Geology and Ore Deposits of the Summitville District San Juan Mountains Colorado

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By Thomas A. Steven and James C. Ratté

ABSTRACT

The Summitville district, in the eastern San Juan Mountains, Colorado, has produced about \$7½ million worth of metals; most of this has been from gold, with lesser amounts in silver, copper, and lead. Copper has been a minor byproduct during several periods of mining at Summitville, and since 1940 copper has averaged between 1 and 5 percent of the annual production value for those years the mines were operating.

All the rocks that crop out in the Summitville district are of volcanic or related shallow intrusive origin. The oldest rocks near Summitville belong to the Conejos formation of the Potosi volcanic series of middle or late Tertiary age; some remnants of younger quartz latite and rhyolite units of the Potosi series are near the western margin of the Summitville district, but these were not studied in detail during the present investigation. The Conejos formation near Summitville is made up largely of a thick sequence of dark, fine-grained porphyritic rhyodacitic flows. This sequence is cut by a large quartz monzonitic stock along Alamosa Creek south of the district, and by a smaller stock of similar rock along Wightman Fork east of the district.

The Fisher quartz latite lies on an irregular erosion surface cut on the older formations. The first eruptions onto this surface were of viscous rhyodacitic lavas which built up a complex heap of volcanic domes, thick local flows, and associated breccias and tuffs. These are cut by two bodies of intrusive rock of similar composition and aspect. The rhyodacitic lavas were followed, apparently without significant time lapse, by eruptions of similar bodies of quartz latitic lavas, and by the intrusion of related quartz latite dikes.

Volcanic eruptions were renewed in later Fisher time, following a period of solfataric activity and erosion, and a series of quartz latite flows spread laterally down radial valleys that had been cut on the earlier Fisher lavas.

A few younger volcanic necks are in the general vicinity of Summitville; these are the only remnants of volcanoes formed during the Hinsdale period of volcanic activity. None of these were studied in detail.

A northwestward-trending fault extends diagonally across the Summitville district. The first major movement followed eruption of the lower member of the Fisher quartz latite and preceded the period of hydrothermal activity that altered large volumes of the older Fisher rocks. The fault was reactivated in the northwestern part of the district after some lavas of the upper member of the Fisher quartz-latite were erupted. Subsequent volcanic activity resulted in the injection of dikes along the fault zone, and in the drilling of a volcanic vent along one branch of the fault.

Two periods of hydrothermal activity altered large masses of rock in the general Summitville region. The earlier of these periods was late in the Conejos period of vulcanism, and apparently was related to the intrusion of the quartz monzonitic stocks along the southern margin of the Summitville district. Unaltered lavas in the lower member of the Fisher rest unconformably on these altered rocks. Most of the rocks altered during Conejos time are outside of the area studied in detail during the present investigation.

The younger period of hydrothermal activity followed eruption of the lower member of the Fisher quartz latite. The largest mass of rocks altered during this period occupies an area of about 1⅓ square miles in the central part of the Summitville district, and local variations in the concentration of the different secondary products suggest that the alteration took place with respect to several centers of hydrothermal activity. A northern lobe, containing all of the productive mines in the district, is centered on the northeast face of South Mountain. The more intensely altered rocks here consist of resistant pipes and veinlike masses of vuggy quartz and quartz-alunite rock that commonly contain economic concentrations of gold, silver, and copper. The ore minerals, largely pyrite, and enargite but also including local barite, galena, sphalerite, and native sulfur, are generally concentrated in the more porous rocks. The resistant veins are commonly surrounded by irregular envelopes of soft, highly argillized ground. Illite and montmorillonite are the most common alteration products in the argillized envelopes, but locally the inner parts of the envelopes contain abundant kaolinite. The bulk of the altered rocks away from the intensely altered quartz-alunite bodies and their clayey envelopes consist of slightly to moderately altered rocks in which the matrix and ferromagnesian crystals have been largely altered to montmorillonite, quartz, and chlorite, but the plagioclase, sanidine, and quartz phenocrysts are still fresh.

The highly silicifed and mineralized veins, and the surrounding argillic envelopes are typical of rocks altered by acid-sulfate solutions, whereas the montmorillonitic and chloritic rocks adjacent to the more highly altered zones are more characteristic products of weakly acidic, neutral, or alkalic conditions of origin. These zonal relations suggest that the altered rocks now exposed at Summitville were formed by a virtually continuous process. Near the original channelways, the rock was leached of its more soluble materials, leaving little more than a porous skeleton of fine-grained quartz. As the acid solutions were progressively neutralized and enriched in soluble bases, alunite as well as quartz formed by the breakdown of the original silicate minerals. Owing to continued

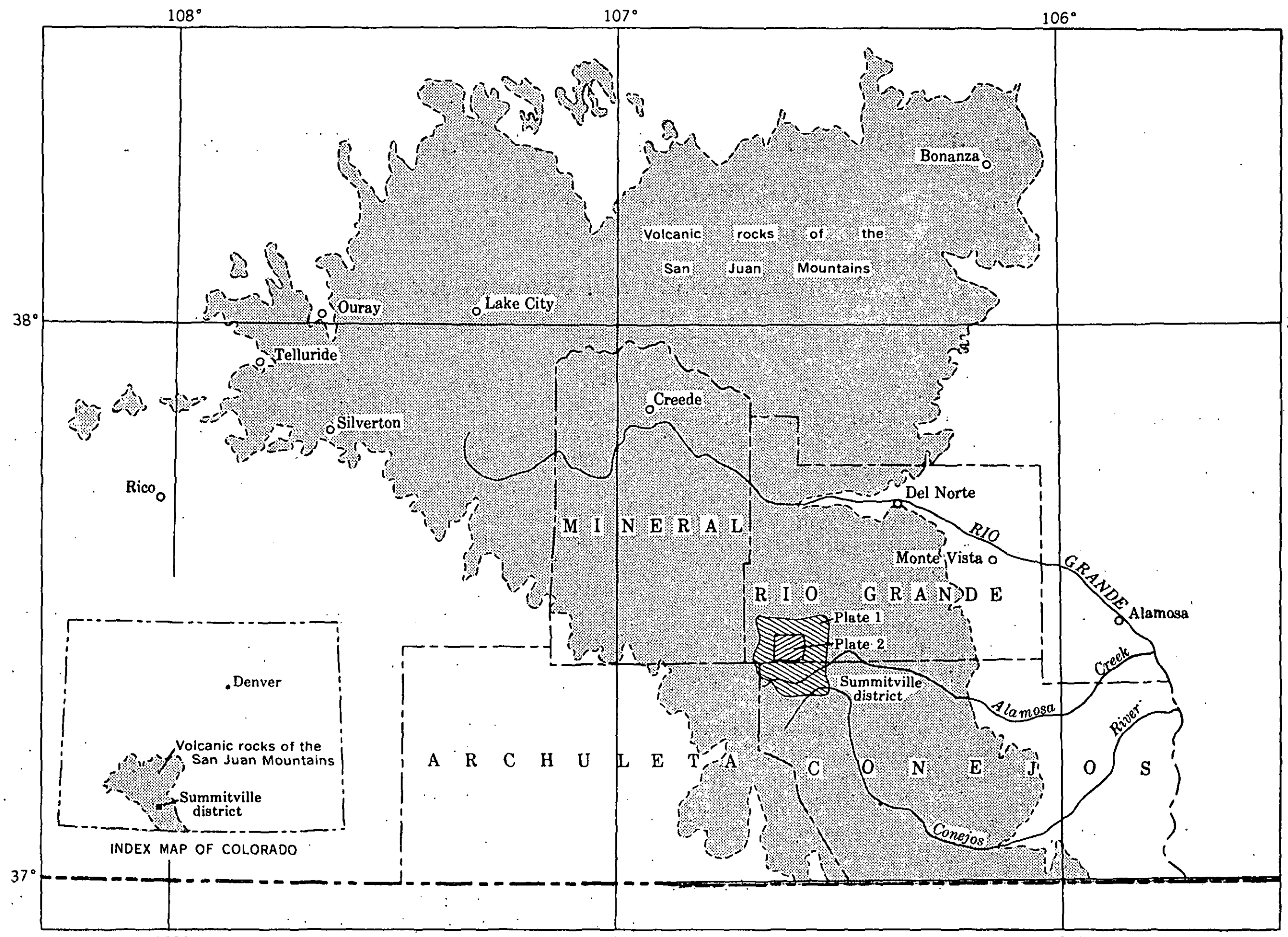

FIGURE 1.—Index map of the San Juan Mountains, Colorado, showing the location of the Summitville district.

neutralization and enrichment in leached bases, the solutions formed first the kaolinitic rocks in the inner part of some of the argillic envelopes, and then formed the illitic rocks comprising most of these envelopes. The acid-sulfate solutions apparently were neutralized or nearly neutralized within the argillic envelopes, and the surrounding montmorillonitic and chloritic rocks were formed under nearly neutral or alkalic conditions as the solutions were dissipated outward from the main channels of solution access.

Deposition of the ores was consistently late in the sequence of rock alteration, and took place under much different conditions of origin. Whereas the host rocks in the intensely altered zones formed in an oxidizing, acidic environment, the ore minerals were deposited subsequent to the most intense silicification and leaching and formed in a generally reducing environment. Complex paragenetic relations are characteristic in the ores, and the local occurrence of hypogene barite and native sulfur indicates that in places partly oxidizing conditions prevailed at times even during the period of generally reducing conditions that accompanied ore deposition.

Although the veins in the Summitville district are irregular, discontinuous, and difficult to project, company mine maps indicate that most of the known vein zones extend from the surface to the level of the lowest mine workings (the Reynolds level), and that in many places metal concentrations of commercial interest extend to that depth. Lacking knowledge of changes in ore grade or mineralogy with depth, we cannot predict how deep the ore may extend, but similar ore deposits in the Red Mountain district, Colorado, the Goldfield district, Nevada, and other places have bottomed at shallow depths.

INTRODUCTION

The Summitville district, in the eastern San Juan Mountains, Colorado (fig. 1), has produced about $7½ million worth of metals from an area no greater than 4,000 feet long by 1,000 feet wide. The chief values have been from gold, with lesser values from silver, copper, and lead. Although copper has been a minor byproduct throughout most of the production history, it occasionally accounted for several percent of the ore produced, and since 1940 it has constituted between 1 and 5 percent of the total production.

