rocks constituting the Koipato are essentially similar in degree of preservation and metamorphism to those in the overlying series, a correspondence that further supports the conclusion that they are all essentially contemporaneous.

METADIORITE

An irregular mass of diorite, which has been altered to metadioite, is intrusive into the Triassic limestone just south of Packard Station. Similar rock has not been found to occur elsewhere in the district. It has metamorphosed the limestone surrounding it, having caused numerous prominent crystals and sheaves of actinolite to form, without, however, altering the limestone matrix to marble.

The metadiorite is more or less schistose and has obviously been considerably metamorphosed, as shown by the amphibole it contains, which is in sheaf-like aggregates of fibers. Under the microscope the rock is found to be composed chiefly of granulated feldspar, which rarely shows albite twinning, actinolite in sheaves and radial groups, and chlorite; epidote and titanite are subordinate. It is accordingly termed a metadiorite.

On account of its metamorphic condition, the metadiorite is tentatively held to have been intruded before the post-Triassic deformation and therefore during the Triassic igneous activity.

[34] Knopf, Adolph, Geologic reconnaissance of the Inyo Range and the eastern slope of the southern Sierra Nevada, Calif.: U. S. Geol. Survey Prof. Paper 110, pp. 47–48, 58–59, 1918.

POST-TRIASSIC, PROBABLY LATE JURASSIC IGNEOUS ROCKS

APLITE

GENERAL FEATURES

A fine-grained white granite, a typical aplite, occurs as extensive masses in the district. It is particularly abundant at Lone Mountain and in Limerick Canyon, and it forms the backbone of Black Range. The aplite mass of Black Range is exposed in the gorge of South American Canyon, which cuts through the range, revealing it to a depth of nearly 2,000 feet; and from the summit of the range, with all the clearness of a diagram, the aplite mass can be seen in other deep canyons on the eastern flank of the range to pierce the crown of the great limestone anticline of which the range is here built. All the aplite bodies, whether on the flanks of the anticline or in the crown, are crosscutting intrusions, which have exerted no doming action on the surrounding rocks.

The aplite is intrusive into limestone, trachyte, and rhyolite and is itself intruded by dikes of granite porphyry. It is notably even grained in texture and homogeneous in composition. It is generally massive, though that in the Black Range is intensely shattered, evidently owing to its nearness to post-Tertiary lines of faulting, such as that along the west flank of the range.

A conspicuous feature of all the aplite masses throughout the district is the abundance in them of veins made up largely of black tourmaline and quartz. This prevalence of tourmaline attains its maximum near Lone Mountain, where there is hardly a cubic yard that does not contain a tourmaliniferous vein or veinlet. Furthermore, the keratophyres surrounding the intrusive aplite are intensely tourmalinized, so that it is manifest that here was a focus of powerful pneumatolysis.

PETROGRAPHY

The aplite is a fine-grained rock, devoid of all dark minerals, and is of white or light-gray color. Locally it has an inconspicuous miarolitic structure. Under the microscope the specimen selected for chemical analysis, from the Black Range, is seen to be composed essentially of potassium feldspar and quartz in sharply defined micrographic intergrowth. Albite ($Ab_{95}An_5$) is a rare pyrogenetic constituent, but it occurs in considerable amount as perthite, and this is confirmed by the analysis; its segregation during the breaking up of the original solid solution has been incomplete. Magnetite is a minor accessory. The grain of the rock is uniform, and the largest individuals hardly exceeed 1 millimeter in major dimension. The rock is fairly fresh, showing only minor sericite and a slight amount of kaolin. The chemical composition of the aplite is shown by the following analysis:

Analysis of aplite from Rochester district

[R. C. Wells, analyst]

SiO_2	77.10
Al_2O_3	12.28
Fe_2O_3	1.04
MgO	.04
CaO	.24
Na_2O	2.27
K_2O	6.17
H_2O-, H_2O+	.76
TiO_2	.13
Co_2	Trace.
	100.03

This analysis has been recast into mineral composition, as follows:

Orthoclase	36.7
Albite ($Ab_{95}An_5$)	20.5
Quartz	39.5
Accessory minerals	3.3
	100.0

GENETIC RELATIONS

The plutonic rock to which the aplite is genetically related is not exposed within the district. The nearest mass of this kind is the granite at Rocky Canyon, 5 miles north of the district. From the description and chemical analysis of this rock given by Hague[35] it is apparent that the rock would now be termed a quartz monzonite.

Analysis of granite from the Star Peak Range

[T. M. Drown, analyst]

SiO_2	68.58
Al_2O_3	16.51
FeO	2.52
MnO	.11
CaO	2.91
MgO	.47
Na_2O	4.28
K_2O	4.34
Ignition loss	.45
	100.17

[35] U. S. Geol. Expl. 40th Par. Rept., vol. 2, p. 715, 1877.

The quartz monzonite, as shown by Louderback,[36] is intrusive and is of post-Triassic, probably epi-Jurassic age. It forms a small mass, 4 miles long and 2 miles wide, and is doubtless to be interpreted as a stocklike upward extension of a large batholithic body lying at greater depth. The extensive bodies of aplite in the Rochester area have evidently been injected somewhat farther from the parent magma and locus of their origin than is common around most batholiths. Noteworthy also is the complete absence of lamprophyre intrusions, implying that the aplite has not resulted from the splitting of a parent magma into two so-called complementary magmas. It appears most probable that the aplite magma resulted from fractional crystallization and was subsequently squeezed out from the locus of differentiation.

The abundance of aplite associated with many of the Cordilleran batholiths is truly astonishing. In the Boulder batholith of Montana aplite occurs as innumerable dikes and as large stocks cutting the quartz monzonite, altogether aggregating between 5 and 10 per cent of the 1,100 square miles of the exposed area of the batholith.[37] In the Mount Whitney region of the Sierra Nevada aplite occurs in enormous abundance in the immense volume of quartz monzonite which there makes up the range.[38] The great escarpment of the Sierra shows, moreover, that the zone of aplite injection has a vertical extent of at least 6,000 feet. In neither the Sierra nor the Boulder batholith is there sufficient lamprophyre (in fact, lamprophyre is practically absent) to meet the demands of the hypothesis that aplite and lamprophyre are the complementary fractions of the differentiation of a parent magma.

GRANITE PORPHYRY

Dikes and small masses of granite porphyry occur throughout the Rochester district, though none, so far as known, occur in the productive part of the district. They are conspicuously porphyritic, mainly because of the prominent quartz crystals they contain, though in some dikes both quartz and feldspar phenocrysts are prominent. As the groundmass of the porphyry is light-colored and aphanitic, the rocks resemble the Weaver rhyolite. A point of difference, which, however, is not an intrinsic difference, is that the orthoclase phenocrysts of the granite porphyry have commonly been altered to aggregates of minutely scaly biotite. These biotite aggregates weather

[36] Louderback, G. D., Basin Range structure of the Humboldt region: Geol. Soc. America Bull., vol. 15, pp. 317–318, 1904.

[37] Knopf, Adolph, Ore deposits of the Helena mining region: U. S. Geol. Survey Bull. 527, pp. 34–35, 1913. Billingsley, Paul, and Grimes, J. A., Ore deposits of the Boulder batholith of Montana: Am. Inst. Min. Eng. Trans., vol. 58, p. 289, 1918.

[38] Knopf, Adolph, A geologic reconnaissance of the Inyo Range and the eastern slope of the southern Sierra Nevada, California: U. S. Geol. Survey Prof. Paper 110, p. 71, 1918.

readily to limonite, and the porphyry is commonly dotted with small rusty masses of limonite. It can not be affirmed that the porphyry ever contained any original ferromagnesian mineral.

The granite porphyry, or alaskite porphyry, as it may possibly be called, is the youngest member intruded during the Jurasside igneous activity. Its position in the igneous sequence is fixed by the fact that in Limerick Canyon a dike, 100 feet wide, cutting the Triassic keratophyre can be traced into the aplite, as shown in Plate I, and therefore must be younger than the aplite. Near Packard Springs a long dike of the porphyry traverses the great mass of aplite there.

Under the microscope the porphyry from the dike in Limerick Canyon shows phenocrysts of quartz, orthoclase, and albite, which are embedded in a groundmass that, remarkably enough, is partly spherulitic. The orthoclase phenocrysts are almost wholly replaced by deep-brown, highly birefringent biotite in small flakes. This alteration to biotite was evidently effected by solutions at high temperature. The alteration of pyroxene or hornblende to biotite is common during contact metamorphism or "high-temperature" vein formation, but the conversion of orthoclase to biotite appears to be less common. As if to leave no doubt concerning the character of the agency that produced the alteration, deep-blue tourmaline is associated with the biotite. Sericite also is developed.

The granite porphyry dikes and masses as a rule are much altered—by alteration of the orthoclase phenocrysts to pseudomorphs consisting of finely flaky biotite and by sericitization in general. The granite porphyry was injected after the aplite and before the main epoch of tourmalinization and attendant pneumatolysis, hydrothermal activity, and ore deposition. If these energetic tourmalinizing solutions originated within still unconsolidated portions of the aplite magma, as appears to be a reasonable hypothesis, then they must have ascended from great depths, for the aplite into which the granite porphyry was injected was cold enough to cause the porphyry magma to cool and consolidate so rapidly as to produce a spherulitic groundmass. A considerable interval must therefore have elapsed between the time of consolidation of the aplite now exposed to view and the emission of the tourmalinizing solutions, which were released after the intrusion of the granite porphyry into the aplite.

TERTIARY (?) ROCKS

PLIOCENE (?) ALLUVIAL-CONE DETRITUS

OCCURRENCE AND CHARACTER

Coarse detrital material consisting of angular blocks, some of which are as much as 6 feet in diameter, occurs in the western part of the district. It appears to be but loosely consolidated. It occurs at the mouth of Limerick Canyon, where it is maturely dissected to a depth of 400 feet, thus forming a series of rounded piedmont hills along the front of the Star Peak Range; it is widespread at the mouth of Rochester Canyon and extends continuously up to a point high on the east slope of the Humboldt Lake Range, and it occurs at Little Black Knob.

The detritus is evidently the material making up a series of ancient alluvial cones. It consists largely of boulders of Triassic trachyte and rhyolite derived from the Star Peak Range, but in places, as at Little Black Knob, it consists chiefly of fragments of limestone. Only rarely can the exact locality from which the detritus was brought be determined, but when boulders of the dumortierite rock are found it is at once manifest that the source was Lincoln Hill. Such boulders, several feet in diameter, occur high on the flank of the Humboldt Lake Range, 500 feet above the bottom of Rochester Canyon. They prove how deeply the alluvial cones have been dissected since they were built.

The thickness of the alluvial-cone detritus is unknown but exceeds 500 feet.

AGE

That the alluvial-cone detritus is of Pliocene age appears probable from the following considerations:

The detritus is overlain by the series of basalt flows that form so prominent an element in the architecture of the Humboldt Lake Range. These flows have been faulted and tilted, and it is this faulting and tilting, as is so convincingly demonstrated by Louderback,[39] that gave the range its elevation and essential topographic form. In short, the alluvial-cone detritus is older than the range. Since the range has come into existence it has been attacked by erosion, and deep, widely flaring canyons have been gnawed into it, some of them extending almost through it. Because of the diversity of events since the amassing of the alluvial-cone detritus—the eruption of great basalt flows, the blocking out of a mountain range, and the subsequent great erosion of this range—it seems reasonable to regard the alluvial-cone detritus as at least as old as Pliocene.

Subangular conglomerate, overlain by basalt and having the same stratigraphic position and geologic history as that in the Rochester district, occurs in the Yerington district, in western Nevada.[40]

BASALT

Basalt occurs only in the southwestern part of the district, which includes a bit of the eastern edge of the Humboldt Lake Range. It

[39] Louderback, G. D., Basin Range structure of the Humboldt region: Geol. Soc. America Bull., vol. 15, pp. 304–312, 1904.

[40] Knopf, Adolph, Geology and ore deposits of the Yerington district, Nev.: U. S. Geol. Survey Prof. Paper 114, pp. 26–27, 30, 1918.

makes up a number of superposed sheets, which rest on the older coarse alluvial detritus and tilted 12° E.

The basalt collected is highly vesicular and carries rather inconspicuous phenocrysts of glassy feldspar. Under the microscope the phenocrysts are seen to be bytownite ($Ab_{20}An_{80}$) and augite. The texture is seriate porphyritic. Basalt from Little Black Knob is compact and practically nonporphyritic. The sporadic phenocrysts in this basalt also prove to be bytownite ($Ab_{20}An_{80}$).

Olivine, partly altered to iddingsite, occurs in small crystals and grains. Augite is restricted to the groundmass, where it occurs in extremely minute grains. Both basalts are fresh.

The basalts of the Humboldt Lake Range were particularly studied by Louderback,[41] because they supply stratigraphic evidence that the west slope of the range is a fault scarp. Where seen by him they rest on Tertiary rhyolite or older rocks, but at the extreme north end of the range, in the Rochester district, they rest on a considerably younger formation, the Pliocene (?) alluvial-cone detritus. Because they overlie this detritus they are tentatively considered to be of late Pliocene age.

QUATERNARY ALLUVIUM

The floors of the canyons and of the valleys upon which the canyons open are covered with angular gravel. Locally the gravel contains gold, as in the broad basin at the head of Limerick Canyon. The shaft sunk farthest out in the flat in prospecting these gold-bearing gravels reached bedrock at a depth of 30 feet. In general, however, not much is known about the thickness of the gravel.

Along the sides of the canyons the gravel merges imperceptibly into the mantle of loose débris that covers the lower slopes of the ridges. On many slopes, especially south slopes, this mantle extends up surprisingly far. As a consequence prospect tunnels may have to be driven 50 feet or more before they cut bedrock. The extreme example of this is seen in the tunnel at an altitude of 6,269 feet northeast of Nenzel Hill; the tunnel, which is 200 feet long, does not penetrate to solid bedrock. As the slope of the hill is here 18°, the thickness of the débris mantle exceeds 60 feet.