This small but highly mineralized area is remote from the other productive mining camps in the San Juan Mountains, and at the time this investigation began, the geology of the district was little known. Several geologists with the U.S. Geological Survey, chiefly W. S. Burbank and B. S. Butler, had visited the area briefly in connection with other geologic investigations, and were impressed with the apparent similarity of the altered rocks here with those in the Red Mountain district in Ouray County, Colo. The ores at Summitville are also associated with some of the younger rocks in the volcanic sequence comprising the San Juan Mountains, and many problems relating to age and geologic associations of ore deposits in these mountains seemed more likely to be solved here than in the more deeply eroded areas that include the major producing mining camps in the western part of the mountains. Accordingly, the U.S. Geological Survey began its study of the Summitville district in 1952 with two primary objectives: to appraise the potential of the little known Summitville district as a producer of base metals, and to obtain background geologic information essential to projected studies in other mineralized areas in the San Juan Mountains.

Unfortunately, the mines were closed throughout the period of field investigations, and all the main underground workings either were caved or were blocked by ice. Field investigations of the mineral deposits, therefore, were limited to surface exposures where most of the ore had been removed long ago. The general course of rock alteration and mineralization was determined, but many problems relating to the distribution and occurrence of the ore minerals remain unanswered.

The regional studies, on the other hand, have been more productive than was anticipated. The ores at Summitville were found to be of different age and genesis from the deposits in small, nearly nonproductive mineralized districts along Alamosa Creek, a few miles south of the Summitville district. The age of mineralization at Summitville has been dated closely, and the relations of the ore deposits to the volcanic environment at the time of origin have been interpreted with fair confidence.

ACKNOWLEDGMENTS

It is a pleasure to acknowledge the cooperation received from the property owners in the Summitville district, particularly Mr. and Mrs. George H. Garrey, and Mr. Ben T. Poxon. The surface and mine maps provided by Mr. Garrey were especially helpful in our studies of the mineral deposits, and we are further indebted to Mr. Garrey for a great deal of historical data on the district. Mr. Robert L. Jones held a lease on many of the properties during the first summer of our fieldwork, and both he and his employee, Mr. Lisle Morgan, assisted in every way they could. Newmont Mining Corp. held an option on the mines during 1953 and was actively testing the deposits at the time we were mapping them. Their field staff, headed by Mr. John Livermore, was most cordial and cooperative. Analyses were made by Lucile N. Tarrant, Paul L. D. Elmore, Katrine E. White, Paul R. Barnett, and Faye H. Neuerburg, all of the U.S. Geological Survey. Line sketches were made by John R. Stacy of the U.S. Geological Survey from photographs. The photomicrographs were taken by Wendell Walker.

This investigation is part of a long-range program for the study of mineral-producing areas in Colorado that is being done by the U.S. Geological Survey in cooperation with the Colorado Metal Mining Fund Board.

GEOGRAPHY

The Summitville district is located high in the southeastern San Juan Mountains near the southwest corner of Rio Grande County, Colo. (fig. 1). Altitudes at the townsite of Summitville range from 11,200 to 11,400 feet, and the mine workings are all between 11,300 and 12,300 feet above sea level. The district is remote from centers of population and from good means of transportation. The nearest town is Del Norte, the seat of Rio Grande County, about 30 miles to the northeast by mountain road. Another road leads east from Summitville, down Wightman Fork to Alamosa Creek, where it joins a road connecting Platoro with the San Luis Valley. This road is somewhat better than the one from Summitville to Del Norte, but it is nearly 50 miles by this route to Monte Vista, the nearest main town. The Denver and Rio Grande Western Railroad passes through both Del Norte and Monte Vista.

The topography of the San Juan Mountains near Summitville has a distinct three-level aspect, with a mature upland surface surmounted by mountain peaks and cut by deeply incised canyons (fig. 2). The upland surface is a rolling, somewhat dissected plateau, ranging from 11,200 to 12,000 feet in altitude. Near Summitville, most of the surrounding peaks are between 12,300 and 12,700 feet above sea level, but along the Continental Divide 6 to 8 miles southwest of Summitville, the highest peaks are Montezuma and Summit Peaks, with altitudes of 13,131 and 13,272 feet respectively. The incised canyons range from a few tens of feet deep near the headwaters to about 2,000 feet deep along the main streams.

The upland surface is well preserved in a belt about 1½ to 3 miles wide which extends about 5 miles northeast and 6 miles southwest from Summitville. This summit area of subdued relief serves as headwaters for many radially arranged streams, which are sharply and progressively incised downstream. Alamosa Creek and its tributaries Wightman Fork and Bitter and

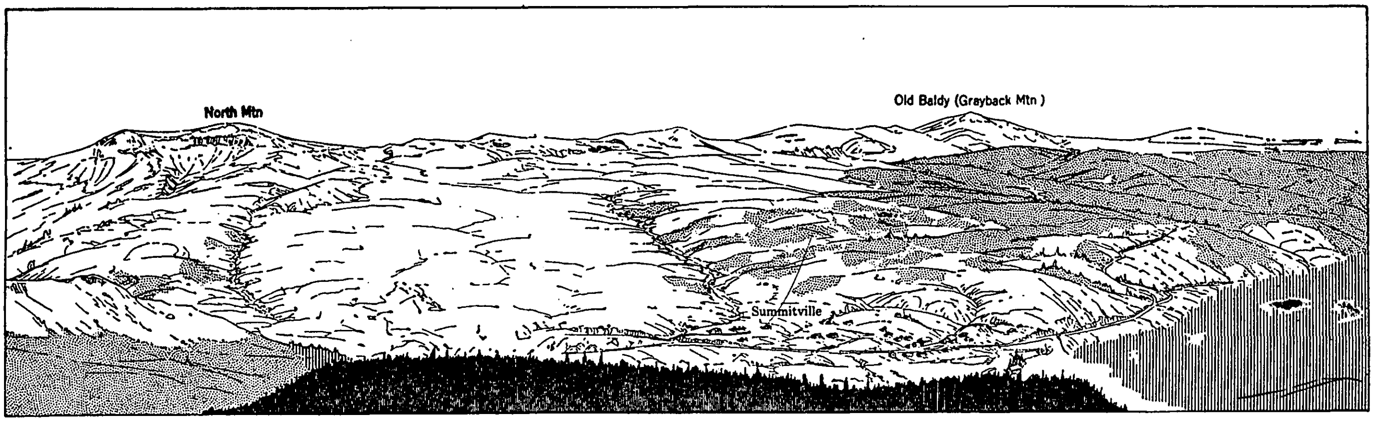

FIGURE 2.—View looking north across Wightman Fork from the top of South Mountain.

Iron Creeks, drain the eastern and southern parts of the area; Pinos and Beaver Creeks drain the northern, Park Creek drains the northwestern, and the headwaters of the San Juan River drain the western parts of the area.

Because of its high altitude, the Summitville district has long, cold winters and short, cool summers. Winter snowfall is extremely heavy in normal years, and commonly some of the more protected snowbanks persist from year to year. Thunderstorms are common during the summer, particularly in July and August when they are likely to occur daily.

Many of the lower slopes, and some of the higher, northward-facing slopes around Summitville are covered by a heavy spruce forest. Much of the upland surface, however, is mountain meadowland interspersed with patches of spruce. The higher peaks all project well above timberline, which generally is between 11,700 and 12,000 feet in altitude, depending on local conditions.

Mining, lumbering, and grazing have been the chief industries in the vicinity of Summitville. Most of the lumber produced has been used in connection with the mining operations, and the industry has fluctuated in direct response to the activity at the mines. None of the mines were operating at the time fieldwork was being done for this report, nor was the lumbering industry operating. The high meadowlands, however, are used annually as summer pasture for sheep, and commonly as many as three of four separate bands of grazing sheep were seen at a time from high peaks or vantage points. Most of this grazing is on National Forest land, and is done under supervision of the U.S. Forest Service.

HISTORY AND PRODUCTION

The earliest successful discoveries of gold in the San Juan Mountains were made in the summer of 1870 in the Summitville district and in Arrastra Gulch in San Juan County. These finds were preceded only by the reported discovery of gold near Lake City in 1848 by a member of an exploration party under the direction of John C. Fremont, and by the discovery of mineralized rock but not commercial deposits in the Rico district in 1869. News of gold at Summitville and Arrastra Gulch began a rush to the San Juan Mountains which resulted in the discovery within a few years of most of the other major producing mining camps in the region.

The discovery and early development of the ore deposits at Summitville have been described in detail by Raymond (1877, p. 326–334) and excellent summaries of the early history of the camp have been given by Patton (1917, p. 65–67) and Henderson (1926, p. 201–206). The following bibliography lists in chronologic order the published sources of information used in assembling this historical sketch; additional data have been obtained from conversations with Mr. George H. Garrey, Mr. B. T. Poxon, and others who have been closely associated with mining in the district.

Bibliography of historical and production data on the Summitville mining district

1. Raymond, R. W., 1877, Statistics of mines and mining in the States and Territories west of the Rocky Mountains: U.S. Treasury Dept., 8th Ann. Rept., U.S. Commissioner Mining Statistics p. 327–328.
2. Patton, H. B., 1917, Geology and ore deposits of the Platoro-Summitville mining district, Colorado: Colorado Geol. Survey Bull. 13, p. 65–67.
3. Henderson, C. W., 1926, Mining in Colorado: U.S. Geol. Survey Prof. Paper 138, 263 p.
4. Guiteras, Jos. R., 1938, Mining and milling methods and costs at the Summitville Consolidated Mines Inc., Summitville, Colorado: U.S. Bur. Mines Inf. Circ. 6990.
5. Vanderwilt, J. W., 1947, Mineral resources of Colorado: Colorado Mineral Resources Board, p. 182–186.
6. Annual report for the year(s) 1897–1953: Colorado Bur. Mines Ann. Repts., 1898–1954.

7. U.S. Geological Survey, 1882–1923, Mineral resources of the United States [yearly], 1883–1927; 1924–31.
8. U.S. Bureau of Mines, 1927–34, Mineral resources of the United States [yearly], 1927–34.
9. ——— 1932–51. Minerals yearbook [yearly], 1933–53.

As described by Raymond (1877, p. 327–328):

The first discovery of gold in the Summit district was made in Wightman's Gulch about the last of June 1870, by a party consisting of James L. Wightman, E. Baker, J. Cary French, Sylvester Reese, and William Boran, Wightman getting the first "prospect." All of the party, with the exception of Wightman and Reese, left by the middle of September, the latter remaining, engaged at sluicing, until the 9th of November when they left, heavily packed, and made their way out through snow waist-deep, reaching the Rio Grande in three days.

In the spring of 1871 a large number of people flocked into the summit, hundreds arriving while the snow was yet very deep and work impracticable. A general disgust soon took possession of the prospectors, and by the last of August there were but three men in the district, J. L. Wightman, P. J. Peterson, and J. P. Johnson. These then remained until about the 20th of October, Wightman and Peterson being the last to leave. They took the gold realized by sluicing to Denver, and had it refined at the mint, dividing $170 between the three after paying all expenses of the season's operations; not a very encouraging yield for a hard summer's work. Several lodes had in the meantime been found, or at least lode locations made. The specimens found in the gulch indicated to the miners that they had not washed far, and they believed that parent ledges in place were close by.

In 1872 a few locations were made, and 1873 witnessed a new emigration into the district, and in that year the richest mines in the summit were located. The Esmond and Summit lodes were staked during the summer, and on September 13, F. H. Brandt and P. J. Peterson located the Little Annie, Del Norte, and Margaretta Mines, the former being named after a daughter of Mr. Peterson, the latter after a sister-in-law of Mr. Brandt.

During 1874 a vast number of new locations were made, and the attention of the owners was turned to the matter of getting in machinery. Dr. Richard F. Adams, after locating the Summit mine, shipped a small amount of the ore to be tested, and, having become satisfied that the enterprise would pay, located a mill-site and ordered a mill, which was brought in and commenced to run the following spring.

During the winter 1874–1875 negotiations were opened by the mine owners with capitalists for the purpose of getting in mills. The owners of the Little Annie, Del Norte, and Margaretta, of the Golden Queen, and of the Golden Star, entered into contracts by which the parties putting in the mills were to have an interest in the mines.

The spring of 1875 marked the opening of permanent mining operations at the Summit. Dr. Adam's 5-stamp mill began work as early as the advance of the season permitted. In the latter part of May the machinery for the Little Annie and Golden Queen mills reached Del Norte from Chicago, and was drawn by mule-teams on a road cut for the purpose over Del Norte Mountain, 13,000 feet high, and costing over $4,000. The machinery for the two mills weighed more than 50 tons, but was successfully transported above the lower cloud-belt, and placed in position before the close of September.

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Although the first gold discovered in the Summitville district was in stream gravels, and placer mining continued intermittently until at least 1888, the total production from this source has been minor. Specific records of placer-gold production were available only for 1887–88, when $7,000 was produced during the 2 years. Total production from the placers probably did not exceed three or four times that amount.

Lode mining on a significant scale (table 1) began in 1875; at first the deposits were worked by opencuts but these were soon followed by shafts and underground workings. The oxidized ores near the surface were rich and easy to beneficiate and most of the gold mined during the early boom period came from shallow depths. By the end of 1887, most of the known and easily accessible oxidized ores had been mined. The underlying sulfide ores were much lower grade and more difficult to mill and concentrate; production from the district dropped off rapidly and by 1893 the district was practically deserted.

TABLE 1.—*Gold, silver, copper and lead produced by the Summitville district, Colorado*

[Production figures: 1873–1923, from Henderson (1926, p. 206); 1924–49 from U.S. Bureau of Mines, Minerals Yearbook]

Year	Gold	Silver	Copper	Lead	Total
1873	$2,000				$2,000
1874	5,000				5,000
1875	272,044	$9,590			281,634
1876	121,148	8,971			130,119
1877	195,337	9,281			204,618
1878	102,866	8,894			111,760
1879	28,500	8,662			37,162
1880	6,000				6,000
1881	290,000	8,739			298,739
1882	210,000	17,635			227,635
1883	180,000	8,585			188,585
1884	130,000	12,019			142,019
1885	130,000	10,486			140,486
1886	149,266	8,729			157,995
1887	122,380	7,832			130,212
1888	16,260	2,748			19,008
1889	35,760	3,532			39,292
1890	25,716	1,351			27,067
1891	38,592	7,674			46,266
1892	14,487	10,898			25,385
1893		621			621
1894	16,816	794			17,610
1895	15,795	2,183			17,978
1896	1,870	920	$148	$14	2,952
1897	22,592	4,901	75	432	28,000
1898	3,720	925	1,214	91	5,950
1899	19,202	1,631	57	74	20,964
1900	107,629	1,906	1,427	1,155	112,117
1901	32,927	4,156	10,956	29	48,068
1902	14,262	1,681	154	7	16,104
1903	12,939	1,841	698		15,478
1904	4,010	1,323	83		5,416
1905	4,051	644	19		4,714
1906	8,580	103			8,683
1907					
1908	764				764
1909					
1910	1,306	33	11	11	1,361
1911					
1912	5,549	551	4,896	14	11,010
1913	243	66	88		397

TABLE 1.—*Gold, silver, copper and lead produced by the Summitville district, Colorado*—Continued

Year	Gold	Silver	Copper	Lead	Total
1914	474	9			483
1915	14, 968	165			15, 133
1916					
1917	24	43	166		233
1918					
1919					
1920					
1921					
1922					
1923	1, 662	132	32	65	1, 891
1924	3, 558	73		128	3, 759
1925	3, 510	355		392	4, 257
1926	105, 799	55			105, 854
1927	133, 530	152			133, 682
1928	245, 579	355			245, 934
1929	33, 782	3, 229	949	3, 480	41, 440
1930	8, 590	92		75	8, 757
1931	1, 053	22			1, 075
1932	186	2			188
1933	3, 903	10		7	3, 920
1934	41, 977	1, 547	480		44, 004
1935	284, 165	8, 929	3, 735		296, 829
1936	454, 620	19, 572	6, 440		480, 632
1937	537, 929	26, 340	3, 509		567, 849
1938	691, 901	32, 876	980		725, 757
1939	505, 575	36, 288			541, 863
1940	442, 295	26, 464	14, 690		483, 449
1941	594, 265	9, 969	944		605, 178
1942	192, 465	5, 110	11, 301	54	208, 930
1943	115, 045	997	2, 210		118, 252
1944	75, 390	869	2, 025	56	78, 340
1945	19, 600	480	324		20, 404
1946	64, 190	1, 889	2, 268		68, 347
1947	74, 515	2, 210	3, 885	346	80, 956
1948					
1949	2, 870	182	788		3, 840
Total	7, 001, 031	348, 321	74, 552	6, 430	7, 430, 334

Between 1873 and 1887 the Summit (Summitville) district produced more than $2 million worth of gold and silver, 95 percent of which was in gold. By 1883 the district was the third largest gold producer in the State, and the record output for a single year during the 15-year period was $290,000, produced in 1881. During this period the Little Annie mine produced most of the ore. At first the ore was hauled to the mills by team and wagon in the summer, and by men pulling rawhides over the snow in the winter. In 1876 a 2,125-foot-long gravity tramway was constructed for this purpose (fig. 3). The number of mills increased from the initial 5-stamp mill built by Dr. Adams in the spring of 1875 to 11 mills with more than 165 stamps by 1884. Mine development and production kept pace until about 1883, but as the mine workings became deeper, the ratio of base metals to gold increased in the ore, and the poor recovery of gold even from the free-milling highly oxidized ore, made milling unprofitable.

A few prospectors returned to the district in 1894 and their numbers increased steadily for awhile as the mines produced a few thousand dollars worth of gold each year. However, from 1894 to 1915, the total returns from the district were less than $350,000, and except for 1900 and 1901 when production was $112,117 and $48,068 respectively, the highest single-year production of the district was only $28,000 (1897). During this period, the value of gold produced dropped to about 85 percent of the total, but silver increased to about 10 percent of the production values. In 1896 the first copper and lead production was reported, and copper accounted for about 4 percent of the value of metals produced between 1894 and 1916.

By 1915 all of the mines in the Summitville district were owned either by A. E. Reynolds of Denver or by the Consolidated Gold Mining Co. of New York, and in August of 1915 the two companies merged and became known as the Summitville Gold Mines Inc. From 1916 to 1925 a few thousand dollars worth of ore was shipped by lessees, but most of the mining activity in the district was mine development work.

In 1926 Jack Pickens and his partner Judge Wiley reported a strike of high-grade gold ore on their lease in the Little Annie group. According to unwritten accounts, Pickens had seen the outcrops of rich ore in the ruts of a wagon road many years earlier, but it took him nearly 20 years to obtain a lease on the property without arousing suspicion that would have led others to his discovery. Between 1926 and July 1, 1931, Pickens and Wiley received $501,261.42 from 864 tons of hand-sorted shipping ore, with the price of gold at $20 an ounce. Most of this ore was taken from the Pickens cut (pl. 3), a small mine opening near the southeast end of the Annie vein. Production from the Pickens lease decreased sharply in 1930, and between 1930 and 1934 the total production of the district was slightly less than $14,000.

In 1934, Summitville Consolidated Mines Inc. was organized, and obtained control of most of the properties in the camp. Under H. F. Detrick as president and Edward Thornton as general manager, the district entered the most productive period of its history. In 1934, a 100-ton flotation-cyanidization mill and a gold retort plant were constructed at the camp, and a high-tension powerline was built between Del Norte and Summitville. By the end of 1935, the mill capacity had been increased to 300 tons daily, about 100 new buildings including schools, post office, and hospital had been constructed, and 300 men were employed in the district. On August 1, 1942, the Summitville Consolidated Mines Inc. relinquished its lease to the Gold Links Mining Co., which that year completed conversion from the flotation-cyanidization mill to a straight flotation mill. The Gold Links Mining Co. continued as the chief producer in the district until