During the spring, when the snow is melting, the mantle of débris has the consistency of mud and is in a state of flowage toward the canyon and valley bottoms. This flowage of rock detritus, or solifluxion, as it has been termed, is the chief process by which erosion is now going on in the region.

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[41] Louderback, G. D., op. cit.

STRUCTURE

FOLDING AND FAULTING

The major structural feature of the Star Peak Range is the broad anticline into which the Triassic rocks have been folded. In the latitude of the Rochester district the volcanic rocks form the core of the anticline, and the limestone that overlies them stratigraphically appears only in a narrow belt on each side of the range, as shown in Figure 2. Farther south, in the Black Range, or southern prong of the Star Peak Range, the limestone predominates. The anticlinal arch of limestone, spanning the full width of the range, can be seen remarkably well from the summit of the Black Range.

The dips of the western limb of the anticline are moderate, 30° W. being the average. On the east limb the dips are higher, averaging 60° E. The massive limestone on the ridge on the north side of American Canyon dips as much as 70° E., but this high dip is doubtless in part due to rotation of the limestone in the course of faulting that occurred long after the folding, probably while the range was being uplifted as a fault block. Though the structure is thus complicated by later faulting and concomitant steepening of dips by rotation, it appears probable that the anticline is asymmetric and that its axial plane dips steeply westward (75° W.).

In the Rochester district the axis of the anticline crosses near the head of Rochester Canyon in a northerly direction. It should pass through Sunflower Hill, as is inferable from the dips plotted on Plate I, but when a structure section is drawn through the hill (section *A–A′*, in Pl. I), it is seen that the structure demands a reverse fault along the axial plane of the anticline. The estimated displacement of this fault is 4,000 feet. If, however, part of the great thickness of the felsitic trachytes forming the western limb of the anticline, as shown in the section from Sunflower Hill to Independence Hill, is due to repetition by faulting, the amount of displacement along the axial plane becomes correspondingly reduced. Although this fault was sought for on Sunflower Hill, it could not be located on the ground because of the uniformity of the felsites there. On the north side of Rochester Canyon, however, the fault appears to cross the ridge where the Highline road crosses over into Limerick Canyon, there being an abrupt change in lithology on the two sides of the road. The extension of the fault southward from Sunflower Hill is doubtless the easily traceable fault on the south side of Weaver Canyon, which brings the Rochester trachyte against the Weaver rhyolite and is demonstrated by the mapping to be a reverse fault dipping 65° W. The crown of the anticline is here clearly broken by this fault. It is the known dip of this fault that warrants the dip that is given to the fault shown in the structure section.

The anticline appears to pitch southward, as indicated by the distribution of the Weaver rhyolite. Consequently the beds west of Sunflower Hill strike northwest and those east of it strike northeast; they converge southward to the nose of the anticline at Packard. This southward pitch of the anticlinal axis accounts for the fact that the limestone that stratigraphically overlies the Weaver rhyolite predominates in the south end of the range. Along the western flank of the range the strata strike 30° or 35° west of north, and consequently they make an angle of 30° or 35° with the meridional trend of the front of the range.

The simplicity of the broad anticlinal structure of the Star Peak Range is impaired within the Rochester area, as has already become apparent, by faults and by intrusions. The faults are many and include both longitudinal and transverse faults. Evidence of several periods of faulting is recognizable, and the main periods may be tentatively classified as (1) that which accompanied the folding at or near the end of Jurassic time, (2) that which accompanied the opening of the mineral-bearing fissures, and (3) that which accompanied the block-faulting by which the Star Peak Range was uplifted near the end of Pliocene time. As the range was uplifted during at least two stages separated by a protracted halt, the possibility of a fourth period of faulting is indicated.

The recognition of faulting within the area underlain by the Rochester trachyte is practically impossible, because of the essential uniformity of that formation. But in the overlying rhyolite sequence, where distinctive beds are recognizable, such as a conglomerate bed, or sandstone-like tuffs, faulting is readily determinable. Therefore, considerable faulting is shown on the map to occur on Nenzel Hill; indeed, it might be said that the amount of faulting detectable at any locality is proportional to the number of key horizons.

The section through Nenzel Hill shown in Figure 3 indicates further that even more faults occur there than are shown on the geologic map.

The earliest faulting appears to have taken place during the up-arching of the anticline. Such appears to have been the origin of the steep reverse fault on the south side of Weaver Canyon, which brings the Rochester trachyte over the Weaver rhyolite.

The faulting by which the vein fissures were opened resulted in both normal and reverse faults. Subsequent to the mineralization renewal of movement occurred along some of the veins, intensely crushing them, and is best illustrated by the East vein. Later than this postmineral shattering both normal and reverse faulting occurred, displacing some of the veins.

Extensive faulting occurred at the end of Pliocene time, when the range was uplifted as a great block of the earth's crust. Many faults are demanded by the physiographic features, and some of them can be found by detailed geologic mapping. The fault extending along the front of Independence and Lincoln hills occupies the position demanded by the physiographic consideration that the west slope of the range is a fault scarp. The dip of this fault as indicated by the mapping is 45° W.

The best example, however, is in the southern part of the district. The Black Range south of Packard Springs (at the edge of the area mapped) has clean-cut triangular facets upon its basal spurs, and the faulting to which these are due has produced a notable "oversteepening" along the base of the range. The fault thus indicated by the physiographic evidence as extending along the foot of the range south of Packard Springs passes north of the springs into the body of the range. It is there traceable as a fault between the aplite and the Rochester trachyte, and as determined from the mapping it dips 50° W. Physiographically it produces the terrace-like form, or shoulder, that at an altitude of 6,450 feet breaks the escarpment's otherwise even slope from the crest to the foot of the range.

SCHISTOSITY

The rhyolites, trachytes, and keratophyres are roughly schistose. The degree of schistosity varies widely, the rocks ranging from those that are almost imperceptibly foliated to those that are fairly well foliated. The lavas as a rule are only slightly schistose, but the associated pyroclastic beds, especially the finer tuffs, are notably foliated, and some of these rocks have been transformed into white phyllite or sericite schist.

The schistosity has essentially a regional constancy of direction; it strikes parallel to the trend of the volcanic rocks but dips invariably westward, both in the east and in the west limbs of the broad anticline into which the rocks of the Star Peak Range have been folded. The prevailing dip is 60° W., though on the west limb of the anticline the schistosity has a tendency to conform with the bedding and accordingly may in places dip as low as 25° W. Where tuffs and breccia alternate in thin beds, refraction of the schistosity in passing from bed to bed is well shown. Some of the least schistose rocks in the district are those on the summit of Nenzel Hill, where even the tuffs are massive; consequently it appears probable that they have escaped foliation because they occupy the crown of the anticline.

The peculiar relation of the schistosity to the bedding—roughly parallel to the bedding on the west limb of the anticline and transverse to it on the east limb—is noteworthy. If, as has been inferred, the anticline is an overturned arch whose axial plane dips 75° W., then the observed dip of the regional schistosity (60° W.) agrees fairly well with the dip of the axial plane of the anticline—an agreement that accords with certain theories on the origin of schistosity.

PHYSIOGRAPHIC HISTORY

The clues to the earliest history of the present land forms are in the deeply dissected alluvial deposits at the entrances of Rochester and Limerick canyons. The make up of these deposits, which consist of bouldery detritus containing angular blocks as much as 6 feet in diameter, shows that they were laid down at a time when the near-by country was of considerable relief and the streams that flowed from it were of great carrying power—in short, the alluvial deposits are the cones that were built up at the mouths of the canyons that indented the escarpment of a youthful fault-block range. They are the evidence of the initial uplift of the Star Peak Range; manifestly the southern division of the Humboldt Range—the Humboldt Lake Range—had not yet come into existence, for some of the alluvial cones extended over the site of the future range.

Subsequently the alluvial cones were partly buried under the succession of basalt flows that were poured out late in Tertiary time. The lava sheets now dip 12° E. and form the gentle east slope of the northern part of the Humboldt Lake Range, which here overlaps the south end of the Star Peak Range. The abrupt west slope of the Humboldt Lake Range is a fault escarpment, as has been so amply demonstrated by Louderback[42] by the concordance of structural, stratigraphic, and physiographic evidence. During the period of faulting by which the Humboldt Lake Range was formed the Star Peak Range was again uplifted.

That the Star Peak Range has attained its present altitude by two uplifts which were separated by a long halt is best recorded in Limerick Canyon. Near its mouth the canyon is a deep, acutely V-shaped valley, but upstream it widens, and at its head it has opened out to a broad, capacious basin, flat floored and underlain by gravel. (See Pl. I.) In an accentuated way it thus exhibits the feature so characteristic of valleys developed on the scarp flanks of fault-block ranges—that is, the valley is more mature headward. The prominent remnants of a high bedrock terrace along the lower part of the canyon, several hundred feet above the canyon floor, indicate that there were two stages in the dissection of the canyon and

[42] Louderback, G. D., Basin Range structure of the Humboldt region: Geol. Soc. America Bull., vol. 15, pp. 289–346, 1904.

therefore that a protracted standstill interrupted the uplift of the range. When the second uplift commenced the stream began to cut down to its present level, and the alluvial cones that had been built up along the front of the range as the result of the initial uplift began to be eroded. The cones are now maturely dissected to a depth of 400 feet and form a piedmont fringe of rounded hills.

The great block of the earth's crust that was lifted into the zone of erosion and sculptured into the Star Peak Range was not elevated as a single unbroken mass but was more or less internally fractured by subordinate dislocations. During the uplift of the main mass movements occurred along the other faults, as well as along the major fault that determines the west front of the range. The terrace-like forms on the scarp of Black Range have already been mentioned. By movement along the faults within the range some remarkably anomalous physiographic features have been produced. The most noteworthy is a rift valley, which is much like some of those along the San Andreas and Haywards faults of the Coast Ranges of California.[43] This rift valley lies east of Nenzel Hill and trends north; it is a relatively broad, open valley of alluviated floor and mature aspect. The northern part of the valley is drained by American Creek, and the southern part by South American Creek, but the divide between the two parts is almost imperceptible. The specially noteworthy feature is that the east wall of the rift valley is breached by South American Canyon, a sharp V-shaped gorge 2,000 feet deep. Evidently the faulting by which the valley was formed took place so slowly that the feeble stream in South American Canyon was able to maintain its course across the relatively rising edge of the fault block on the east side of the rift valley. As a result South American Canyon transects the Black Range, which here forms the east wall of the rift valley.

The main canyons of the district—Limerick, Rochester, and Weaver—have notably asymmetric cross sections, the north slopes being long and relatively gentle and the south slopes short and steep. In the spring the snow on the north slopes melts rapidly, and the débris mantle becomes a mass of mud and stones and flows toward the canyon floor. This solifluxion appears to be the main factor in the processes of erosion now at work. On the south slopes, however, owing to the poorer insolation, the snow persists much longer and hence a larger portion disappears by evaporation in the dry desert atmosphere. This greater evaporation of the snow on the south slopes appears thus to be the determining cause in the development of the asymmetric cross sections of the canyons.

[43] Lawson, A. C., U. S. Geol. Survey Geol. Atlas, San Francisco folio (No. 193), p. 17, 1914.

Part III.—THE ORE DEPOSITS

GENERAL FEATURES

The ore deposits of chief economic importance in the Rochester district are silver-bearing quartz veins and stockworks. Gold veins are of minor importance; and other deposits, carrying quicksilver or copper, are, so far as now known, only of geologic interest. The deposits are all inclosed in the Triassic volcanic rocks, chiefly the rhyolite and trachyte.

The silver-bearing veins are of the replacement fissure type. They occur mainly on Nenzel Hill and yield the larger part of the district's output of precious metal. Their economic value depends on the amount of argentite that they contain. As the argentite is of supergene origin, it diminishes in quantity downward, and below a moderate depth the veins are unprofitable.

The silver-bearing stockworks occur only at Packard, in the southern part of the district, and have yielded a notable portion of the output. Their tenor of silver is largely determined by their content of cerargyrite. The stockworks consist of masses of Weaver rhyolite that are cut by a widely spaced network of narrow veinlets. In freshly broken ore the veinlets are invisible, but after exposure to the weather they become apparent as extremely narrow seams, as is shown in Plate II. The stockworks are large bodies of elliptical surface area, but at shallow depths, not exceeding 30 feet, they become of too low grade to be workable. The ore mined has averaged under 8 ounces of silver to the ton.

The ore of the stockworks is commonly sericitic and more or less stained with limonite, but the cerargyrite is so finely disseminated as to be generally imperceptible. It is found very rarely as greenish waxy films. High-grade ore is indicated by an abundance of small pits or cavities that are due to the removal of sulphides, presumably sphalerite and pyrite. Much of the ore mined looks like mere country rock and has no visible indication that it is ore. These deposits are described in more detail on pages 70–73, under the description of the Nevada Packard mine, the only mine on stockworks.

RELATION OF ORE DEPOSITS TO WATER LEVEL

The abrupt relief and the arid climate cause the water table in general to lie at considerable depth. As a result water level has been reached in only two mines. In the Nevada Packard water level was cut in a prospect shaft at a depth of 235 feet below the lowest adit, whose portal is at an altitude of 5,590 feet. The position of the water level here is nearly 300 feet below the bottom of commercial ore. At the Buck & Charley mine water level was reached in the winze 42 feet below the lowest adit, whose portal is situated near the floor of Rochester Canyon: evidently this water represents the underflow of Rochester Canyon. Good ore was found in the winze and persists below water level.

On Nenzel Hill the East vein has been explored 1,600 feet below the outcrop, as measured on the vein, which dips 35° W., and water level has not been reached. In this vein as well as in other veins cut by the deep-level tunnels the downward limit of ore sufficiently enriched by argentite to be profitably workable has been found. The water table, however, lies far below that level. The enrichment, therefore, was not determined by the present position of the water table.