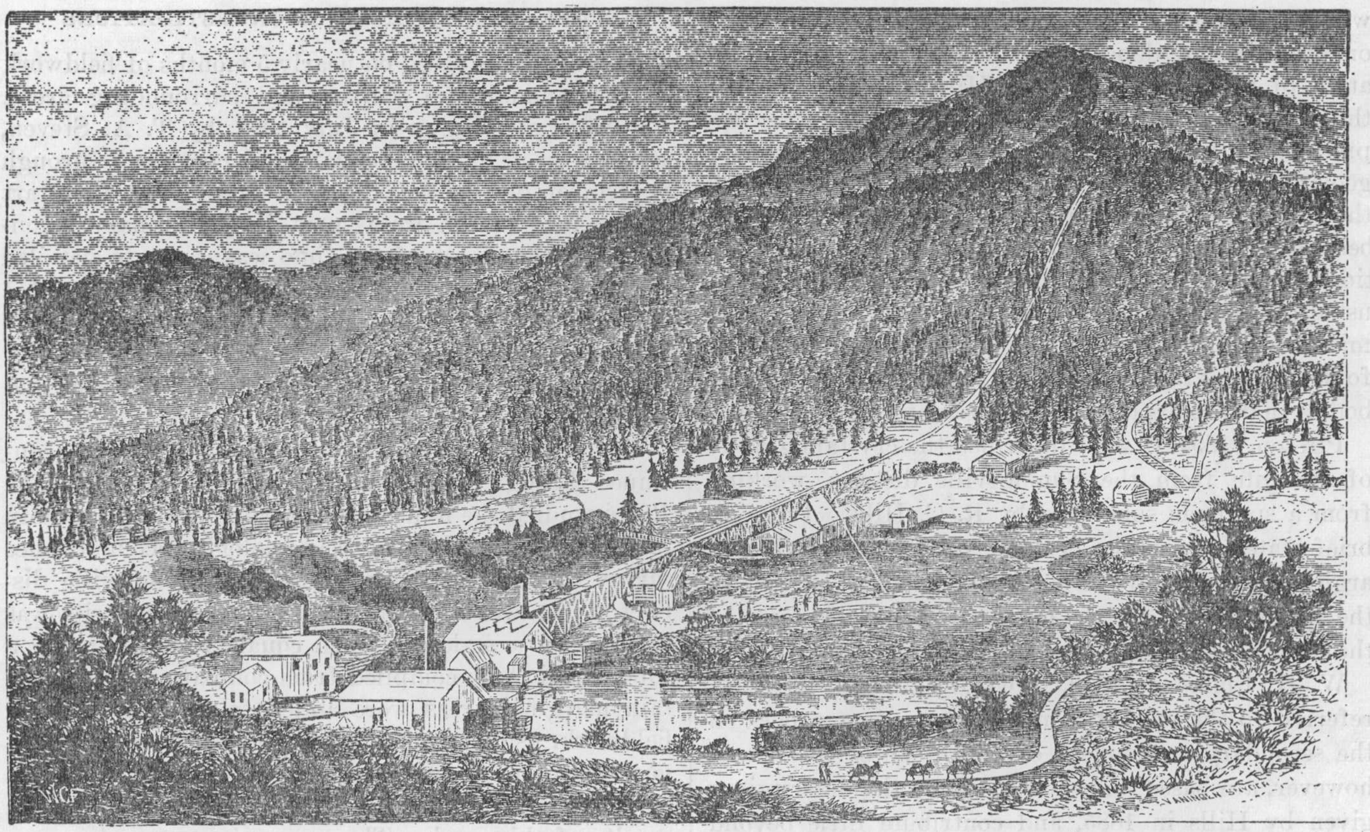

FIGURE 3.—South Mountain and Little Annie mining camp, Summit district, Colorado. Tramway brought oxidized ores from the Little Annie mine to the first stamp mill in the district. South Mountain comprises the southwestern part of a large volcanic dome. The ore deposits formed in the core of the dome. (Reproduced from Raymond, 1877, facing p. 329.)

June 20, 1946, when its holdings were transferred to the Summitville Mining Co., which at the time of fieldwork for the present report controlled most of the property in the Summitville district. The total production from the Summitville district, from 1934 to 1947, exceeded $4 million, of which 95 percent of the value was in gold, about 3 percent in silver, about 1 percent in copper and 0.01 percent in lead.

In 1948, the camp was idle until September when Robert L. Jones and H. O. Nylene of Leadville, Colo., obtained a lease from the Summitville Mining Co. They reopened the flotation section of the mill to treat gold-copper ore from dumps and surface diggings. They continued work in the district for 4 months in 1949 but shipped less than $4,000 worth of concentrates. The district was again idle until 1953 when the Newmont Mining Corp. leased about 2,000 acres of the mining property owned by the Summitville Mining Co. The Newmont exploration department conducted a sampling, drilling, and geophysical program for several months in 1953, and subsequently relinquished their lease. No metals were produced from the Summitville mining district between 1949 and 1954.

General Minerals Corp. obtained a lease on the property in late 1955 or early 1956, and began exploration and rehabilitation of the mine workings in the summer of 1956.

PREVIOUS GEOLOGIC INVESTIGATIONS

The earliest description of the geology of the Summitville district (or the Summit district, as it then was known) was made by F. M. Endlich (1877, p. 172), a geologist with the Hayden survey. Endlich visited the district on June 28, 1875, only a few years after its discovery, and his account of the geology is remarkably perceptive considering the brief period spent on the ground and the few mine workings open at the time. Endlich noted that the ore did not occur in definite veins, but was in an area of altered rocks impregnated with pyrite ("red stratum"). He recognized that the free gold associated with limonite that formed the ore being mined at the time of his visit was derived by weathering of pyritic ores, and he correctly predicted that the free-milling ore would pass into lower grade sulfide ore with depth.

R. C. Hills (1885, p. 20–37) published an account of the geology of the Summitville (Summit) district in which he discussed the structure, mineralogy, and origin of the ore deposits, and the hydrothermal alteration of the adjacent rocks. Hills' consideration of the altered rocks and oxidized ores showed a keen appreciation of the importance of these factors in the geology of the ore deposits, and he seems to be among the first to recognize that some of the gold may have been enriched by supergene processes. These contributions, however, are somewhat overshadowed by his unusual postulate that the veins represent a silicified and mineralized contact that was subsequently closely folded, giving rise to the series of subparallel silicified bodies that are exposed at the present erosion surface.

Pirsson (1894, p. 212) described the crystallography of enargite from the Summitville district, working from a specimen submitted by R. C. Hills. Pirsson's brief statement on the geologic occurrence of the enargite was taken from a note submitted by Hills with the specimen and for the most part reiterates some of the ideas already published by Hills.

W. H. Emmons (1912, p. 66–67; 1913, p. 226–227) referred to the ores at Summitville in two papers on the secondary enrichment of gold. These references, however, are based almost entirely on the descriptions given by Hills in 1885, and contribute little beyond what was in the pioneer work.

Hills (1917, p. 205–207) discussed the oxidized ores from Summitville again in 1917 in a brief note calling attention to the association of gold with limonite, barite, and enargite. He suggested that the gold was deposited in association with these minerals by secondary processes.

The only comprehensive and detailed discussion of the geology of the Summitville district prior to the present report was published in 1917 by Patton (1917). The rock units differentiated by Patton differ significantly from those used by subsequent workers in the area (Cross and Larsen, 1935); Larsen and Cross, 1956; this report) and the regional geologic picture he presented has since been modified considerably. His discussions of the mines and mineral deposits, on the other hand, have proved invaluable as he presented more detailed information on the mineralogy, mineral associations, and distribution of valuable metals in the ore deposits at Summitville than it was possible to obtain during the present investigations. Patton's report is still the best available source of detailed geologic information on the mines and ore deposits in the small Platoro, Jasper, Stunner, and Gilmore districts that occur in the fringe area to the south and southeast of the Summitville district.

SCOPE AND METHODS OF INVESTIGATIONS

This report is based on nearly 5 months of fieldwork in the Summitville district and surrounding areas. The work was begun in July 1952, by T. A. Steven, assisted by J. C. MacLachlan, and continued through September of that year. Several weeks at the start of the field season were spent in preliminary reconnaissance, but most of the time was given to detailed mapping of the Summitville district on a scale of 1 inch equals 1,000 feet (pl. 2). A preliminary account of the geology of the district, based on the first summer's fieldwork, was published in 1953 (Steven and MacLachlan, 1953).

Fieldwork was resumed in early August and continued through September 1953, when Steven and J. C. Ratté studied the mineralized area on South Mountain in detail, and made a hurried geologic reconnaissance survey of the area surrounding the Summitville district. The area including the main ore deposits was mapped on a scale of 1 inch equals 100 feet, using a topographic base compiled from company maps. Certain marginal areas were added to this base during fieldwork, using planetable and telescopic alidade. A geologic map (pl. 3) of the main metal-producing area of the Summitville district, Colorado, illustrates the results of this work. The reconnaissance survey was done on an enlarged copy of the topographic map of the Summitville quadrangle, Colorado, on which the geology taken from U.S. Geological Survey Bulletin 843 (Cross and Larsen, 1935, pl. 1) had been plotted. The previously mapped geology was field checked and revised, areas of altered rocks were delimited, and the Fisher quartz latite (see pages 13–25) was subdivided into members recognized earlier in the present investigation. Plate 1 illustrates the results of this survey.

Fieldwork in the Summitville district was complicated by the massive character and close similarity of many of the rock units, and by generally poor exposures. Many of the high rounded mountain tops that project above timberline are strewn with frost-riven boulder fields or felsenmeer, and the steeper slopes are covered in large part by soil, solifluction debris, landslides, or talus. Many of the lower slopes and valley bottoms have a discontinuous veneer of morainal material, and commonly are covered by a dense spruce forest and thick soil. Geologic contacts and faults could rarely be traced directly in the field, and the technique used in mapping much of the district and in studying the vein zones was to seek out and map all of the scattered outcrops that could be found and then to interpolate geologic boundaries where they best fit the available facts. Most of this interpolation was done in the field concurrent with outcrop mapping; those boundaries drawn in the office after petrographic studies will be indicated in the rock-description sections of this report. The resulting maps (pls. 2 and 3), therefore, are interpretive maps of the bedrock geology, and do not show any of the surficial deposits that cover much of the Summitville district.

A different technique was used in the reconnaissance study of the areas surrounding the Summitville district. Traverses were made along all of the ridge crests and along many of the valleys to seek out areas of altered rocks and to find areas where the Fisher quartz latite could be subdivided. Such areas were mapped hurriedly, as were any other areas discovered where previously mapped geology seemed in error.

Most of the laboratory and office work for this report was done jointly by Steven and Ratté. The thin section petrography and laboratory studies of the altered rocks were done chiefly by Ratté, whereas most of the ore microscopy, map work, and assembling of the initial manuscript were done by Steven. J. C. MacLachlan compiled the topographic base used for plate 3, and assembled many of the mine maps used in describing the ore deposits. The investigations by the authors were done concurrently, and ideas were so freely interchanged that it is impossible to assign specific responsibility for individual parts of the report.

GEOLOGIC SETTING

The San Juan Mountains in the vicinity of the Summitville district (pl. 1) consist almost entirely of volcanic rocks and related shallow intrusive rocks of middle or late Tertiary age; the only exceptions are the surficial deposits, which are not discussed in this account of the bedrock geology. The oldest rocks exposed in the area belong to the Potosi volcanic series, which constitutes the bulk of the central and eastern San Juan Mountains. These rocks are separated by an erosional unconformity from the overlying Fisher quartz latite. The youngest volcanic rocks exposed in the area are remnants of the Hinsdale formation, which forms volcanic necks or lava flows that rest unconformably upon an erosion surface across the Potosi and Fisher rocks.