During the existence of the great Quaternary lake known as Lahontan the Humboldt Range formed a long peninsula jutting into it.[44] Inasmuch as the lake eventually disappeared by desiccation, the water table in the surrounding ranges doubtless sank concurrently during the increasing aridity. This sinking of the water table probably accounts in part for the fact that it now stands so far below the bottom of the zone of enrichment, but the main reason is probably that the enrichment took place much earlier in the history of the district. It may tentatively be suggested that the enrichment was effected during the initial uplift of the Star Peak Range and that the considerable vertical distance between the bottom of the zone of enrichment and the present position of the water table is due to the second and major uplift of the range.

SILVER VEINS

DISTRIBUTION AND GENERAL CHARACTER

The chief productive silver veins are on Nenzel Hill. They crop out in the Nenzel rhyolite breccia or in the overlying stratified rhyolite tuff of sandstone-like appearance. The outcrops are well exposed naturally, in places projecting 3 or 4 feet above the surface, and are easily traceable, some for distances exceeding 500 feet. The veins in general are narrow, averaging about 3 feet in thickness, though the two most productive veins, the East and West veins, average nearer 6 feet. At the outcrops they dip steeply westward, from 60° to nearly 90°. Both the East and West veins, of which more is known than of the other veins, flatten notably at depth, dipping 35° W. and locally as low as 15° W.

[44] Russell, I. C., Geological history of Lake Lahontan: U. S. Geol. Survey Mon. 11, pl. 4, 1885.

At moderate depth the veins pass from the Nenzel rhyolite breccia into the underlying flows and tuffs of the Rochester trachyte. A conspicuously flow-banded felsite, made up of an alternation of wavy bands each a fraction of an inch thick, is the prevailing country rock in depth. It has been considerably mineralized, so that most of the trachyte making up Nenzel Hill carries finely disseminated pyrite and sphalerite, and its gas cavities are lined or filled with quartz, sphalerite, pyrite, and galena.

The veins occur along fissures that have generally been produced by normal faulting. Along the East vein the displacement parallel to the dip amounts to 120 feet. (See p. 62.) A marked sheeting was developed parallel to the fissure and at many places has produced surfaces that simulate walls, which bound the ore. Much of the quartz filling has been formed by replacement of the wall rocks and is generally fine grained, a large part of it being almost or entirely chalcedony-like in appearance. The veins are therefore of the replacement fissure type. On account of the prevailing fine-grained nature of the quartz the veins on first examination appear to be of Tertiary age, or possibly of an analogous type that was formed in connection with the eruption of the Triassic rhyolites, but both impressions, as will be shown later, prove to be wrong. Some of the veins have been crushed by postmineral movement, and thick gouges have been produced along both footwall and hanging wall of one and the same vein. In its narrower portions a vein may be wholly reduced to a white gouge filled with angular fragments of crushed quartz. In places postmineral fissuring has produced gouges in the country rock, and as those gouges consist of felsitic fragments they resemble exactly the gouges resulting from the crushing of the chalcedonoid quartz veins.

In addition to the veins on Nenzel Hill, which have supplied the bulk of the silver that Rochester has produced, other veins of essentially similar character occur in the western part of the district, at Lincoln Hill, Lower Rochester, and Octopus Gulch. They are of subordinate economic importance but have proved genetically more illuminating than those on Nenzel Hill.

The Contact lode at Packard (pp. 71–73) differs markedly from the other silver deposits of the district, consisting of sheared, highly sericitized rhyolite adjoining a fault; but, like the other deposits, it contains ore only where it has been enriched by descending solutions, and the protore carries less than an ounce of silver to the ton.

NATURE OF THE ORE

The ore of the veins on Nenzel Hill is prevailingly composed of fine-grained quartz. The only recognizable metallic mineral in most of the ore is pyrite, which is scattered through it as minute grains in small amount; but there can be seen, especially in the richer ore, many small blackish patches, of bluish cast and suffused outline, whose presence immediately indicates, to those familiar with the ore, that such ore is high in silver. Ore showing these blackish mottlings becomes, when simply heated in the forge to redness, coated with innumerable bright beads of metallic silver. In thin section the ore of this kind is seen to contain scattered particles of a lead-gray metallic substance, which is therefore identified as argentite.

In ore from the deeper levels, especially in unoxidized ore, resinous sphalerite is fairly common though nowhere abundant, galena is occasionally detectable, and tetrahedrite occurs as minute particles. The bluish-black mottlings also occur. In high-grade ore, which is characteristically somewhat porous from the partial removal of sulphides by leaching, minute scales of covellite can easily be recognized as lining the pores, and covellite of this kind persists down at least to the level of the Friedman tunnel, 800 feet in vertical depth below the outcrop of the veins. In addition to the pyrite, sphalerite, galena, tetrahedrite, and covellite already mentioned, chalcopyrite becomes apparent in thin sections and polished specimens as a very minor constituent, and argentite is seen to form narrow borders around grains of sphalerite and tetrahedrite. Covellite is closely associated with some of the argentite, but most of the covellite occurs alone as borders around grains of sphalerite.

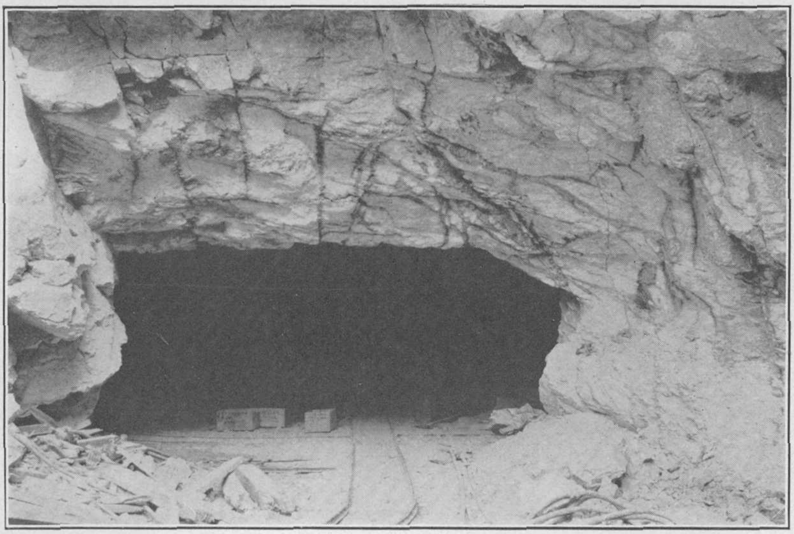
The ore is commonly deeply stained with limonite, which gives it the prevailing rusty color. Jarosite (a potassium-ferric sulphate) occurs in some of the ore of the upper levels and appears to have been formed as the result of the reaction of ferric solutions on sericite.

In places the oxidized ore contains pure-white, waxy halloysite, which checks upon drying. Locally some of the veins where cut by the Friedman tunnel are coated by an efflorescence of copper sulphate.

The partly oxidized, limonite-stained condition of the quartz-silver ores persists down to the greatest depth attained by mining, which on the East vein is 1,600 feet as measured on the vein. Because of the low dip of the vein and the slope of the surface this depth is vertically only 300 feet.

ENRICHMENT BY SUPERGENE ARGENTITE

The tenor of the silver ores of the Rochester district depends largely, if not wholly, on their content of argentite. This argentite is rarely distinctly visible, and even where visible it does not occur in particles that are large enough to be surely identified by the unaided eye, though its presence gives rise to a bluish-black mottling of the quartz in which it is inclosed. At the Octopus mine, however, it is



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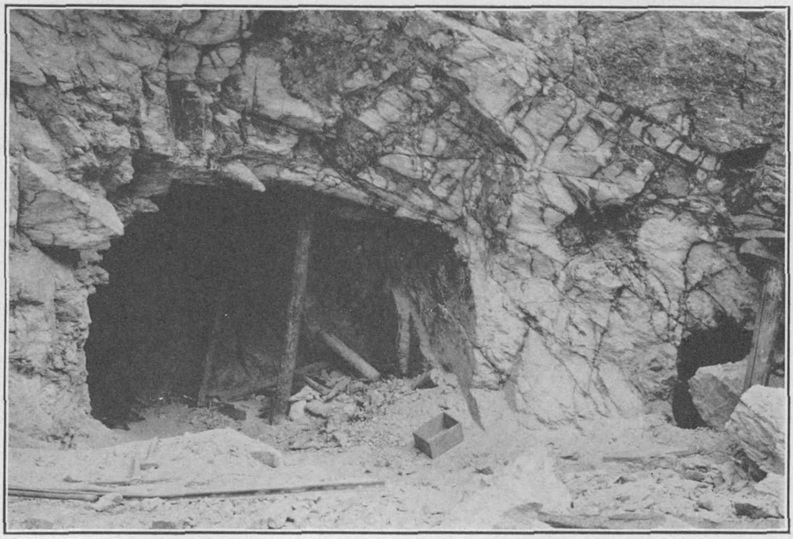
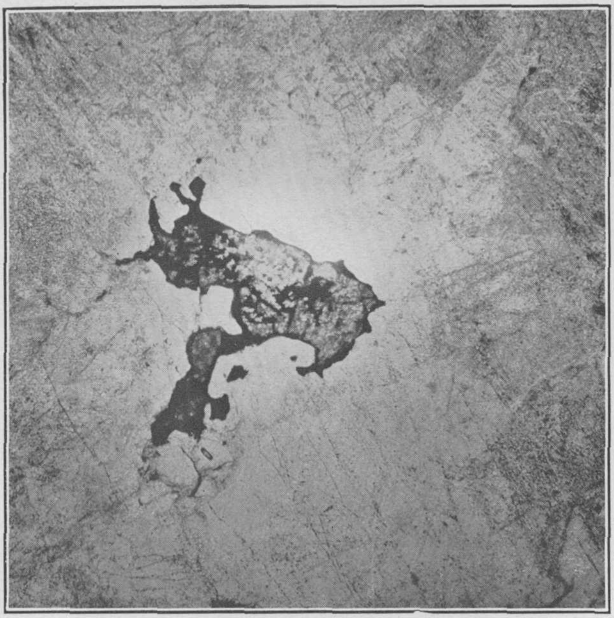
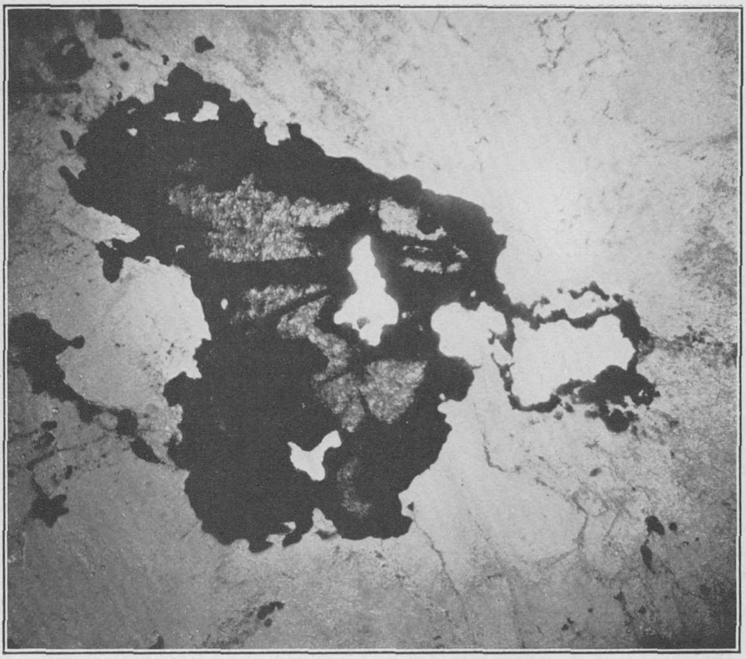


B

SILVER-BEARING STOCKWORK AT THE NEVADA PACKARD MINE



A. INCIPIENT REPLACEMENT OF SPHALERITE BY SUPERGENE ARGENTITE



B. ADVANCED REPLACEMENT OF SPHALERITE BY SUPERGENE ARGENTITE present in fairly large blebs of soft, dull-blackish material, which on chemical examination proves to be pure argentite free from admixed copper or lead compounds. It is a rather compact form of the so-called sooty argentite.

The argentite, as seen under the microscope, commonly occurs as a border around sphalerite and as embayments in the sphalerite. It is clearly of later origin than the sphalerite and has formed at the expense of that sulphide. An early stage of replacement of the sphalerite by argentite is shown in the specimen illustrated in Plate III, *A*, in which the argentite forms a discontinuous fringe on the sphalerite. The tendency of projecting points of the sphalerite to succumb completely to replacement early in the process is well shown. Some argentite has formed also within the interior of the sphalerite grains, the solutions that caused this replacement having doubtless gained access to the interior by way of the cleavage cracks. In Plate III, *B*, is illustrated a more advanced stage of replacement, as indicated by the thicker coating of argentite on the sphalerite. Some unreplaced nuclei of sphalerite in the coating can still be discerned in the illustration. The partial control exerted by the cleavage on the course of the replacement, as indicated by certain rectilinear boundaries, is also well shown; but on the whole, in this grain as well as in all other grains of sphalerite, it is remarkable how little the excellent cleavage of the sphalerite has directed or controlled the course of replacement. The replacement has proceeded centripetally by increase in thickness of the border of argentite. The smaller grains of sphalerite originally scattered through the ore have in this way been wholly transformed into argentite. Covellite is commonly associated with the argentite; but it is far more abundant alone, occurring as borders around grains of sphalerite. It forms also rims around the galena, tetrahedrite, and chalcopyrite and perhaps around some of the pyrite, though covellite as a coating on pyrite has not been positively identified. Although grains of pyrite are common in the ore, none of them were found to be coated with films of argentite, and none, with perhaps insignificant exceptions as already noted, are coated with films of covellite—in other words, the pyrite was practically immune to the reactions that produced the argentite and covellite, and this immunity is to be attributed to the fact that the easily attackable sphalerite was present in abundance. It is clearly manifest that the sphalerite reacted much more readily to form argentite and covellite than any other hypogene sulphide in the ore, except possibly the galena.