The Conejos formation forms the base of the Potosi volcanic series, and is the most widespread sequence of rocks in the Summitville region (pl. 1). It consists mainly of a thick succession of low-dipping, uniformly textured flows. According to Larsen and Cross (1956, p. 97) this sequence of lava flows is characteristic only in the central part of the Conejos. They describe the Conejos formation toward the east and northeast of the area shown on plate 1 as an accumulation of bedded breccias and volcanic gravels, that also includes minor intercalated flows.

Intrusive bodies of Conejos age (Larsen and Cross, 1956, pl. 1) are widely distributed in the areas of the eastern San Juan Mountains that are underlain by Conejos flows. The largest of these Conejos intrusive bodies is a dioritic to quartz monzonitic stock along Alamosa Creek in the southern part of the Summitville region (pl. 1). A smaller stock of similar composition occurs along Wightman Fork east of the Summitville district.

A large mass of Conejos extrusive rocks along the northern margin of the stock flanking Alamosa Creek and parts of the stock were intensely altered by solfataric action before extrusion of the Fisher quartz latite. Similarly altered rocks also occur near other stocks of Conejos age in adjacent parts of the San Juan Mountains.

Formations of the Potosi volcanic series younger than the Conejos formation occur along the Continental Divide west of Summitville, where Larsen and Cross (1956, pl. 1) show rocks belonging to the Treasure Mountain rhyolite, Sheep Mountain quartz latite and Alboroto rhyolite. No detailed observations of these younger Potosi rocks were made during this investigation, and they were mapped with the underlying Conejos formation as areas of undivided Potosi rocks (pl. 1).

Post-Potosi erosion cut a hilly terrain across the area prior to Fisher volcanic activity, and total relief on this buried surface is nearly 2,000 feet within the area shown by plate 1.

The Fisher quartz latite in this region consists of rhyodacitic and quartz latitic lavas, that are cut by two types of intrusive rocks. The geologic relations of the Fisher rocks are discussed in detail in later sections of this report.

The geologic history of the Summitville region subsequent to Fisher time is not fully recorded by the rocks. A period of erosion followed the eruptions of later Fisher time, but the depth of erosion and character of the surface developed are unknown. Several rhyolitic volcanoes were formed on this surface during the Hinsdale period of volcanism, and remnants of these are in the northeast quarter of the area (pl. 1).

Erosion has dominated near Summitville since the Hinsdale eruptions and has resulted in a deeply dissected mountainous terrain. Glacial erosion modified many of the higher peaks as well as the main stream valleys, and morainal deposits are widespread throughout the area. Other surficial debris, including soil, talus, landslide deposits and alluvium, covers much of the area and obscures the bedrock geology on many lower slopes. As the chief emphasis in this investigation concerns the bedrock geology and its relation to the ore deposits, the surficial deposits and the geomorphology were accorded scant attention. However, we believe that any investigation of the more recent geologic history of the San Juan Mountains will find the Summitville region a fruitful source of data.

ROCKS

The detailed descriptions and interpretations presented in the following sections are limited chiefly to rocks exposed within the area shown on the geologic map of the Summitville district (pl. 2). Some specimens of the rocks observed during the brief reconnaissance of surrounding areas were collected for comparison, but these are so few and are from such widely scattered localities that few generalizations can be made from them.

Only two rock sequences, the Conejos formation and the Fisher quartz latite, are exposed within the limited area of the Summitville district (pl. 2). The Conejos formation here consists largely of flat-lying dark rhyodacite flows. The overlying Fisher quartz latite consists of two members separated by an erosional unconformity. The lower member is a complex assemblage of rhyodacitic and quartz latitic flows, volcanic domes, and breccia, cut by distinctive quartz latite dikes, whereas the upper member consists of quartz latite flows and related volcanic necks.

The age of both the Conejos and Fisher is given by Larsen and Cross (1956, p. 92–93) as Miocene. This designation, however, is contradicted in part by evidence given in the same report (Larsen and Cross, 1956, p. 167) for a very late Miocene or early Pliocene age of the Creede formation, which crops out along the Rio Grande and its tributaries 24 to 34 miles northwest of Summitville. The Creede formation is younger than the Potosi volcanic series, of which the Conejos is the oldest formation. Larsen and Cross (1956, p. 173–174) report the Fisher to be younger than the Creede, but subsequent work by us in the area has shown the two formations to be intertongued and of the same age. In addition, MacGinitie (1953, p. 73) has given his opinion that the Creede formation cannot be older than Pliocene, and probably is middle Pliocene in age. From these data, it seems probable that the Fisher quartz latite is Pliocene in age, and if MacGinitie is correct, some of the Potosi may be Pliocene as well. These age relations are being investigated further in our studies near Creede, and for the purposes of this report we will refer to both the Conejos and the Fisher as being middle or later Tertiary in age.

ROCK CLASSIFICATION AND NOMENCLATURE

In classifying the volcanic rocks of the Summitville district we have followed Larsen and Cross (1956, p. 10) in using the Johannsen system. To be widely applicable, this system, and all similar systems which are based on the mineralogic compositions of igneous rocks, require that approximate equilibrium be reached during solidification of a magma. This requirement commonly is not met in the porphyritic volcanic rocks that have fine-grained or glassy matrices such as are characteristic in the Summitville area; for these rocks it is necessary to calculate theoretical mineral compositions from chemical analyses (Johannsen, 1939, p. 149). For this investigation, we have calculated normative compositions of the rocks according to the CIPW classification system, and have assumed that these would correspond with the modal compositions of granular igneous rocks with the same chemical compositions. Although this correspondence is one of degree only, the differences are significant only where the rock compositions are borderline between major rock types.

According to Larsen and Cross (1956, p. 97, 175) the lavas of both the Conejos and Fisher are predominantly quartz latites. Using the analyses quoted by them, however, we have had difficulty reconciling these identifications with the Johannsen system from which they were derived. This difficulty stems from the use by Larsen and Cross (1956, p. 10) of the term "quartz latite" as the extrusive equivalent of granodiorite, whereas according to Johannsen (1932, p. 356, 307–310) rhyodacite is the extrusive equivalent of granodiorite, and quartz latite is the extrusive equivalent of quartz monzonite.

On plotting the normative compositions of the Conejos and Fisher rocks as determined by Larsen and Cross (1956, table 21, p. 190) and in this report on the Johannsen diagram (figs. 4, 9), we found that two-thirds of the analysed Conejos rocks and slightly more than half of the analysed Fisher rocks are rhyodacites; the remainder of both the Conejos and Fisher are quartz latites.

The general character of the Conejos rocks is described by Larsen and Cross (1956, p. 97) as follows:

> Fragmental beds make up considerably more than half of the Conejos quartz latite, and, although in the central, thickest part of the formation near the corner of the Creede, Del Norte, Summitville, and Conejos quadrangles, massive rock is more abundant than on the average, near the outer limits of the formation on the south, west, and north, clastic beds greatly predominate. In the central, thick part of the formation the breccia is mostly chaotic and pyroclastic, with angular fragments little modified by water transportation, and for any bed or group of beds consists almost entirely of one kind of rock which in many places is similar to that of the associated flows. Farther away from the center of tuffs are finer-grained and are better-sorted and bedded. They consist of subangular or even well-rounded fragments of a variety of rocks, which clearly have been transported by water, and they show some

evidence of weathering. In the New Mexico area this tuff grades into sands and gravels in part derived from Pre-cambrian rocks.

From the overall heterogeneity indicated by the chemical analyses and by this lithologic description, it seems advantageous to call the Conejos a formation rather than use the petrographic term quartz latite.

Similar reasoning might apply to the Fisher quartz latite, as this formation shows (fig. 9) a range in composition similar to that of the Conejos formation (fig. 4), and rhyodacite flows form at least half of the bulk of the formation near Summitville. However, the Fisher rocks subsequently mapped by us in the Creede district, 25 to 40 miles to the northwest, seem to be more silicic on the average than those at Summitville. It seems preferrable, therefore, to wait until we have examined the large mass of Fisher rocks on Fisher Mountain, south of the Creede district, before any change in nomenclature is suggested.

CONEJOS FORMATION

The great pile of dark flows of the Conejos formation near Summitville is exposed vertically for nearly 2,800 feet, as measured from the level of Alamosa Creek near the east edge of the Summitville district to the highest exposure of the Conejos flows on the ridge extending northeastward from Cropsy Peak (pl. 1). The base of the Conejos is not exposed near Summitville, however, and the total thickness of the pile is probably much more than 3,000 feet. Within the Summitville district (pl. 2), the Conejos formation is made up of many individual flows that generally range from 5 to 50 feet in thickness, but in the cliffs flanking lower Wightman Fork the flows seem to be much thicker, perhaps several hundred feet. Very little pyroclastic or fragmental material is interlayered with the flows, and fresh rocks are uniform in appearance and apparently in composition throughout the vertical range exposed. Individual flows could not be traced far because of generally poor exposures and the megascopic similarity of adjacent flows, and accordingly it is not known whether the flows form elongate tongues or widespread sheets. Although many local exceptions exist, most of the flows seem to have low to moderate dips.

The Conejos flows near Summitville are cut by two intrusive bodies of dioritic and quartz monzonitic composition (pl. 1), which are believed by Cross and Larsen (1935, p. 74; Larsen and Cross, 1956, p. 108–110) to be also of Conejos age. Neither of these bodies is within the area studied in detail during the present investigation, but the stock south of Alamosa Creek was examined briefly during the reconnaissance survey of areas adjacent to the Summitville district. This stock was intruded into the thick succession of flows, and crystallized as an even-textured, medium-grained rock that contrasts markedly with the dark flows that it invades.

A great area of intensely altered rocks along Alamosa Creek is localized near the northern margin of the larger stock of Conejos age (pl. 1). These rocks were altered before eruption of the Fisher quartz latite, and probably during a period of widespread hydrothermal activity following intrusion of the stock. The relations of these highly altered rocks will be discussed later in this report under the section on "Altered and mineralized rocks."

LITHOLOGY

The rhyodacite flows of the Conejos formation near Summitville consist typically of a dark-drab to black rock that crops out in blocky ledges. Flow layering is generally obscure, and in many small exposures the attitude of the flows cannot be determined. In larger exposures, however, the rock generally shows a crude layering owing to contacts between flows, and to joints and fractures that appear to parallel the flow boundaries. Many of the rocks, particularly in the thicker flows, are strongly sheeted locally, and split into innumerable thin slabs. Sheeting was noted both parallel to and at high angles to the flow boundaries.