It is noteworthy that the boundaries between the hypogene sulphides, such as those between sphalerite and tetrahedrite or chalcopyrite, are sharp, clean-cut, and rectilinear as seen in polished sections of ore, whereas the boundaries between argentite and sphalerite and those between covellite and sphalerite are highly irregular through innumerable minute indentations, and as a result they characteristically appear fuzzy or blurred.

The argentite and the covellite intimately associated with it were obviously formed later than the sphalerite, tetrahedrite, galena, and chalcopyrite. The soft, pulverulent condition of the argentite, the leached appearance of the rich ore, and the marked decrease in the quantity of argentite in the deeper levels all combine to prove that the argentite was formed by descending solutions that had derived their silver from the oxidation of sulphides in the zone of weathering. In short, the argentite, which determines the silver content of the ore, is of supergene origin.

The source of the silver in the supergene argentite appears to have been the tetrahedrite in the ore, which is the only hypogene mineral that is probably silver-bearing that has been found in the ore. Hypogene argentite may occur, but if so it has not been recognized. When the hypogene sulphides—pyrite, sphalerite, tetrahedrite, and chalcopyrite—were attacked by atmospheric waters as the tops of the veins became exposed at the earth's surface, they yielded solutions containing sulphuric acid and sulphates of iron, zinc, silver, and copper. These solutions moved downward along the veins without change of chemical composition until they came into contact with unaltered sulphides. Thereupon they began to react with the sulphides, especially with the sphalerite, as shown so abundantly in the microscopic sections of the ores. The reactions that were of chief importance are expressed by the following equations:

$$(1)\quad ZnS+Ag_2SO_4=Ag_2S+ZnSO_4$$
$$(2)\quad ZnS+CuSO_4=CuS+ZnSO_4$$

and possibly

$$(3)\quad CuS+Ag_2SO_4=Ag_2S+CuSO_4$$

The first two equations give the reactions by which the argentite (Ag_2S) and the covellite (CuS) were formed at the expense of the sphalerite (ZnS). That both reactions took place appears to be proved beyond all doubt by the microscopic evidence. Which reaction occurred first depended upon the relative concentrations of silver and copper ions in the descending solutions.

Because of the far greater abundance of primary copper minerals that were being oxidized in the outcrops of the veins, the copper ions were present in enormous excess over the silver ions. The solubility product[45] of silver sulphide is 4×10^{-50} and that of cupric sulphide 1.2×10^{-42}, as given by Stieglitz.[46] Therefore, from a solution containing both silver and copper ions silver sulphide will be precipitated alone until the cupric ion becomes 3.3×10^{7} as concentrated as the silver ion. Cupric sulphide will then be precipitated, with traces of silver sulphide. In spite of the enormous excess of cupric ions in the descending solutions, it is probably not great enough to prevent the silver sulphide from being precipitated first, because the solubility product of the silver sulphide is exceedingly small.

On applying these chemical principles to the problem of silver enrichment at Rochester, it appears likely that the process was as follows: Highly dilute solutions of ferric, cupric, and silver sulphates were formed in the outcrops of the veins. As these solutions trickled downward they gradually reached the primary sulphides, where the silver ions combined to form silver sulphide (argentite) with the available sulphur ions, which were furnished chiefly by the sphalerite. Evidently this reaction took place before the ferric ions were reduced to ferrous ions by the primary sulphides, for no native silver was precipitated, as it would have been if there had been an appreciable concentration of ferrous ions. As the solutions moved downward they gradually became depleted in silver ions, until eventually the concentration of the cupric ions relative to the concentration of the silver ions became sufficiently high to cause the precipitation of cupric sulphide (covellite). Therefore, the zone in which covellite was formed should extend farther in depth than the zone in which argentite was formed. The actual extent of the covellite zone in the Rochester veins matches with this conclusion, for supergene covellite perists in noteworthy abundance below the zone in which argentite has formed in economic quantity. That covellite was precipitated instead of chalcocite indicates, as does the absence of metallic silver, that the concentration of ferrous ions in the descending solutions was low.

Because of the steadily progressive lowering of the surface by erosion, the zone of oxidation must in the course of time have encroached upon the zone of enrichment. The supergene silver in the enriched ore thus attacked must have been redissolved and carried farther down. As it moved downward it must first have descended through a zone in which the sphalerite had either all been used up

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[45] The principle of the constant solubility product "is an extremely convenient condensation, into a very simple mathematical form, of the main factors involved in the precipitation and solution of difficultly soluble salts, acids, and bases" (Stieglitz, Julius, Qualitative chemical analysis, pt. 1, p. 143, 1916). This principle is that in a saturated solution of a difficultly soluble salt the product of the concentrations of the ions of the salt is constant at a given temperature. Precipitation of the difficultly soluble salt will therefore result when the product of the ion concentrations becomes greater than the solubility-product constant for that substance.

[46] Op. cit., pp. 224, 212.

or had been insulated with coatings of supergene covellite. In theory the solutions should then have reacted with the covellite according to the equation

$$CuS+Ag_2SO_4=Ag_2S+CuSO_4$$

This reaction has been experimentally established by Posnjak.[47] The copper thus dissolved during this reaction would be carried downward and reprecipitated on sphalerite in the lower part of the zone of silver enrichment.

Material sufficiently enriched by the deposition of supergene argentite to be ore has a maximum vertical range on Nenzel Hill of 800 feet, or 1,400 feet as measured on the vein. Formerly the vertical range must have been greater, for ore containing supergene argentite occurs at the outcrop. During the present cycle of erosion the zone from which the silver was leached to supply the zone of enrichment has been eroded away from some of the veins, and the enriched zone has consequently been exposed at the surface. The vertical extent of the portion of the enriched zone thus removed by erosion is, of course, not determinable.

During the present cycle of erosion, while the water level has stood so low under Nenzel Hill—more than 900 feet below the outcrops of the chief veins—oxidation has deeply stained the enriched ore with limonite derived from the pyrite. That in the course of this oxidation any silver has been carried down to form an enriched zone at present water level is highly improbable, inasmuch as the abundant finely divided supergene covellite below the zone of argentite enrichment would inhibit the silver from moving far downward, because of the ease with which it would be precipitated. That such an enriched zone is not absolutely impossible, however, is suggested by the fact that if the descending silver-bearing solutions moved rapidly enough down through the veins, all their silver may not have been precipitated until they had been slowed down at or below water level.

WALL-ROCK ALTERATION

The wall rocks have been altered by the primary ore-depositing solutions, mainly by silicification. In fact, much of the quartz gangue of the veins themselves is due to replacement of the country rock by quartz; hence the prevailing fine grain of the ore. Where the Nenzel rhyolite breccia has been replaced phenocrysts of quartz remain as relicts. In some of the ore, in which shattered and brecciated country rock has been replaced, "ghosts" of the angular fragments are still visible, and the various stages of obliteration and

[47] Posnjak, Eugene, Determination of cuprous and cupric sulphide in mixtures of one another: Am. Chem. Soc. Jour., vol. 36, pp. 2475–2479, 1914.

disappearance of the phantom fragments as the result of more thorough silicification can readily be followed.

The best megascopic evidence of siliceous replacement is assuredly to be seen in those places where quartz veinlets break across the conspicuous flow banding of the Rochester trachyte. The central portion of the veinlets consists of moderately coarse white quartz, and this is bordered on each side by an irregular band of dark-gray chalcedonoid quartz, which cuts off diagonally the flow bands of the trachyte. In general, the microcrystalline quartz formed by the replacement of the rhyolite and trachyte is exceedingly like the felsitic groundmasses of those rocks; and it is probable, therefore, that the amount of silicification is likely to be overestimated by the eye.

Under the microscope it was found that silicification was the dominant process near the veins and that the development of sericite was the main alteration effected at greater distances from the veins. The quartz of replacement origin has characteristically an extreme variability of grain, ranging from cryptocrystalline to moderately granular within fractions of the area of a thin section. The microcline phenocrysts of the trachyte were more easily replaced than the groundmass and have commonly been pseudomorphosed by relatively coarse aggregates of quartz. In less highly altered rock sericite is abundant, generally as ultra-fine fibers and scales. Pyrite and sphalerite are common in the altered wall rocks.

The descriptions of the preceding paragraphs apply especially to the veins on Nenzel Hill, which carry no tourmaline. In the tourmaline-bearing silver veins, such as the Octopus and Raven, the ore is essentially like that of the nontourmalinic veins, and the metasomatic alteration of the wall rocks is also similar, except that the ore in places carries multitudes of minute prisms of black tourmaline and that tourmaline has developed in the wall rocks along with the quartz, sericite, and sulphides.

GOLD VEINS

GENERAL CHARACTER

The gold-bearing veins of the Rochester district are few and have been worked on a noteworthy scale in only one mine. They are quartz veins inclosed in the Triassic volcanic rocks. They are all notable in that either they contain tourmaline in their gangue or their wall rocks contain it.

The most productive mine is the Lincoln Hill, where several narrow quartz veins have been worked. Short shoots of ore high in free gold have been extracted.

The quartz in the gold veins is coarsely granular, in marked contrast with that in the silver veins, which is commonly so fine grained as to be almost like chalcedony in appearance.

Some of the gold-quartz veins are remarkable in that they contain abundant coarse microcline. The Hagan lode, which is in keratophyre, consists of quartz, tourmaline, and microcline that shows the characteristic plaid twinning under the microscope. The Horseshoe vein, which cuts the Weaver rhyolite a mile east of Packard and in places is 12 feet thick, contains abundant microcline and silvery-white mica in its gangue of coarse milky-white quartz. The microcline in this vein resembles albite in appearance, but its refractive indices and plaid twinning fix its identity. The twinning of the microcline in both these veins is not due to dynamic deformation, as the associated quartz is uncrushed and optically normal.

Tourmaline-bearing dumortierite-quartz veins, tourmaline-bearing gold-quartz veins, and tourmaline-bearing silver-quartz veins occur in close proximity to one another on Lincoln Hill, but there are no transitions between veins of any of the three types, nor are there any transitions between them elsewhere in the district.

NATURE OF THE GOLD ORE-FORMING SOLUTIONS

The wall rocks of the gold veins have been altered by the action of the ore-depositing solutions, which have caused the development in them chiefly of quartz, tourmaline, and pyrite and subordinately of sericite. Adjoining the Oro Fino vein the alteration has been so thorough that the original wall rock has been converted into a black rock composed wholly of tourmaline and quartz, which forms a selvage 1 to 2 feet thick on each side of the vein. The gangue of the Hagan lode is pegmatitic, consisting of a coarse aggregate of quartz, microcline, and columnar tourmaline. The evidence is clear that the gold ores were deposited from solutions at a very high temperature. The microcline in the veins indicates that the temperature was between 400° and 600°.[48]

The tourmaline content of the veins and the clear connection between the aplite masses and tourmalinization, so obvious in the field, point unmistakably to a genetic relation between the mineralizing solutions and the aplite intrusions. It will be assumed that, in conformity with current doctrine, the mineralizing solutions were differentiates or distillates from deep-lying portions of the aplite magma.

The gold veins do not grade into the silver veins. This is well shown on Lincoln Hill, where both gold and silver veins occur.

[48] Mäkinen, E., Ueber die Alkalifeldspäte: Geol. Fören. Förh., Band 39, pp. 121–184, 1917.

Moreover, the large area of dumortieritized trachyte interlaced with innumerable dumortierite-quartz veins and veinlets is on Lincoln Hill, and though this dumortieritization is undoubtedly the earliest mineralizing effect of the aplite intrusion, there is no trace of a gradation between this effect and the later ones, as represented by the gold and silver veins.

OTHER MINERAL DEPOSITS

A few other mineral deposits occur, which differ widely from the gold and silver deposits already described. They include a cinnabar deposit, a jamesonite-quartz vein, a tourmaline copper-bearing vein, and a baritic deposit. They do not appear to be of economic value, but they are of interest in showing the diversity of mineralization in the district.

CINNABAR

A cinnabar deposit occurs in American Canyon a mile east of the area shown in Plate I. A small reduction plant was erected here about 1908, and a little quicksilver was produced. An incline sloping 15° NE. and 200 feet long was sunk in the deposits, and considerable drifting was done. This work has failed to disclose the shape of the deposit, which is noteworthy for the numerous white walls that traverse it at various angles and that for evenness, whiteness, and smoothness rival artificial walls finished with plaster of Paris.

The deposit consists of soft white crushed material containing numerous fragments of a fairly hard substance of unctuous appearance suggestive of compact sericite. It was originally described by Ransome [49] as a kaolinized zone in rhyolite, and under the supposition that the material is kaolin several wagon loads of it were shipped out in 1917 to determine its ceramic availability. Under the microscope the material of the kind shipped is seen to consist of sericite and quartz, and this determination is confirmed by the accompanying chemical analysis. The original rock from which the sericitic material was derived is a highly flow-banded felsite, typical of the Rochester trachyte. Consequently, the analysis of the type specimen of the Rochester trachyte is given here again, in order to show the drastic changes that accompanied the sericitization. These changes comprise chiefly the addition of silica and water and the removal of potassa in large quantity.

[49] Ransome, F. L., Notes on some mining districts in Humboldt County, Ariz.: U. S. Geol. Survey Bull. 414, p. 37, 1909.

Chemical analyses of sericitized trachyte and unaltered trachyte

[R. C. Wells, analyst]

	1	2
SiO_2	74.58	67.01
Al_2O_3	17.24	15.97
Fe_2O_3	.65	2.54
FeO	----------	.44
MgO	Trace.	Trace.
CaO	.18	.19
Na_2O	.27	1.92
K_2O	4.47	11.42
H_2O-	2.72	.28
H_2O+		
TiO_2	.17	.39
CO_2	Trace.	----------
	100.28	100.16

1. Highly sericitized trachyte from Quicksilver mine, Rochester, Nev.
2. Unaltered trachyte, Gold Mountain, Nev.

With $K_2O.2H_2O.3Al_2O_3.6SiO_2$ as the formula of sericite, computation of the analysis shows that the material consists of 55.50 per cent of quartz, 42.03 per cent of sericite, and 1 per cent of other minerals.

Some specks of cinnabar were found in places scattered through the sericitic mass and were the incentive that led to the exploration of the deposit. Small siliceous masses or blebs not exceeding a foot in length occur sporadically through the deposit. In these the sericite is coarse enough to show a silvery luster, and the small druses in them contain small fibers of black tourmaline. Under the microscope the tourmaline and sericite appear to be contemporaneous, which leads to the unexpected conclusion that this quicksilver-bearing deposit was formed under conditions that admitted the formation of tourmaline. The evidence thus indicates that the quicksilver-bearing deposit, like the other metalliferous deposits in the district, is genetically related to the igneous intrusions at or near the end of Jurassic time.

MISCELLANEOUS DEPOSITS

A narrow fissure vein in aplite has been partly explored by two tunnels at an altitude of 6,675 feet on the west flank of the Black Range. The ore contains abundant jamesonite and resinous sphalerite, with traces of galena in a quartz gangue. This vein is the only one in the district in which jamesonite has been found. Jamesonite, however, was abundant at the Sheba mine, 10 miles north of Rochester, on the east flank of the Humboldt Range. The ore there, presumably formed during the same metallogenetic epoch as the Rochester veins, consisted of white quartz carrying argentiferous jamesonite, galena, sphalerite, pyrite, and tetrahedrite.[50] Some of the jamesonite

[50] Ransome, F. L., Notes on some mining districts in Humboldt County, Nev.: U. S. Geol. Survey Bull. 414, p. 43, 1909.

from the Sheba vein, selected with great care and to all appearance perfectly homogeneous, was found to contain 6.14 per cent of silver.[51]

A copper-bearing vein occurs at the shaft above the jamesonite-quartz veins. It is in places 3 feet thick, strikes N. 15° W., and dips 30° E. It consists of coarse milky-white quartz, slightly tourmaliniferous, carrying chalcopyrite, now largely oxidized to copper pitch ore and minor chrysocolla and malachite.

Another mineral deposit differing even more widely than the preceding from the prevailing ore deposits in the Rochester district is the baritic vein in South American Canyon, on the south slope of the 6,648-foot peak. The prospect opened here shows a deposit that contains a little pyrite and chalcopyrite in a gangue of barite and subordinate quartz and sericite.

GENESIS OF THE ORES OF THE DISTRICT

The silver-bearing quartz veins were formed mainly by the replacement of sheeted and shattered zones in Triassic rhyolite and trachyte. In some of the veins considerable tourmaline was introduced along with the quartz, and contemporaneously the hypogene sulphides, pyrite, sphalerite, galena, tetrahedrite, and chalcopyrite, were deposited. The vein filling thus formed was not sufficiently high in silver to constitute ore, and its subsequent conversion to ore by the deposition of supergene argentite took place by very different processes, as described on pages 46–50, where this phase of the genesis of the ores is fully discussed.

The lean silver-bearing veins were formed shortly after the intrusion of the large aplite masses and the granite porphyry dikes, at or near the end of Jurassic time, and evidently are genetically related to the intrusion of the parent magma from which these differentiates were derived. This relation is significant, for the great volume of aplite in the region implies that the parent magma from which the aplite was derived had already differentiated to a very notable extent; and as there are no visible masses of complementary lamprophyre in the region and it is unlikely that they occur in depth, because the post-aplitically injected material is granite porphyry, it is probable that the aplite originated by fractional crystallization and that the volatile components originally contained in the parent magma became concentrated in the aplite fraction. This concentration of the volatile matter in the aplite magma, it may be noted in passing, did not suffice to cause that magma to consolidate as pegmatite, as might perhaps be expected.

[51] Burton, B. S., Contributions to mineralogy: Am. Jour. Sci., 2d ser., vol. 45, pp. 36–38, 1868.

Highly heated solutions, doubtless gaseous, were evidently given off from the magma that underlay the aplite that is now exposed by erosion. The first to be given off appear to have been the hot boron-bearing solutions that produced the very remarkable dumortieritization and concomitant development of andalusite on an enormous scale. This intensive activity was not accompanied by the development of any ore or sulphides. Next followed the deposition of the tourmalinic gold ores. The abundance of tourmaline in some of the gold deposits and the coarse pegmatitic character of the ore in others, as in the Hagan lode, where the ore consists of quartz, microcline, and tourmaline, indicate that high temperatures (between 400° and 600° C.) prevailed during the deposition of the gold ores. As deposits of both the dumortieritic and the auriferous tourmalinic types occur within the same area, namely, on Lincoln Hill, and as they do not grade into each other, the difference between them is obviously not due to a zonal arrangement of mineralization around a focus of emission of mineralizing solutions. It may represent a superposition of the auriferous tourmalinic type on the dumortieritic type, due to retrogression of the conditions of deposition toward the focus, but in view of the lack of lateral gradation anywhere between deposits of the two types, this hypothesis appears hardly probable.

The silver veins were presumably formed last and doubtless at lower temperatures, as indicated by the fine-grained texture of the quartz, the lesser abundance of tourmaline, and the minute acicular instead of coarse columnar habit of the tourmaline. The most productive silver veins, those of Nenzel Hill, contain no tourmaline, though otherwise identical with the tourmaliniferous silver veins. They are evidently the end members of the series of veins formed in the district, being those that were deposited in an environment too cool to admit of the deposition of tourmaline. An extraordinarily significant fact is that certain tourmaliniferous silver veins, such as the Octopus, are faulted by very highly tourmalinic veins, proving that while the silver-bearing quartz veins were being deposited there was a temporary or local reversion to conditions of higher temperature. Such faulting may have facilitated the escape of somewhat hotter solutions by opening pathways to deeper-lying pockets of still fluid magma charged with gases. This renewal or recrudescence of higher-temperature conditions may indicate that the period of ore deposition was relatively short—so short, in fact, as to leave the igneous mass with great stores of heat energy. However, the focus of emission, the still fluid magma from which the ore-forming solutions were presumably expelled, was situated at great depth, for the consolidated aplite had cooled sufficiently for the subsequently injected granite porphyry to assume a spherulitic habit even where it was inclosed in aplite; and the tourmalinization and vein formation took place after the injection of the granite porphyry.

In recapitulation, there are, then, at least three types of boron-bearing deposits of high-temperature origin in the Rochester district. As the members of the several types were nowhere found to intersect, their sequence in time was not directly determinable, but their internal characters indicate that the three types were formed successively, and each at a somewhat lower temperature than the preceding. The three types are, in the probable order of decreasing temperature, (1) dumortieritic deposits, which carry only sporadic tourmaline and no sulphides, (2) tourmalinic gold deposits, and (3) tourmalinic silver deposits. A fourth type may possibly be represented by the innumerable coarse quartz veins, notably tourmaliniferous and carrying traces of sphalerite, galena, and pyrite, that occur in the aplite, as at Lone Mountain, and in some of the granite porphyry. Transitions or gradations between the different types do not exist. Furthermore, deposits of all three types may occur within a small area, as on Lincoln Hill. In short, these three types are not zonally distributed around the intrusive masses or around foci of emission of mineralizing solutions.

The conclusion adopted is that the three types of deposits owe their origin to solutions of distinctive character, which were given off successively by the consolidating magma. In other words, the composition of the mineralizing solutions changed abruptly at three successive stages, presumably because of internal changes in the consolidating magma from which they were issuing.

The discontinuity in the processes of primary ore deposition in the Ely district of Nevada led Spencer[52] to the belief that a magma undergoing consolidation might pass through critical stages, "on either side of which the products of differentiation might be very different." This same problem was considered in some detail by Hills[53] in his monographs on the great zinc-lead sulphide deposits of the Read-Rosebery district, Tasmania, where tourmaline veins and zinc-lead sulphide deposits overlap, although both are genetically related to the same intrusion of igneous rock. The evidence there led to the conclusion that the overlapping is due to the successive release of magmatic differentiates of distinctive composition from the gradually cooling and differentiating magma, each successive differentiate having been at a lower temperature than the first.

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[52] Spencer, A. C., Geology and ore deposits of Ely, Nev.: U. S. Geol. Survey Prof. Paper 96, pp. 68–69, 1917.

[53] Hills, Loftus, The zinc-lead sulphide deposits of the Read-Rosebery district, pt. 2, Rosebery group: Tasmania Geol. Survey Bull. 23, pp. 86–88, 1915.

The principle that successive ore-forming differentiates ("distillates"), each with its own distinctive constituents and characteristics, are given off during successive stages of a progressively cooling magma will be found, it is here suggested, to be widely applicable in the study of ore deposition. As a modifying factor the principle of zonal distribution is recognized as having been operative in some districts, but of and by itself the principle of zonal variation in ore deposition is of very narrow application. The metallic content and composition of the vast majority of ore deposits genetically related to igneous rocks are determined primarily by those unknown but fundamental factors that determine the origin of petrographic provinces and that correlatively determine metallogenic provinces.

PLACERS

Gold was discovered in 1913 in the gravel that occupies the broad basin at the head of Limerick Canyon. Several miners were successful at that time in winning about $1,100 in placer gold during 37 days' work.[54] In the long run, however, it was found that the returns did not exceed poor wages, and the excitement soon subsided. The total output was roughly $10,000, of which $7,374 was obtained in 1914.[55]

The placers were worked by sinking shafts to bedrock and drifting on bedrock, chiefly near the upper edge of the alluvial detritus, where the gravel is thin. The deepest shaft is 30 feet deep. The gravel taken out was either treated in dry washers or was hauled a mile to water to be washed. The gravel is wholly angular but is not coarse. It is said to carry from 3 to 5 cents to the pan. Bedrock was found to contain depressions or runways, and in mining these headward the gold content improved. In this way the Hagan lode was discovered, for the pay streak was found to head against a gold-bearing lode in place. (See p. 76.)

The lode is a tourmaline-bearing quartz deposit carrying coarse gold. Tourmaline-quartz stringers are common in the volcanic rocks and granite porphyry on both sides of Spring Valley Pass and were doubtless the source of much of the placer gold formerly mined at Fitting or Spring Valley and American Canyon.

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[54] U. S. Geol Survey Mineral Resources, 1913, pt. 1, p. 827, 1914.
[55] Idem, 1914, p. 685, 1916.

PART IV. MINES AND PROSPECTS

SILVER MINES AND PROSPECTS

ROCHESTER MINE

The bulk of the silver that the Rochester district has produced has come from the veins on Nenzel Hill, chiefly from two—the East and West veins. There are many other veins in the hill, and these were formerly held by various companies, but this divided ownership led to controversy and finally threatened disastrous litigation. The two principal veins were being worked by the Rochester Mines Co., and its title to the most productive vein, the East vein, was threatened in 1917 simultaneously by the Rochester Elda Fina Mining Co. and the Rochester Merger Mines Co. Fortunately a compromise was reached, and the holdings of these companies were merged under one ownership by forming the Rochester Silver Corporation, incorporated in 1920, after an attempt to consolidate these companies, together with the Nenzel Crown Point Mining Co. and the Rochester Combined Mines, as the Rochester Nevada Silver Mines Co. had failed. The capitalization is $2,000,000 in 2,000,000 shares of $1 each, a considerable reduction from the sum total of the capitalizations of the three constituent companies.

The Rochester Mines Co., incorporated in 1912, paid only one dividend, $80,000, which was distributed in 1918. Its successor, the Rochester Silver Corporation, paid its initial dividend on June 20, 1921, amounting to $88,536; and two more dividends were paid that year, bringing the total for 1921 to $177,523.95. In 1922 $141,646 was distributed in dividends.

The ore is treated in a 160-ton cyanidation mill, situated 2 miles down Rochester Canyon from the mine. The mill was built by the Rochester Mines Co. in 1915, and the ore was delivered to it from the mine, known as the Rochester mine, by the Nevada Short Line Railroad. The service, however, was expensive and unreliable, and eventually an aerial tramway was built, which went into operation in April, 1917. Power is supplied by the Nevada Valleys Power Co. from the Lahontan dam, a Government irrigation project 85 miles distant.

The veins are opened in depth by three long adit tunnels. The chief of these is the Friedman tunnel, 1,600 feet long, whose portal is at an altitude of 6,427 feet, between 700 and 800 feet below the outcrops of the East and West veins. The West vein was the site of Nenzel's original discovery, and this vein, with the more productive East vein, have so far yielded most of the silver that has come out of Nenzel Hill.

In 1920 the Rochester Silver Corporation milled 42,820 tons of ore, from which $595,351 in bullion was obtained. The ore contained 12.63 ounces of silver and 0.139 ounce of gold to the ton, of which 82.1 per cent of the silver and 91.7 per cent of the gold was won. In former years the ore was of considerably higher grade: for example, during 1913, the first year of large-scale mining, the Big Four lease on the West vein yielded 5,308 tons of ore carrying 60 ounces of silver to the ton, and the Codd lease 9,304 tons of ore carrying 30 ounces to the ton. This high-grade ore was mined above the 300-foot level. From that time the grade of the ore rapidly declined, and during the years 1918 to 1920 it averaged from 10 to 12 ounces to the ton. Numerous veins were cut by the Friedman tunnel, the so-called 1,360-foot level, but their silver content proved disappointing. The report of the corporation for 1920 says: "On the whole, our work from this lowest level of the mine was decidedly unfavorable and showed the veins to have become unpayable at this depth."

The main haulageway of the Rochester mine is the Friedman tunnel, from whose portal an aerial tram extends to the mill. In the early history of the mine the upper levels were worked mainly through the Transportation tunnel, or 500-foot level, whose portal is at an altitude of 6,900 feet. From this level the Codd winze was sunk on the East vein, dipping 35° W., and the 650, 700, and 800 foot levels were turned off from it. These workings were eventually connected with the Friedman tunnel below, and all ore was thereafter sent to the surface through this tunnel. At the 900-foot level the Codd winze cut a large fault, which terminated the downward extension of the East vein in the winze, stopped for a number of years downward exploration of the East vein, and rendered doubtful any decision as to which of the veins cut by the Friedman tunnel was the downward extension of the East vein. By 1919, however, the faulted segment had been found.