Fresh Conejos flow rock is black to dark bluish- or greenish-gray porphyry with an aphanitic groundmass. Small plagioclase crystals, generally an eighth of an inch or less long, but locally as much as one-half inch long, are the most abundant phenocrysts; pyroxene and magnetite phenocrysts are recognizable in some hand specimens. The fresh rock seems to be massive, although small pores, which may be filled with quartz, chlorite, and carbonate minerals, are commonly visible with a hand lens.

Some flows consist of earthy- or granular-appearing greenish-gray rocks characterized by abundant fine-grained chlorite and carbonate minerals. Pyrite is readily visible in many of these rocks, and pore spaces are commonly filled with calcite, chlorite, and quartz or chalcedony. In the field some of these rocks resemble fine-grained, well-indurated and somewhat altered tuffs, but thin sections clearly show that they are altered phases of the flow rocks. These altered rocks are interlayered with fresh, hard rocks, and the alteration apparently is a characteristic of individual flows or flow margins rather than the result of a general period of hydrothermal activity such as caused the intense alteration of the rock along Alamosa Creek south of the Summitville district. The chlorite- and carbonate-bearing rocks are easily weathered and generally are exposed only in road cuts or stream banks.

PETROGRAPHY

As seen under the microscope, the Conejos flow rocks are distinctly porphyritic with phenocrysts and microphenocrysts of andesine-labradorite, augite, hypersthene, magnetite-ilmenite, and rare biotite; the phenocrysts average about 30 percent of the rock, and range from a few tenths of a millimeter to several millimeters in length. The groundmass is a microcrystalline to cryptocrystalline aggregate consisting of 75 to 90 percent plagioclase, 1 to 3 percent pyroxene, 2 to 5 percent magnetite-ilmenite, 5 to 20 percent potash feldspar, and 5 or less percent quartz. Groundmass textures generally are microlitic, but locally are trachytic or granophyric.

Plagioclase phenocrysts constitute 15 to 30 percent of most Conejos rocks, and have an average composition estimated to be intermediate to calcic andesine.[1] The composition is commonly not uniform, and nearly homogeneous-appearing plagioclase crystals in the same rock may have anorthite contents ranging from An_{40} to An_{65}. Zoned crystals show a similar range in composition within single crystals, and some local zones are as calcic as An_{75}.

Many plagioclase phenocrysts, particularly the larger crystals, are strongly zoned. Few of these phenocrysts show simple progressive zoning from calcic cores to more sodic rims; more commonly the zoning is oscillatory with many crystals showing 10 or more narrow zones of oscillating composition. The cores of crystals with oscillatory zoning may be either more calcic or more sodic than the next succeeding zone. Some plagioclase phenocrysts show rounded cores mantled by more calcic rims. The small microphenocrysts generally are unzoned or inconspicuously zoned, and compositional differences are minor.

The ferromagnesian phenocrysts in the Conejos flow rocks are augite, hypersthene, magnetite-ilmenite, and sparse biotite. Except for the magnetite-ilmenite, these minerals are greatly altered in most of the rocks, and in only 3 of 25 thin sections of the Conejos that were examined were they sufficiently fresh for the optical properties to be determined. Augite and hypersthene grains, generally a few tenths of a millimeter in diameter, constitute from 5 to 10 percent of the rock with augite about twice as abundant as hypersthene. Magnetite-ilmenite ranges in abundance from about 2 to 8 percent of the rock; some of this is in fine accessory granules in the groundmass and the rest is in larger crystals associated with the other ferromagnesian phenocrysts. Where present, biotite generally constitutes less than 1 percent of the rock.

Euhedral apatite crystals are common in the Conejos flow rocks. Locally they are about a millimeter long, although normally they are much smaller; many of the apatite grains are distinctive yellowish brown and pleochroic.

The plagioclase microlites in the groundmass commonly are narrow albite-twinned laths less than 0.1 mm long, with a pilotaxitic arrangement. In some rocks the texture is more trachytic, and the microlites are somewhat larger and more nearly equidimensional. As seen in thin section, the plagioclase microlites show low relief above quartz and the mounting medium of the thin section, and index of refraction determinations indicate that the composition is in the oligoclase-andesine range. Groundmass pyroxene, probably augite, occurs as anhedral grains about 0.1 mm in diameter. Both the groundmass pyroxene and microlitic plagioclase are surrounded by a crystalline or partly crystalline mesostasis of plagioclase and potash feldspar highly charged with magnetite dust. Quartz also occurs in the mesostasis of a few of the rocks in granophyric intergrowths with the feldspars, and locally it makes up nearly 5 percent of the rock.

Secondary minerals are abundant in the altered, earthy greenish-gray rocks that are interlayered with the more normal dark Conejos flows. The chief secondary minerals are calcite, chlorite (penninite), and sericite; subordinate secondary minerals are magnetite, hematite, limonite, jarosite, pyrite, epidote, rutile, leucoxene, chalcedony, and clay minerals. These secondary minerals are so abundant in the more altered flows that primary textures are obscure, and some of the altered flows were mistaken in the field for fine-grained, well-indurated tuffs. Observed microscopically, however, they all show relict textures similar to the textures of less altered flow rocks.

Even fresh-appearing Conejos flows are commonly slightly altered, and some of the pyroxene and biotite phenocrysts are replaced by pseudomorphs of calcite and chlorite (bastite?). The plagioclase crystals are partly replaced by calcite and sericite. Small amounts of secondary magnetite or hematite are commonly formed by the breakdown of ferromagnesian phenocrysts, and spotty concentrations of carbonate or chlor-

[1] Compositions of plagioclase cited in this report were determined for the most part by flat-stage extinction-angle measurements with supplemental index determinations in immersion mounts. In addition, numerous checks were made by the Rittmann method, using the universal stage to measure maximum extinction angles in the zone perpendicular to the 010 plane. Extinction angle measurements were converted to plagioclase compositions using the low-temperature plagioclase curves of Winchell (1951) and Tröger (1952). The high-temperature plagioclase curves of Tröger (1952) would lower the estimated anorthite content of the average plagioclase by 5 to 8 percent and of some of the more calcic zones by as much as 15 percent.

ite in the groundmass probably represent altered groundmass pyroxene.

Where observed, chiefly in the vicinity of the main roads, the stock of Conejos age along Alamosa Creek is a pinkish-gray, medium-grained quartz monzonite consisting largely of white and pink feldspar, quartz, and amphibole. Andesine (approximately An_{40}) comprises 40 to 45 percent of the rock, orthoclase 35 to 40 percent, quartz 10 to 15 percent, hornblende about 4 percent, and biotite less than 1 percent of the rock. Epidote, chlorite, calcite, and sericite are secondary minerals that formed by partial or complete alteration of hornblende, biotite, and plagioclase crystals; they total about 4 percent of the rock. Accessory grains of pyrite and magnetite are scattered throughout much of the rock. Locally the rock is somewhat porphyritic. Both Patton (1917, p. 40–46) and Larsen and Cross (1956, p. 108–109) have described wide ranges in composition and texture.

CHEMICAL COMPOSITION

Patton (1917, p. 31) gives two analyses of Conejos rocks from the vicinity of Summitville. One of these is of an "augite andesite" collected from the bed of Cropsy Creek within the main Summitville district (pl. 2); the other is from the quartz monzonite intrusive body along Alamosa Creek near the old mining camp of Stunner (pl. 1). A fresh sample of typical lava of the Conejos was also collected by us from a road cut at the east end of the bridge across Wightman Fork about 500 feet west of the mouth of Cropsy Creek and was analysed by the U.S. Geological Survey. These analyses are given in table 2.

The normative compositions are plotted on a Johannsen diagram (fig. 4) for classification purposes. Both of the flow rocks plot within the rhyodacite field, whereas the intrusive rock plots within the quartz latite (quartz monzonite) field. For purposes of comparison we plotted all of the norms of Conejos rocks given by Larsen and Cross (1956, table 21) on the same diagram. One intrusive rock falls in the trachyandesite (syenogabbro) field, two intrusive rocks and eight lavas fall in the rhyodacite (granodiorite) field, and two intrusive rocks and four lavas fall in the quartz latite (quartz monzonite) field. The rocks from near Summitville contain less than average normative quartz, but they are well within the spread of points obtained by plotting all of the available norms of the Conejos.

TABLE 2.—*Chemical analyses and normative compositions, in percent, of rocks from the Conejos formation*

	1	2	3
Chemical analyses			
SiO_2	59.07	59.81	57.31
Al_2O_3	16.94	14.55	17.83
Fe_2O_3	3.82	5.10	3.21
FeO	1.92	3.03	2.96
MgO	2.04	2.90	2.35
CaO	5.41	4.52	5.76
Na_2O	3.37	3.88	3.60
K_2O	3.13	4.17	3.05
H_2O^-	.60	.09	.32
H_2O^+	.97	.76	1.30
TiO_2	.98	.98	.82
ZrO_2	.17	none	----------
CO_2	1.35	.04	.94
P_2O_5	.11	.12	.41
MnO	.13	.13	.11
Cl	trace	.03	.00
SO_3	.26	none	.00
S	none	none	.00
F	----------	----------	.07
Total	100.27	100.11	100.04
Less O			.03
			100.01
Normative compositions			
[CO_2 was disregarded in calculating the norms. Calcite is a common secondary mineral in most of the rocks, where it occurs as an alteration product of plagioclase, pyroxene, and rarely biotite. Asterisk (*) indicates field number; ** laboratory number]			
Quartz	14.0	10.0	9.7
Orthoclase	18.5	24.6	18.0
Albite	28.5	32.8	30.4
Anorthite	21.8	10.0	23.5
Diopside	3.3	9.1	2.0
Hypersthene	3.6	3.0	6.4
Magnetite	3.4	7.4	4.7
Ilmenite	1.9	1.9	1.6
Hematite	1.5	----------	----------
Apatite	.3	.3	1.0
Zircon	.3	----------	----------

1. Analysis quoted from Patton (1917, p. 31). "Augite-andesite" from bed of Cropsy Creek. Analysts: George Roher and Esbon Y. Titus, Colorado Univ.
2. Analysis quoted from Patton (1917, p. 31). "Monzonite" from near sawmill above Stunner. Analysts: George Roher and Esbon Y. Titus, Colorado Univ.
3. (SA-8*; A-159**) Rhyodacite from road cut just east of the bridge across Wightman Fork and 500 feet west of the mouth of Cropsy Creek. Standard rock analysis Mar. 3, 1955; analyst: Lucile N. Tarrant.