The West vein crops out on the west side of Nenzel Hill. At its south end it is just under the brow of the summit. It has been stoped to the surface continuously for several hundred feet and was found to range in width from 3 to 10 feet. It strikes N. 45° E. and on the average dips 75° W. At the northeast end it reaches the summit, and here some of the croppings are intact, projecting 3 or 4 feet above the surface. They consist of extremely fine grained quartz, much resembling chalcedony. The silver in this ore occurs in minute suffused points of argentite. The country rock inclosing the West vein is the Nenzel rhyolite breccia, which dips 15° E.; it is here extremely massive and resistant.

Below the 250-foot level the dip of the West vein flattens notably—in fact, in the south end of the drift on the 250-foot level the dip decreases abruptly from 55° W. to 15° W. In 1917 the West vein was regarded as worked out, and little work had been done on it below the 250-foot level, although it contained here one of the best blocks of ore in the mine, and no work had been done below the 500-foot level. Later, however, under new management, a fine ore shoot was found on the 500, 600, and 700 levels. The corporation's report for 1920 says: "Our drift north on the 500 level was carried through for a connection with a drift off the Transportation tunnel for ventilation and disclosed at this point that if the former operators had driven two rounds more on their drift they would have opened this splendid shoot of ore."

The ore of the West vein is identical in appearance with that of the East vein. It is prevailingly oxidized and hence is stained with limonite. Less oxidized ore carries finely disseminated pyrite together with some zinc blende and contains bluish-black mottlings due to mixtures of covellite and argentite. In places the vein is crushed and has gouges on both foot and hanging walls.

The East vein, as its name implies, is east of the West vein. Its great importance first became apparent underground from the development work done there, and for a time considerable uncertainty existed as to where the East vein apexed, whether within the boundaries of the Rochester Mines Co. or within the neighboring claims. In 1917 two shafts were sunk—the Emma shaft, on the Elda Fina claim of the Elda Fina Mining Co., and the C P X shaft, on the Crown Point Extension claim of the Rochester Merger Mines Co.—to establish apex rights and hence ownership to the East vein.

No large amount of ore has been mined on the East vein above the 250-foot level, but raising has been done to establish the continuity of the vein to the surface. At first the Rochester Mines Co. holed through to the surface on a vein dipping 80° W. This vein is readily traceable on the surface for 150 feet, ranges from 6 to 18 inches in thickness, and is tightly frozen to both walls. It proved to be a hanging-wall spur of the East vein, which crops out prominently 42 feet east of the outcrop of its spur.

The East vein has a strong outcrop of quartz, which is traceable with certainty only for 330 feet on the surface. On the north it branches, one branch trending N. 10° W. and the other N. 20° E. Blocky, well-stratified tuff resembling sandstone lies between the branches. At the outcrop the East vein dips 60° W., but at a moderate depth the dip flattens to 35°, which it maintains with great regularity. At the outcrop due east of the so-called Apex shaft the vein is inclosed in well-stratified tuff dipping 35° E.; at a vertical depth of 70 feet it passes into the Nenzel rhyolite breccia; and between the Transportation level and the 600-foot level it passes into the underlying Rochester trachyte.

The vein occupies a zone of fissuring produced by a normal fault, on which the displacement now measurable is 120 feet. This displacement is best seen in winze 302, sunk on the vein from the 500-foot level to the 650-foot level south of the Codd incline: the hanging wall of the vein from one level to the other is Nenzel rhyolite breccia dotted with prominent quartz crystals, whereas the footwall is flow-banded felsite of the Rochester trachyte. How much of this displacement is due to premineral movement and how much to postmineral movement appears to be indeterminable.

The prevailing ore is a highly oxidized breccia (due to postmineral crushing) consisting of angular fragments of fine-grained quartz and silicified country rock in a clayey limonitic paste. Generally the limonite colors the whole mass a rusty red, but where it is absent the ore is white. Much of the quartz is nearly as compact and fine grained as chalcedony and is mainly the result of the replacement of rhyolite breccia in the higher levels of the mine and felsite (Rochester trachyte) in the lower levels. In unoxidized ore finely disseminated pyrite and sphalerite occur in some abundance and galena and tetrahedrite occur rarely. The high-grade ore has a leached appearance, due to the partial removal of these sulphides, and the resultant pores are lined with covellite or, as the microscope shows, a mixture of covellite and argentite. These darkish sulphides give the ore a characteristic appearance and indicate at once to those familiar with the mine the unusual grade of the ore.

Spangles of native silver are found occasionally, even as deep as the 800-foot level. Masses of waxy white halloysite occur locally in the ore and testify to rearrangements effected by waters of atmospheric origin.

A marked sheeting was developed parallel to the East vein and manifestly facilitated the silicification of the rocks and their conversion to ore. This sheeting makes it unsafe to regard any one wall on either side of the vein as the footwall or the hanging wall, for in many places the present operators have found ore above what the previous operators considered to be the hanging wall, and they have also found ore below what had been considered to be the footwall.

In 1917 extraordinary importance was attached to a white gouge associated with the East vein along much of its course. It is commonly pure white, though locally striped red and white, and consists of angular fragments of rhyolite, whose corners have been somewhat rubbed off by attrition, embedded in a kaolinic matrix. Locally it is 2 feet or more thick. It occurs in some places on the footwall, in others on the hanging wall of the East vein; in some places it occurs in the middle of the vein, and in others it is separated from the vein by 6 feet of hard rhyolitic breccia, as on the 250-foot level of the C P X shaft, which was sunk on the white gouge in order to establish apex rights to the East vein. The gouge has evidently been produced by postmineral movement along a fissure that in places coincided with the East vein and in places diverged from the vein. The gouge can not be regarded as peculiar to the East vein, for identical gouges occur in the Rock tunnel and the Nenzel Crown Point tunnel.

At certain intersections of the East vein with what are either hanging-wall spurs or more steeply dipping veins the gouge of the East vein cuts through the steeper vein at the junction, showing that the postmineral movement has been chiefly parallel to the East vein. At such intersections unusual quantities of good ore were stoped out, but such ore did not generally persist far up the steeper vein. The reason for the failure of the ore to extend up the steeper vein is probably that the ore was due to downward enrichment and the meteoric water percolating down the steeper vein was temporarily halted or impounded at the intersection by the nearly impervious gouge of the East vein, and therefore more of the silver in solution, having more time to react with the zinc blende and other sulphides, was precipitated as argentite.

The East vein has been stoped for a length of 500 to 800 feet. It reaches a maximum of 10 feet, but probably 5 feet is a fair average. In places it splits, inclosing horses of massive country rock as much as 12 feet thick, and both branches have well-defined walls, and both have suffered postmineral crushing. On the south the vein splits and becomes unprofitable; north of its intersection with the West vein it has not been found to carry ore. In places the vein intersects more steeply dipping veins or sends off branches into the hanging wall and footwall. Probably both independent veins and spurs or branches are represented. An example of the first kind is doubtless the footwall vein that was higher in gold than the East vein; it was stoped from the 1,000-foot level to the 800-foot level and was from 360 to 400 feet long. It is a steep quartzose vein, dipping 70° W., and has less gouge than the East vein.

The East and West veins intersect on the 500-foot level 80 feet north of the Transportation tunnel. The average divergence in strike is 40°, the East vein striking N. 5° E. and the West vein N. 45° E. The West vein is about 20° steeper than the East vein, and its abrupt steepening above the 250-foot level throws the intersection far to the north in the upper levels. The gouge of the East vein cuts through the gouge of the West vein, showing that the last postmineral movement was along the East vein, but the displacement, if any, is not clearly exposed.

In exploring the East vein in depth by means of the Codd incline, the vein was found to be cut off by a fault at the 900-foot level. This fault proved to be normal, and it strikes N. 8° E. and dips 80° E. The displacement is 45 feet, and the fault drag contained enough ore to make stoping for a considerable height profitable. A fair tonnage of ore was obtained from the East vein below the 900 fault, as it is called, but the grade was below the average. It is thought that the ore in this part of the mine has been practically all taken out.[56] This impoverishment in depth had been clearly indicated several years before by the low silver content of the numerous veins cut by the Friedman tunnel (or 1,360-foot level). Long drifts have been run both northward and southward from the Friedman tunnel. A winze was sunk on the East vein from the level of the Friedman tunnel for several hundred feet (as measured on the vein), the dip being 30° W., though for large stretches it is as low as 15°. The vein filling is as deeply oxidized here as on the higher levels, but no ore was found. Water level was not reached, even at this considerable vertical depth. The results of the exploratory work on the Friedman tunnel level have shown, as already mentioned, that the veins have become unprofitable at this depth. As but little lateral development was done in the earlier history of the mine, much ground remains to be explored on the upper levels.

BOUGHTON & HACKLEY MINE

The Boughton & Hackley mine is on the west flank of Nenzel Hill, and the portal of the tunnel by which it was developed is at an altitude of 6,841 feet, or 356 feet above the portal of the Pitt tunnel. The mine is now part of the property of the Rochester Silver Corporation.

The vein is cut by the tunnel about 70 feet below the outcrop; it dips 50° W., and in places it has been stoped to the surface. The hanging-wall country rock is finely banded trachyte; the footwall country rock is Nenzel rhyolite breccia. This relation means that the vein was formed along a reverse-fault zone, for the trachyte normally underlies the Nenzel rhyolite breccia. Twenty feet west of the vein a normal fault of large displacement, dipping 70° E., is exposed in the tunnel. This fault must cut off the Boughton & Hackley vein 15 feet below the tunnel level and doubtless accounts for the failure to find the vein in the Pitt tunnel below, which was expressly driven to cut the vein in depth. The geologic relations are shown in Figure 4.

[56] Rochester Silver Corporation, report for year 1920, 1921.

NENZEL CROWN POINT PROPERTY

The principal workings on the Nenzel Crown Point Co.'s property are on the east side of Nenzel Hill. A shaft at an altitude of 6,896 feet was sunk 200 feet on the Big Chief vein. Later an adit, whose portal is at an altitude of 6,784 feet, was driven to the shaft, and a crosscut was driven westward 1,200 feet; near its end this crosscut was connected with the Pitt tunnel, 300 feet below, which penetrates Nenzel Hill from the west flank for a distance of 1,800 feet.

The 1,200-foot crosscut is entirely in Nenzel rhyolite breccia, except for the first 25 feet. The fault known as the Jones fault is well

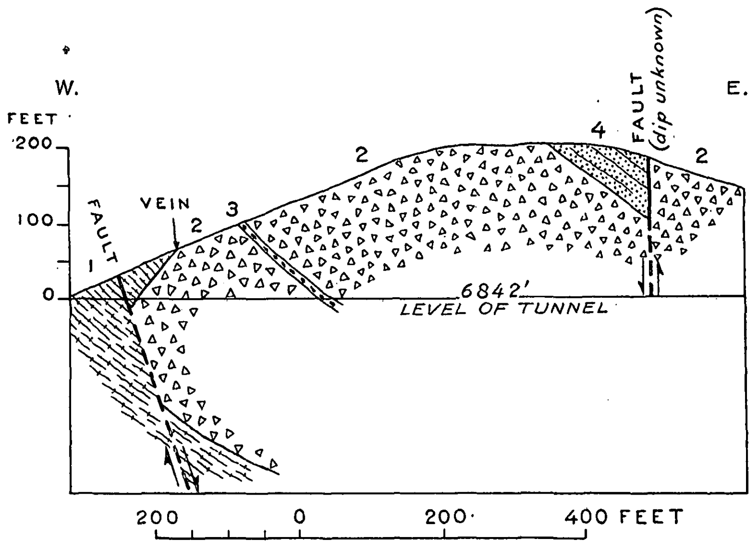


FIGURE 4.—Geologic section from portal of Boughton & Hackley tunnel to northeast corner of North Crown Fraction claim. 1. Rochester trachyte; 2, Nenzel rhyolite breccia: 3, conglomerate member of Nenzel rhyolite breccia; 4, well-bedded tuffs resembling sandstone

shown in the crosscut, where it strikes N. 80° E. and dips 40° N., and it reappears in the adit. It has a notable gouge, and the rock in the fault zone has been reduced to a rubble 5 feet thick. It is a normal fault, as can be seen on the summit of Nenzel Hill, where it displaces the sandstone-like tuff. The fault will be found to displace all the veins that have been cut in the crosscut, but as the character of the displacement is known, the faulted segments can be readily discovered.

The Big Chief vein is vertical near the surface but dips 70° E. in depth. It averages about 3 feet in thickness. The ore is that typical of Nenzel Hill, consisting of fine-grained and cryptocrystalline quartz showing bluish-black patches and sporadic specks of pyrite. Though no silver mineral can be recognized, silver appears in countless small beads all through the ore after the ore has been brought to a red heat in the forge. Chemical tests show that the silver is present as argentite.

At the surface the Compressor vein (or vein No. 1) lies 50 feet west of the Big Chief; in the crosscut it is 85 feet west of the Big Chief. It dips 60° W. and is from 3 to 4 feet thick. A number of other veins have been cut. Vein No. 5 strikes N. 30° E. and dips 60°. It consists of 2½ feet of fine-grained quartz, somewhat cellular, containing limonite and sericite. The more compact quartz carries a little pyrite, with some zinc blende and covellite. Vein No. 10 strikes N. 40° E. and dips 30° W.; it is 2 feet thick and has a well-defined gouge on its hanging wall. Among the more important veins cut is the Zero vein, on which some drifting has been done. The vein dips 60°–70° W., is quartzose, and at most is 3 feet thick. It has been postminerally shattered but on the whole has no well-defined gouge. On the north the vein is cut off by a fault striking N. 30° W. and dipping 45° W.

In general, at the time of examination little development work had been done on most of the many veins intersected by the long crosscut.