FISHER QUARTZ LATITE

The Fisher quartz latite in the Summitville district can be differentiated into two members, separated by an unconformity. The lower member consists of rhyodacitic and quartz latitic flows, volcanic domes, and pyroclastic rocks (tuffs and volcanic breccia) that were erupted onto an irregular surface cut across the earlier volcanic rocks of the San Juan Mountains. The resulting pile of volcanic rocks was faulted, locally altered by hydrothermal activity, and deeply eroded before renewed volcanic eruptions poured out quartz latitic lava flows to form the upper member of the formation.

LOWER MEMBER

Most of the flow rocks of the lower member of the Fisher quartz latite are nearly structureless gray porphyritic rocks that have much the same appearance

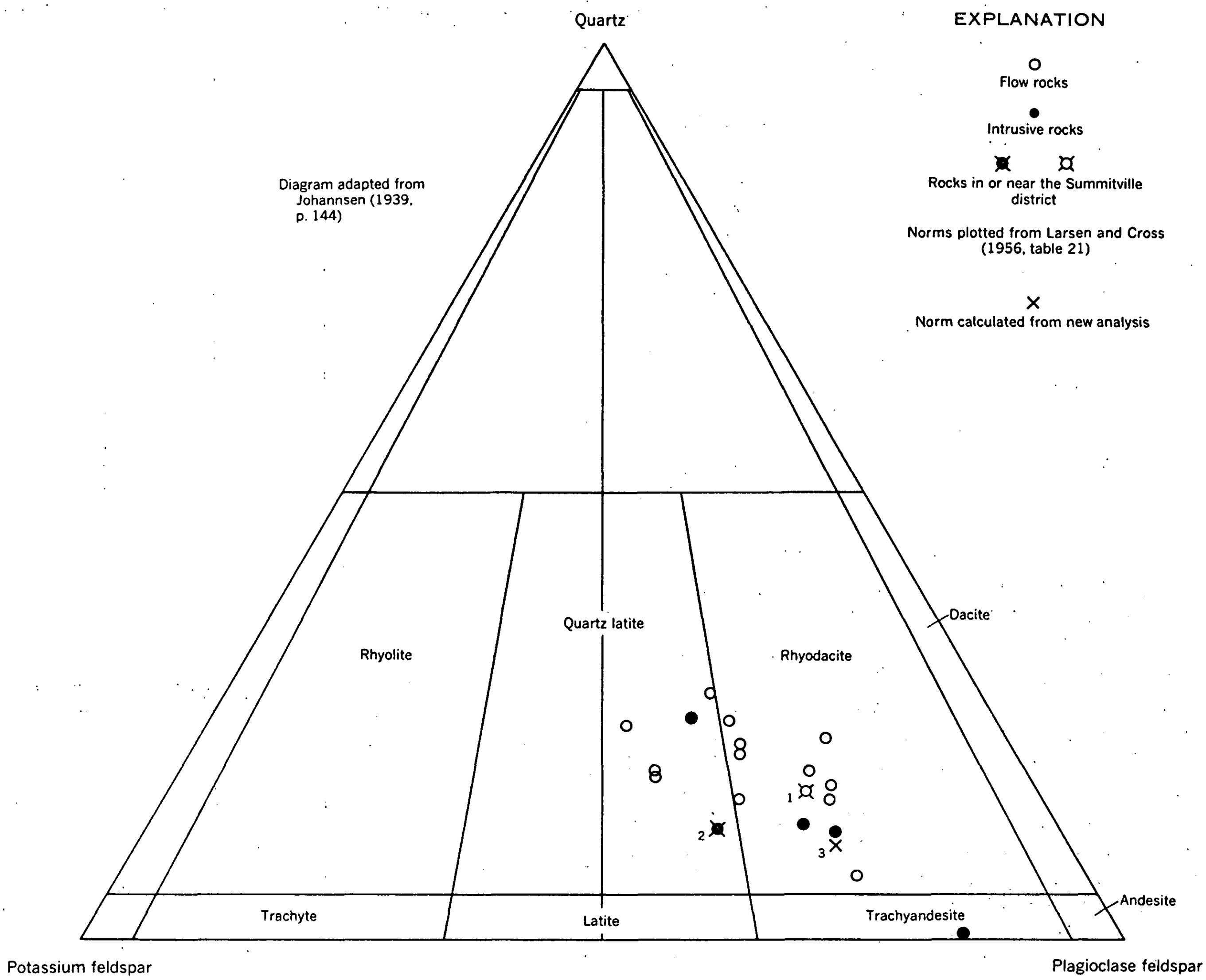

FIGURE 4.—Normative compositions of rocks from the Conejos formation plotted on a Johannsen diagram. Numbers refer to analysis given in table 2.

throughout the district. Minor differences in texture and abundance and type of phenocrysts are common, but abrupt changes in rock type are rare. One of the most conspicuous differences noted in the field was that sanidine and quartz phenocrysts are irregularly distributed and locally abundant in the lava flows in the vicinity of South Mountain and the adjoining area to the south, whereas these crystals are generally sparse or absent in most of the lower Fisher rocks in the western and northwestern parts of the Summitville district. Petrographic studies indicate that the rocks containing few or no sanidine phenocrysts are rhyodacites, and the rocks containing sanidine and quartz phenocrysts are quartz latites.

Although the boundary between the rhyodacites and quartz latites shown on the geologic map (pl. 2) was drawn in the office following petrographic studies, the distribution of the varietal types was noted in the field and the boundary is probably within a few hundred feet of the correct position in most places.

RHYODACITIC LAVAS

The rhyodacites in the western and northwestern parts of the Summitville district include a local basal vitrophyre flow, some irregular and heterogeneous masses of tuff and volcanic breccia, and thick accumulations of massive porphyritic lavas. Local quartz latite flows occur sporadically within the area of predominant rhyodacitic rocks, but the only mass of quartz latite large enough to be shown separately on the geologic map (pl. 2) is near the northwest corner of the district.

No satisfactory sequence of eruptions of the rhyodacitic lavas has been established. The local vitrophyre flow is certainly the oldest unit within the local area where it occurs, but there seems to be no way to establish its position in time with respect to basal flows in other parts of the district. The largest mass of pyroclastic rocks exposed in the district lies directly on top of the vitrophyre flow, and apparently is overlain in turn by a massive flow. Chaotic volcanic breccia is abundant in the mass of pyroclastic rocks, however, and it may represent a marginal accumulation on the flanks of a thick flow or volcanic dome, and thus be equivalent in time and perhaps even younger than some of the massive flows to the west or south. The other body of pyroclastic rocks that was mapped separately is interlayered with massive flows, and clearly formed during the same period that the flows were being erupted.

Some quartz latite flows apparently were erupted during the same period of time that the rhyodacitic rocks were erupted, but the large mass of quartz latite centering on South Mountain probably is somewhat younger (see p. 20).

VITROPHYRE FLOW

Remnants of a local flow of rhyodacitic vitrophyre occurs at the base of the Fisher in the north-central and northwestern parts of the Summitville district, where it apparently is confined by a shallow valley in the preexisting topography. The flow attains a maximum thickness of nearly 175 feet in the preserved remnants and wedges out laterally against partly buried hills of the older Conejos flows.

Where nearly unaltered, the vitrophyre is a dark rock containing abundant small tabular plagioclase phenocrysts in a dull-gray to black, microcrystalline to glassy matrix. The plagioclase phenocrysts range from a small fraction of an inch to about an eighth of an inch in length, and commonly constitute about 20 percent of the rock; in places these crystals are fairly well alined to give the rock a trachytoid texture, but elsewhere are randomly oriented.

Locally the vitrophyre flow was somewhat altered hydrothermally subsequent to its extrusion, and throughout wide areas it was converted to a yellowish rock containing earthy white pseudomorphs of the plagioclase phenocrysts set in a clayey, chalcedonic, or opaline groundmass. Disseminated pyrite is abundant in the more siliceous rocks, and it occurs in other altered rocks as well. The altered rock weathers readily, and the surface of the flow generally is mantled with a yellow sandy soil. Most exposures are in sharp gullies and along fretted stream banks.

The alteration apparently is restricted to the vitrophyre flow and to the underlying Conejos flows, as the overlying rocks show no comparable effects. The alteration thus seems to have resulted from local solfataric action early in the older period of Fisher volcanic activity, and is probably unrelated to the later period of hydrothermal alteration that effected large volumes of rock near South Mountain (see section on "Altered and mineralized rock").

PYROCLASTIC ROCKS

The areas shown as pyroclastic rocks on the geologic map (pl. 2) consist of heterogeneous assemblages of tuff, coarse volcanic breccia, and local lava flows. Exposures are too poor for individual units to be traced in the field, and the distribution and interrelations of the different rock types are not well known. The mass of pyroclastic rocks along the east side of Park Creek, near the northwest corner of the district, apparently consists largely of fairly well bedded tuff. The larger mass of pyroclastic rocks, about 2,000 to 5,000 feet farther east, on the other hand, contains tuff, abundant coarse volcanic breccia, and some interlayered lava flows.

In addition to these larger masses of pyroclastic rocks, local bodies of tuff and volcanic breccia occur throughout the area underlain by rhyodacitic lavas. These bodies are generally exposed only in small scattered outcrops, and in no place could they be traced or studied satisfactorily. Likely they are minor local masses interlayered with the predominant flows.

Most of the local flows as well as the boulders and cobbles in the volcanic breccias consist of porphyritic gray lavas almost identical with those in the adjacent massive flows, which will be described in the following section.

The body of pyroclastic rocks in the northwest corner of the Summitville district is exposed only along the flanks of Park Creek; elsewhere the tuffaceous rocks are indicated by scattered float, and the limits of the area underlain by pyroclastic rocks shown on plate 2 are indefinite. The rocks cropping out along Park Creek consist of well-bedded tuff, lapilli tuff, and fine-grained volcanic breccia, and most of the float fragments along the lower hill-side to the east are tuffaceous. These rocks range from soft friable white tuffs, through earthy-gray well-indurated tuffs and fine breccias, to hard brown and gray highly silicified tuffs. Some of the finer tuffs are well-sorted granular rocks that occur in thin regular beds and probably were water deposited. The lapilli tuffs and fine volcanic breccias are poorly sorted and occur in poorly defined beds, suggesting direct deposition of explosively derived fragments.