BUCK & CHARLEY MINE

The Buck & Charley mine is on the south side of Rochester Canyon a short distance below Lower Rochester. The veins were discovered in 1912. The developments consist of adits, the lowest of which is only a few feet above the floor of the canyon. A winze has been sunk from the lowest or main adit, and two levels have been turned off from the winze, the lower of which is 112 feet below the main adit. Water level was reached about 42 feet below the main adit, and the mine while being worked in 1919 made 80 gallons of water a minute.

To the end of 1917 the mine had produced $47,000. The principal shoot of ore was extracted by J. H. Watters under lease. The smelter returns show that the ratio of silver to gold was remarkably constant—about 1 ounce of silver to every 0.01 ounce of gold. The highest-grade shipment, of 35 tons, carried 134 ounces of silver to the ton.

The main output has come from a steep vein trending roughly N. 40° E. The wall rock is a hard felsite of the Rochester trachyte, which near the vein carries considerable pyrite and zinc blende. The shoot of ore in this vein was from 40 to 100 feet long and 1.5 to 2 feet wide. It plunges to the south, at angles ranging from 70° to 50°. On the bottom level, according to Mr. Myron Warner, who in 1919 operated the mine under a lease, the ore shoot is 55 feet long, of which 25 feet is $100 ore over a width of 16 inches.

The ore is a highly silicified felsite netted with quartz veinlets carrying pyrite, zinc blende, and subordinate galena. It has been somewhat altered by descending solutions, which have specially attacked the zinc blende, producing covellite and doubtless also the rich silver sulphide, argentite.

OCTOPUS MINE

The Octopus mine is in the western part of the district, not far from Lower Rochester. The vein was discovered in 1913 by Sam O'Connell, of Lovelock. The output up to 1917 is reported to be $28,000.

The mine is opened by two drift tunnels, the lower of which is 90 feet vertically below the upper. From the lower level a winze was sunk 115 feet on the vein and some drifting was done. The water level has not been reached in any of the workings. The country rock is felsite (Rochester trachyte).

The vein strikes N. 10° W. and dips 40° W. It ranges in thickness from a few inches to 6 feet and averages nearly 3 feet. The hanging wall is notably well defined, even, and regular. The vein has a strong hanging wall gouge—in fact, the whole vein on the upper level has been largely reduced to the condition of a gouge. The vein is displaced at 200 feet from the portal of the upper tunnel by a steep fault trending N. 50° W., the offset measured along the fault being 24 feet, and a short distance farther in the vein is again faulted, along a fault parallel to the other, this offset being 40 feet. The first fault fissure is occupied by a tourmaline-quartz ledge, the tourmaline forming as much as one-half the ledge matter, which locally carries pyrite and sporadic galena. In the second fault the filling is a soft gray rock 3 feet thick carrying scattered prisms of tourmaline. These faults have also been found on the level driven from the bottom of the winze.

The ore of the Octopus vein is shattered felsite that has been silicified and metallized. It is fairly tourmaliniferous at the portal of the upper tunnel and sparsely so at other places. It is prevailingly oxidized, but on the lower level and in the winze sunk from this level sulphides appear. They consist chiefly of deep-brown or black sphalerite, together with galena and pyrite. Such sulphide-bearing material is low in silver, containing about 2 ounces to the ton.

The ore shoot is 200 feet long on the upper level, where it is reported to average 13 ounces of silver and $2 in gold to the ton over a width of 4½ feet; it is shorter on the lower level, 60 feet carrying 20 ounces of silver to the ton and an additional 86 feet carrying 8 ounces to the ton. Picked specimens of rich ore, stained with limonite and other oxidation products, show notable quantities of soft, sooty argentite. In places it forms masses an inch long and a quarter of an inch thick. The Octopus mine is the only place in the district where the argentite occurs in such large masses, where it can readily be recognized and easily identified. Some of the rich ore shipped in early days by lessees, which averaged 80 ounces of silver to the ton, doubtless contained much of this soft argentite.

RAVEN PROSPECT

The Raven prospect is at an altitude of 6,147 feet on the southeast slope of Lincoln Hill. The country rock is a faintly flow-banded felsite carrying small porphyritic crystals of microcline; it is one of the flows of the Rochester trachyte. The vein strikes N. 30° E., dips 80° W., and ranges from 1 to 2½ feet in thickness. The ore is oxidized and is a somewhat vuggy fine-grained sugary quartz, in many places containing multitudes of minute prisms of black tourmaline. The country rock is laced with quartz veinlets and is tourmalinized and pyritized.

Small shipments of ore carrying silver and gold have been made.

ABE LINCOLN MINE

The Abe Lincoln mine, owned by the Rochester Lincoln Hill Gold & Silver Mining Co., is on the north side of Lincoln Hill at an altitude of 6,346 feet. The output is said to amount to $15,000.

The main opening at the time of visit in 1919 was a tunnel 135 feet long, which had attained a depth of 85 feet below the old workings on the surface. The vein strikes northeast, dips 55° W., and ranges from 1 to 3 feet in thickness. The ore is silicified pyritic felsite (trachyte carrying inconspicuous phenocrysts of microcline); in places it contains sporadic aggregates of tourmaline fibers. It shows postmineral crushing, oxidation, and leaching. It is reported that the vein assays $8.70 in gold and 7 ounces in silver to the ton across a width of 3 feet. Ore sacked for shipment is said to average 75 ounces of silver and $10 in gold to the ton. Inspection of such ore shows that it has been enriched by supergene sulphide.

KAISER BILL PROSPECT

The Kaiser Bill prospect is in Limerick Canyon, at an altitude of 5,775 feet, a few hundred feet north of the road up the canyon. It has been explored by a vertical shaft 100 feet deep. The ore body is a narrow quartz vein inclosed in aplite. It lies between well-defined wavy walls, but only a few inches of the vein filling is considered ore—a coarse quartz carrying sparse zinc blende. The aplite adjacent to the vein is more or less shattered, penetrated by quartz-tourmaline veinlets, and pyritized. Six tons of ore has been shipped and is said to have averaged $25 a ton, mainly in silver.

NEVADA PACKARD MINE

The Nevada Packard mine, owned by the Nevada Packard Mines Co., is in the southern part of the district, on the edge of the foothills. The company owns four claims aggregating 80 acres on a spur locally known as Packard Ridge. Ore was discovered on the property in December, 1912. For a time the chief production was made by lessees, who are said to have taken out $100,000. Later the company erected a cyanide plant having a daily capacity of 100 tons, which began operations in December, 1915. Electric power is obtained from the Nevada Valleys Power Co., which transmits it from the Lahontan dam, 85 miles distant.

The mine is opened by a series of drift tunnels and a number of large open cuts that are worked by the glory-hole method. The lowest tunnel, the 200-foot level, is the main haulageway, and all ore is dropped to this level and trammed to the mill. A shaft was sunk from a point near the face of the 200-foot level to a depth of 235 feet, where the water level was cut. The intention was to continue to a depth of 300 feet, crosscut westward, and explore the downward extension of the Contact lode.

The ore is crushed first in a gyratory crusher and then passed through Garfield rolls, where it is reduced to ½-inch size, then sent through ball mills, and finally cyanided. Seventy per cent of the silver is extracted before the pulp reaches the agitators. The total extraction now averages 90 per cent. When the ore treated carried all its silver in the form of chloride the extraction averaged as high as 94.9 per cent.[57]

To August 1, 1919, there had been milled 114,211 tons of ore, from which was obtained 845,514 ounces of silver. The gold content of the ore is small: in 1918, for example, 30,555 tons of ore yielded 240,411 ounces of silver and 347 ounces of gold, or in the ratio of 1 ounce of gold to 7,000 ounces of silver. Three dividends have been paid to date, amounting to $110,646.

The rocks at and near the Packard mine are members of the formation termed in this report the Weaver rhyolite. They consist of an alternation of massive rhyolite, schistose breccia, pure-white sericite phyllite (which has resulted from the metamorphism of fine-grained tuff), and soft shaly white tuff. The massive rhyolite, representing a succession of lava flows, predominates, but it appears even more abundant than it actually is because it crops out promi-

[57] Thomson, H. G., Construction and operation of the Nevada Packard mill: Min. and Sci. Press, vol. 113, p. 384, 1917.

nently, whereas the soft beds of tuff are covered by the float from the hard rhyolite. The massive rhyolite consists of successive flows, of which a variety mottled in blue and white, locally known as the "hard blue," and a variety containing numerous quartz-filled, originally hollow spherulites are most common. The tuffs are banded, and they include some intercalated beds of shale. They are of special significance because their stratification is readily ascertainable, and so they serve to determine the structure of the rocks. Furthermore, one of the main ore bodies—the Contact ore body—occurred along a fault where a particular belt of tuff formed the hanging wall. The rhyolite flows with their intercalated tuffs strike N. 5° E. and dip 15°–30° W., but the schistosity dips at a considerably higher angle—60°. Consequently, in determining the structural relations of the ore bodies this schistosity must be carefully discriminated from the bedding. In the mine itself and in its near vicinity dips of about 15° W. prevail; but a few hundred feet west of the chief workings the dip is 22° W., as is clearly shown in the Kromer tunnel.

As seen from the settlement of Packard, a prominent line of crags crosses the brow of Packard Ridge. It has been locally named the "dike," but on examination close at hand it is obvious that the crags are not the outcrop of a dike, and they are found to be far less regular than they seem when viewed from a distance. They form an irregular zone, roughly 100 feet wide, bordered on the east by a tuff belt, about 100 feet wide as measured on the surface. This is probably a slightly silicified fault zone, which is possibly the southward extension of the fault by which the Rochester trachyte is faulted against the Weaver rhyolite on the ridge on the south side of Weaver Canyon. (See Pl. I.) Schrader[58] thought that the fault on Packard Ridge was the main factor in the localization of the ore on Packard Ridge, but subsequent development work has not borne out this opinion—in fact, tunnels driven under the "dike" in the belief that it is a locus of mineralization have so far failed to disclose anything of value. The tuffs in the belt east of the "dike" were not found in the crosscuts under the "dike" and therefore must have been cut off by a fault, providing that they dip west, a condition which could not be verified at the time of examination. If they dip east, then it is fairly certain that the "dike" represents the southward extension of the fault previously mentioned.

The ore bodies are of two kinds—lodes, exemplified by the Contact ore body, and stockworks, which have furnished the bulk of the ore. In both the lodes and the stockworks the ore is essentially similar and consists of rhyolite carrying disseminated cerargyrite (horn silver), which is so finely distributed as to be only rarely

[58] Schrader, F. C., The Rochester mining district, Nev.: U. S. Geol. Survey Bull. 580, pp. 335, 351–352, 1914.

perceptible to the eye. The rhyolite in the lodes is roughly schistose and highly sericitic. Some of the tuff beds have been so thoroughly altered to sericite that they are now compact waxy sericite schists. Sericite is the only conspicuous gangue mineral that was formed during the mineralization; quartz is practically absent. In the ore of the stockworks sericite is far less common.

The Contact lode is a zone of mineralization along a fault that trends N. 30° E. and dips 45°–60° W. This fault has brought a belt of soft tuff down against the rhyolite. The normal undisturbed dip of the tuff is 15° W., but near the fault surface it has greatly steepened. These features are most plainly shown in the upper tunnel of the Rochester Combined mine, whose portal is in well-stratified, somewhat banded gray tuff. Naturally, when the base of the tuff was reached in the downward progress of mining, the sedimentary contact of the tuff on the underlying rhyolite was found to diverge abruptly from the fault surface and the fault was found to continue downward in the rhyolite.

The west contact of this tuff belt is clearly exposed in only one place—in a tunnel some 400 feet northwest of cut 23. It is also a fault contact, striking N. 30° E. and dipping 60° W., which like the east contact has been mineralized. A small body of ore on this contact, reported to be 200 tons carrying 25 ounces of silver to the ton, was stoped out to the surface by lessees.

Along the south end of the lode the ore occurred in the sheared rhyolite adjoining the fault, but none occurred in the tuff—hence the name Contact ore body—and the fact that the two dissimilar rocks join against the fault was thought to have determined the localization of the ore. However, as drifting proceeded northward the base of the belt of tuff was found to rise, owing to the differing strikes and dips of the fault and the tuff, and ore was found below the belt of tuff in the sheared rhyolite on both sides of the fault. If anything, then, the tuff was in reality unfavorable to the formation of ore, for where it is not present ore formed on both sides of the fault.

A number of valuable ore shoots were stoped out along a length of 600 feet on the Contact lode. The ore was of higher grade than that obtained from the stockworks, and some of it averaged 13 ounces to the ton. The shoots were as much as 250 feet long and where widest were 40 feet across, but they had a small vertical range, about 50 feet. Some of them did not extend to the surface, as the material in them was not of ore grade above a depth of 40 feet. As the bottom of the ore shoots was reached the ore became more difficult to cyanide, and the extraction fell off to 83 per cent, indicating that part of the silver was locked up in a less amenable compound than the chloride, doubtless the sulphide. The mineralized lode matter below the ore shoots consists of sericitized rhyolite that carries a small quantity of finely disseminated pyrite, zinc blende, and a trace of galena and contains only 0.5 ounce of silver to the ton. The vertical distribution of the mineralization in the Contact lode shows, therefore, a zone of impoverishment near the surface, a zone of enrichment below it, and a zone of unenriched mineralized material, the protore, far too lean to work, extending below the enriched zone. The ore in the zone of enrichment, which when formed consisted of argentite, was later converted into the chloride.

Good ore was found in the Contact lode as far as the north end line of the Nevada Packard mine, and a small amount in the exten-

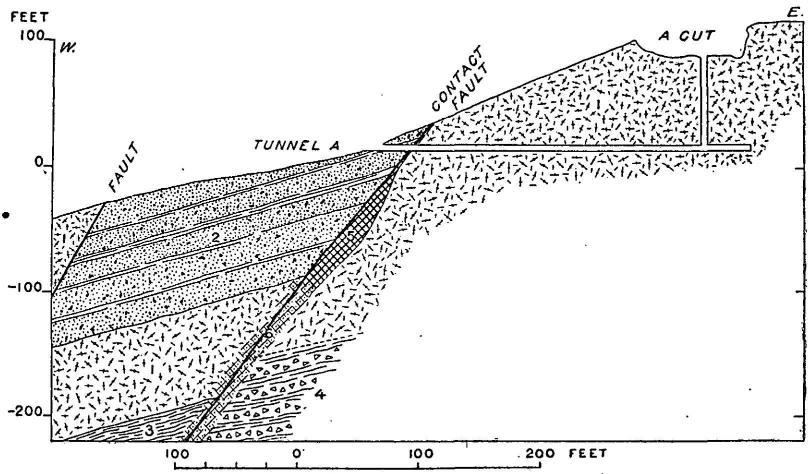
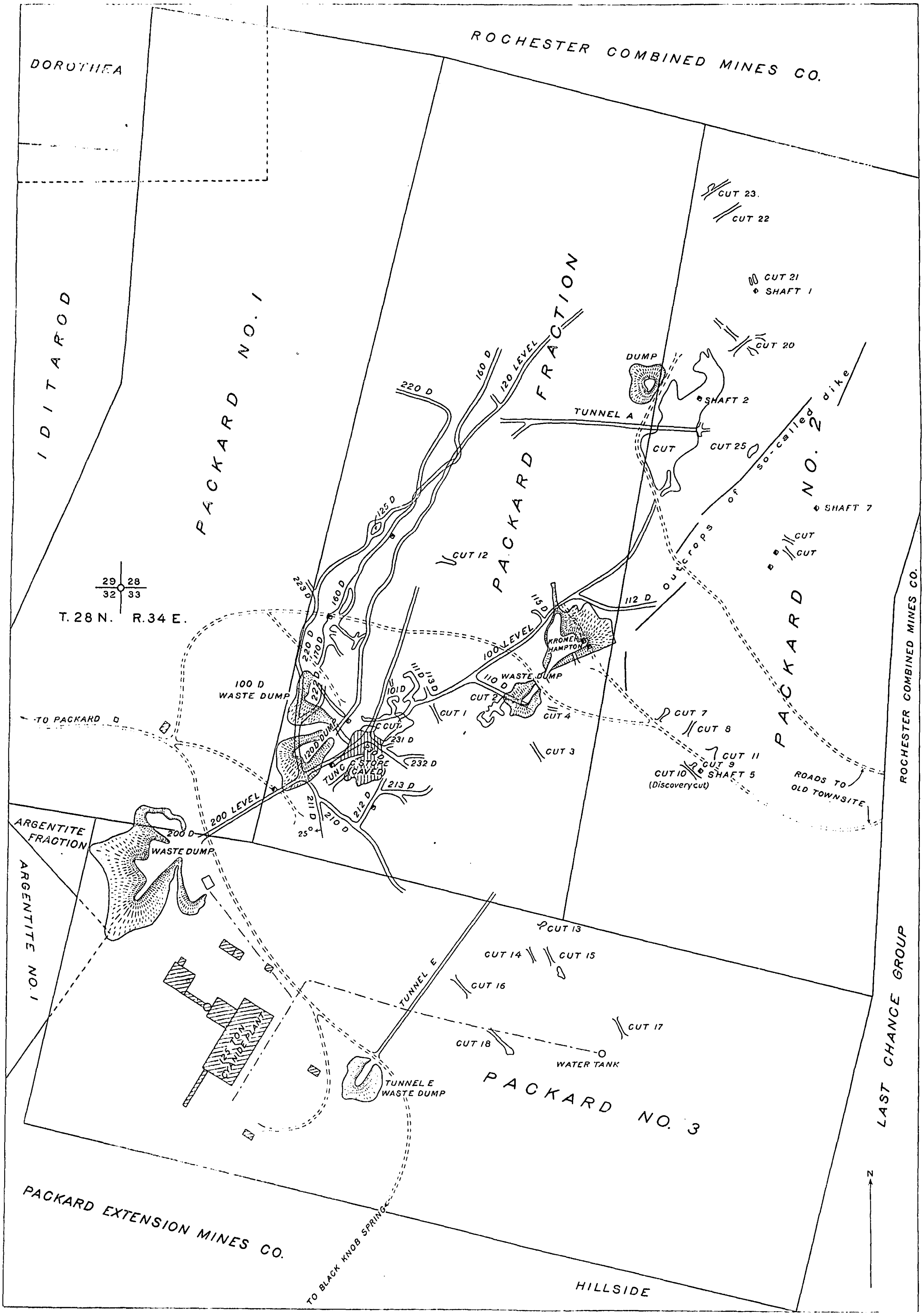


FIGURE 5.—Diagrammatic section through the Nevada Packard mine along the line of tunnel A. 1, Massive rhyolite; 2, soft gray tuff, with some interbedded shale; 3, compact sericite schist; 4, schistose rhyolite tuff and breccia; 5, ore; 6, leanly mineralized lode matter (protore)

sion into the adjoining ground of the Combined mine, which was the only ore found during the great fiasco connected with the exploitation of that mine.

The structural relations of the Contact lode are shown in Figure 5, which is a section drawn along the line of tunnel A. A section drawn across the lode somewhat farther north would show the base of the tuff belt at a higher level and ore occurring in the subjacent rhyolite on both sides of the fault.

The stockwork deposits are mined by large open cuts. There is little to indicate that much of the material mined is ore, as it does not differ perceptibly from the general run of country rock. However, certain of the ore bodies after being subjected to weathering for a time show that the country rock is traversed by a widely spaced



100 0 100 200 300 400 500 FEET

MAP OF NEVADA PACKARD MINE WORKINGS

network of narrow veinlets, as is illustrated in Plate II. The veinlets are fine seams, which in ore newly exposed to the weather are not apparent but which on oxidation become visible. Good ore is indicated by the development of coarser sericite and by the presence of numerous small iron-stained cavities formed as the result of the removal of pyrite and other sulphides by weathering. Assaying, however. is the only reliable method of determining what is or is not ore.

The stockworks are roughly elliptical in plan, the major axis trending N. 25° E. The ore in all of them gives out at a depth of 30 feet or less. The fracture planes of the ore are deeply stained by a deep-blue bloom, possibly vivianite, but this staining, although conspicuous, is of no economic significance. The stockworks occur both east and west of the so-called dike, but the largest quantity of ore has so far been found west of the "dike."

The Kromer Hampton open cut was one of the first from which ore was mined on the Nevada Packard property. It is in an extremely hard mottled blue and white massive rhyolite, known locally as the "hard blue." The fact that this rock is ore runs counter to all ideas as to what ore should look like. The pit is 150 feet long and 100 feet wide and attains an extreme depth of about 30 feet. The position of the Kromer Hampton cut relative to the workings on the Contact lode is shown in Plate IV. A fault trending N. 50° E. and dipping 60° NW. extends southwestward from the cut and converges with the Contact lode at the C stope. The 100-foot level is drifted along this fault, but no ore occurs along it.

The A cut is 250 feet northeast of the Kromer Hampton cut, and much ore was obtained from it in early days. It is 250 feet long and 75 feet wide, but it is rather shallow. The A tunnel was driven under this cut, and a raise was put through to the bottom of the cut, 90 feet above. No ore was found in the tunnel or raise.

In 1919 the mainstay of the mine was the Margrave cut, a large elliptical pit trending N. 25° E. The ore from it averaged $8 a ton in silver. Like the others, however, it proved to be shallow, and it was worked out by the end of the year.

The lessees are reported to have shipped in early days from open-cut workings carload lots of ore running from $30 to $60 a ton. Such high-grade ore was clearly the result of selective mining and careful sorting, for the open cuts have yielded by bulk mining ore that has averaged slightly under 8 ounces of silver to the ton. In addition to the ore, there is an immense amount of rock carrying several ounces of silver to the ton—in fact, the striking feature of Packard Ridge is the widespread dispersion of the silver and its concentration in sporadic shallow bodies of ore.

GOLD MINES AND PROSPECTS

LINCOLN HILL MINE

The Lincoln Hill mine is on the northwest flank of Lincoln Hill. It is opened by two adits, of which the lower, at an altitude of 6,190 feet, is the principal haulageway. It intersects the veins approximately 80 feet below their outcrops. The ore is hauled from the portal of the lower adit by wagon to a small milling plant in Rochester Canyon. The mine is reported to have produced $80,000 in gold and silver up to 1917. The gold bullion produced is of low grade, ranging in fineness from 0.530 to 0.600, owing to the considerable proportion of silver it contains.

The country rock is a quartz trachyte or rhyolite containing numerous conspicuous porphyritic crystals of orthoclase and a few inconspicuous crystals of quartz; in places it is faintly flow banded. Three narrow quartz veins have been worked, which are known as the Peerless, the Dike, and the Spur.

The Peerless vein furnished most of the output prior to 1917. It has been stoped for more than 200 feet along its strike, averaging 6 inches in thickness.

The Dike vein is peculiar in that the quartz ore that is mined occurs along both contacts of a dike locally termed the "tourmaline porphyry." This dike consists of a whitish-gray fine-grained rock specked with fibers and columns of black tourmaline. It strikes N. 40° W. and dips 70° E. Because of the thorough hydrothermal alteration of this dike, its original nature remains obscure, but it appears to have been of aplitic composition. In places secondary biotite has formed in it, but more generally it has been highly sericitized, and the tourmaline prisms formed at the same time give the rock its apparent porphyritic texture.

The ore is a milky quartz, in places carrying some tourmaline. Coarse gold is common, yielding ore that runs several hundred dollars to the ton, and is of primary origin. Sulphides are relatively sparse; black zinc blende predominates, followed by pyrite and by a very minor amount of galena. The wall rocks are pyritized and tourmalinized. The ore was localized in shoots that averaged a few inches in thickness.

The Spur vein branches off from the Dike vein, striking N. 70° W. and dipping 35° E. It averaged about 6 inches in thickness, and the quartz was frozen to both walls. At its junction with the Dike vein, it is said, there was 2 feet of ore averaging $400 a ton.

In drifting south on the Dike vein on the upper level a fault was cut, which gave much trouble before the lost segment of the vein was found. The fault trends N. 30° E. and dips steeply north, nearly vertical. The fault zone is 4 feet wide and is thoroughly crushed.

The crushed breccia where first cut contains east of the vein much quartz, seemingly torn off from the Dike vein, and therefore naturally suggested that the severed segment of the vein lay farther east—in other words, the fault was thought to be a normal fault. Drifting for 200 feet eastward along the fault failed to disclose the vein, however, and it was then discovered that fragments of the distinctive " tourmaline porphyry " occur in the fault drag west of the vein. This clue was acted on, and the lost segment was soon found. The fault thus proved to be of the reverse kind, and the misleading quartz drag was then perceived to have been torn off from the Spur vein, which, along the line of the fault on the upper level, is 45 feet east of the Dike vein. The displacement of the Dike vein as measured on the lower level is 42 feet.

High-grade ore was found in the segment south of the fault. The mining of such narrow high-grade shoots, whose thickness is generally less than 6 inches, yielded only a small tonnage, and in 1919 the policy of breaking a greater width of ore of lower grade was adopted. It was reported that 4 feet of $15 ore was being extracted.

ORO FINO MINE

The Oro Fino mine is in the western part of the district, on Gold Ridge between Rochester and Limerick canyons. The vein was discovered long before the present camp of Rochester came into existence, and it is said to have yielded considerable high-grade gold ore in 1879.[59] It was later abandoned, but in recent years it has been relocated by U. W. Harwood and associates, who have renamed it the Rico Nevada. It was stoped for 200 feet along its strike, and some of the old inclines attain a depth of 120 feet on the vein.

The vein consists of coarse white quartz, in places carrying masses of acicular black tourmaline. It ranges from 3 to 5 feet in width and lies between well-defined walls of fine-grained rhyolite breccia. The portion of the vein lying against the footwall has been severely crushed over a width of 15 inches. The ore carries no visible metallic minerals. It is reported that the gold tenor is spotted—that the ore can be sorted to run $50 a ton, but that other ore apparently similar will carry after sorting only $8 a ton.

HAGAN PROSPECT

The Hagan prospect is in Limerick Canyon near Spring Valley Pass. It is on the Mary McKinney claim, owned by A. F. Hagan. In 1917 it was under lease and bond, and some gold was being mined.

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[59] Schrader, F. C., U. S. Geol. Survey Bull. 580, p. 357, 1914.

The lode was discovered as the result of dry placer operations. It is at the apex of a thin alluvial fan, the gravel of which is gold bearing. The placers, as can be plainly seen from the worked-out ground, headed against the lode on the Mary McKinney claim, and consequently the gold tenor of the gravel in the shallow gulch improved headward, for the gold was not so widely scattered as it was farther down on the alluvial fan, where it was first found.

The lode has been opened up by 200 feet of tunnels and drifts. The footwall rock is a brownish iron-stained sparsely porphyritic rock, which under the microscope in found to be a quartz keratophyre.

The ore is in a fine-grained white rock, probably a trachyte, as it contains phenocrysts of orthoclase in a fine-grained groundmass, and the ore body consists of this white rock cut by stringers and veins composed of quartz, microcline, and tourmaline. The gold, which is coarse, generally occurs embedded in masses of limonite that have resulted from the oxidation of arsenopyrite. In preparing the ore for shipment, the material as mined is screened through a ¾-inch mesh and all but the screenings is rejected. The screenings are reported to carry $20 a ton in gold. The aplite contains innumerable cubes of oxidized pyrite, and the whole mass of rock—that is, the mineralized aplite plus the quartz stringers traversing it—is said to average $4 a ton in gold.

A strong quartz vein, also carrying coarse feldspar and tourmaline like the stringers in the Hagan lode, has been uncovered several hundred yards northeast of the Hagan lode on the same group of claims. Some chalcopyrite occurs in the vein. Pockets high in gold occur in the adjoining highly altered wall rocks.

Early in 1922 it was reported that a 20-ton amalgamation plant had been built on the property and water brought in by a pipe line 6,000 feet long.[60]

[60] Min. and Sci. Press, vol. 123, p. 943, 1921.

INDEX