The larger mass of pyroclastic rocks along the crest of the ridge east of Park Creek shows a much greater variety of rock types. Fine-grained vitric tuff containing scattered fragments of feldspar and biotite apparently predominates near the base along the west edge of the mass, but it is overlain and progressively overlapped to the east by a mixed accumulation of volcanic breccia, tuff, and local lava flows. The tuffs are easily weathered and altered and generally are poorly exposed. In most places their presence in indicated by local patches of yellowish clayey soil or concentrations of tuffaceous float.

The volcanic breccias are exposed only locally; generally they appear as chaotic accumulations of angular to subrounded boulders set in a completely unsorted matrix. In the larger exposures the breccias show a gross layering, but this is absent or not distinguishable in most of the smaller outcrops. Many of the grassy slopes within the area believed to be underlain predominately by pyroclastic materials are strewn with boulders that may have been derived from breccias similar to those seen in the outcrops. The best exposure of volcanic breccia seen was in a landslide along the west side of the mass of pyroclastic rocks. Here, the breccia consists of subrounded gray rhyodacitic boulders as much as 6 feet in maximum diameter set in an unsorted matrix that ranges from yellowish ash to irregular fragments of small boulder size. The layering is poorly defined but distinct, and the "beds" range from a few feet to 15 to 20 feet in thickness. The subrounded character of many of the fragments, the unsorted and heterogeneous matrix, and the rude layering all suggest mudflow transportation and deposition.

A distinctive fragmental rock, possibly a flow breccia, forms the upper unit of the mass of pyroclastic rocks along the northern margin of the area mapped in detail (pl. 2). This rock consists of irregular, generally angular fragments of brownish-gray rhyodacite porphyry set in an unsorted matrix of the same material. The rock is compact and "welded" in appearance, and in many places the fragmental character can be distinguished only on freshly broken surfaces. The angular fragments are set in matrix of similar material, and the welded appearance suggests that the rock formed while the fragments were still hot.

MASSIVE FLOWS

The scattered outcrops of rhyodacite flows are rarely abundant or large enough to permit outlining individual flows, and most of the rock is so massive that the external form cannot be interpreted from internal structures. Some flows in the lower part of the sequence near Schinzel Meadow (pl. 2) appear to be 10 to 20 feet thick, but most of the flows apparently are much thicker. Exposures of the massive lavas in the low hills surrounding Schinzel Meadow, and in the valley of Park Creek are as much as 1,000 feet long, several hundred feet wide and 20 to 200 feet high. No flow boundaries were noted in any of these larger outcrop areas, and flow structures are local and generally obscure. The slight variations in rock type from place to place and the minor but widespread occurrence of tuff and volcanic breccia, however, suggest that the massive rhyodacite consists of many individual flows.

Although local variations in the rhyodacite flows are widespread, massive gray porphyry predominates. This rock is characterized by conspicuous lath-shaped plagioclase phenocrysts and minor biotite phenocrysts set in an aphanitic gray groundmass. The plagioclase phenocrysts range in size from barely perceptible crystals to phenocrysts as much as a half an inch long; they range in abundance from somewhat less than 10 to about 40 percent of the rock. The larger plagioclase crystals are most abundant in rocks where plagioclase phenocrysts make up 30 percent or more of the rock. Shiny black biotite books, generally 0.1 inch or less in diameter, generally constitute from 1 to 3 percent of the rock. Small pyroxene phenocrysts can be recognized under a hand lens in some of the rocks, but they are rarely abundant. The groundmass ranges in color from dark to light gray. The darker groundmasses are generally the finer grained; many appear almost glassy, or are mottled with irregular reddish brown subvitreous patches. The light-gray groundmasses, on the other hand, have a more granular aspect.

A quartz latitic rock was found at three widely scattered localities within the area of predominant rhyodacites. At all of these places the rock is a light-gray porphyry which consists of a fluidal and somewhat vesicular matrix, enclosing phenocrysts of plagioclase (intermediate to calcic oligoclase), biotite, and minor hornblende. Quartz phenocrysts are recognizable at one of the localities, and tridymite was observed in thin sections of rocks from the other two localities. No sanidine phenocrysts were seen, but potassium feldspar is a major constituent of the groundmass of the rocks.

Another local variant is a coarsely porphyritic rock composed of 60 percent or more of plagioclase phenocrysts and 1 to 2 percent of small biotite phenocrysts set in an irregularly vesicular pinkish groundmass. This rock was seen at 2 small outcrops about 3,000 feet apart along the hill slope northeast of Schinzel Meadow. These outcrops probably are not parts of a single flow, as abundant gray rhyodacite porphyry crops out between them.

PETROGRAPHY

Typical rhyodacitic lavas in the lower member of the Fisher near Summitville show a fairly wide range in the kind, abundance, and size of phenocrysts, and in the texture and composition of the groundmass. Plagioclase phenocrysts comprise 10 to 40 percent of the rocks and represent 75 to 90 percent of total phenocrysts. They range in composition from calcic oligoclase to sodic labradorite, and have an estimated average composition near calcic andesine. Most of the plagioclase grains are subhedral to euhedral crystals, although many appear to be broken crystal fragments. Albite, pericline, and Carlsbad-albite twins are common in the plagioclase phenocrysts, although the character of the twinning varies from rock to rock. Many of the plagioclase phenocrysts are complexly zoned, with as few as 3 or 4 or as many as 20 to 30 zones. Some crystals with abundant narrow zones show oscillatory changes in composition with the core either more calcic or more sodic than the next succeeding zone. Such crystals are generally above average in size, and are poorly twinned. Other crystals with many narrow zones show a progressive change in composition, with the core either more calcic or more sodic than the rim; in these, reverse zoning is more common. Many crystals have only two conspicuous zones, consisting of a rounded central core surrounded by a narrow, more calcic rim. The margin of the inner zone is commonly cloudy with small particles of mafic minerals, secondary minerals, groundmass material, and 2-phase inclusions that may in part contain fluid bubbles. Such inclusions are particularly common along those boundaries that show resorption of the inner zone. These probably represent material caught by renewed growth of a plagioclase crystal that either had been dormant for some time, or had been reacting with the surrounding magma.

Other felsic phenocrysts, such as quartz and sanidine, are very rare in the rhyodacitic rocks.

About 10 to 25 percent of the phenocrysts, that is generally less than 5 percent of the rock, are mafic minerals. These consist largely of magnetite-ilmenite but include accessory amounts of pyroxene and amphibole. The biotite is pleochroic from dark brown to straw yellow; many grains are partly to completely resorbed, leaving a residue of iron oxide granules. Biotite grains that show little or no resorption commonly include small plagioclase crystals, and may be altered somewhat along cleavages to carbonate. Most of the pyroxene phenocrysts are monoclinic crystals of augitic composition; hypersthene was observed in but one of the thin sections studied. Relatively unaltered pyroxene grains are subhedral to euhedral, and many are twinned and locally zoned. More commonly, however, the pyroxene is partly resorbed, and many crystals have been altered completely to carbonate. Fresh amphibole crystals are rare, but locally they occur as prisms of pale-green to olive-green hornblende, or dark-brown basaltic hornblende. Former microphenocrysts of amphibole are indicated by pseudomorphs of iron oxide granules that outline the cross sections of typical amphibole prisms. These pseudomorphs are not everywhere reliable, however, as they are easily confused with similar-appearing cross sections that represent resorbed sphene crystals.

Sphene and apatite are common minor phenocrysts and locally occur in euhedral crystals a millimeter or more long. Zircon is rare. A few small grains of olivine were observed during petrographic studies, but these were so few that almost no generalizations can be made concerning them.

The groundmass of the typical rhyodacitic flow rocks appears in thin section as an aggregate of microlitic plagioclase with interstitial potassium feldspar. Tridymite is abundant in the fine-grained parts of some rocks, particularly in the pores. The plagioclase microlites, probably calcic oligoclase or sodic andesine, range from less than one-tenth to several tenths of a millimeter in length. The potassium feldspar content is estimated to average about a third of the fine-grained material, but some of the finely granular material called potassium feldspar may be tridymite. Mafic minerals in the groundmass constitute only 1 to 2 percent of the rock, and consist of tiny disseminated iron oxide grains and resorbed crystals of biotite, sphene, and probably some amphibole. Pyroxene grains are in the matrix of a few of the rocks. The small mafic crystals tend to be subhedral in form, and generally are less than 0.1 mm long.

The groundmass of many of the rocks is clouded by dirty-appearing aggregates of carbonate, clay, and minor epidote. Microlitic plagioclase and granular pyroxene were particularly susceptible to carbonate alteration. Clear patches and veinlets of granular quartz, commonly associated with chlorite, appear to fill small vesicles or pores. Deuteric alteration and weathering are believed responsible for these alteration effects.

Although the vitrophyre flow contrasts strongly with the typical rhyodacite flow rocks in hand specimen, examination of two thin sections showed that the rock clearly is one of the rhyodacitic lavas. One of the sections shows a matrix of reddish-brown glass of low index of refraction containing andesine-labradorite phenocrysts and a very minor amount of partly altered microphenocrysts of biotite, pyroxene, and magnetite-ilmenite. The groundmass of the second thin section consists of a felted aggregate of plagioclase microlites surrounded by a microgranular material of a low index of refraction, presumably potassium feldspar and tridymite. Tridymite is especially abundant in the porous parts of the groundmass. The phenocrysts in the second thin section are also dominated by plagioclase crystals of intermediate composition, but other phenocrysts include quartz, brown biotite, green amphibole, sphene, and apatite. The plagioclase phenocrysts in both thin sections examined show multiple zoning and evidence of partial resorption during a complex crystallization history.

QUARTZ LATITIC LAVAS AND INTRUSIVE ROCKS

Quartz latitic rocks in the lower member of the Fisher near Summitville (pl. 2) predominate in the vicinity of South Mountain and Cropsy Peak, and along the east flank of Park Creek valley near the northwest corner of the district. Owing to the similarity in appearance of many of the massive lava flows in the lower member of the Fisher and to the generally poor exposures, satisfactory age relations for the different flows could not be established. The quartz latites near the northwest corner of the district are surrounded by rhyodacitic lavas and may be interlayered with them. On the other hand, some of the quartz latites near South Mountain and Cropsy Peak are similar to quartz latite dikes that cut rhyodacitic lavas along Park Creek, and thus may be younger.

QUARTZ LATITES EAST OF PARK CREEK

The quartz latites near the northwest corner of the Summitville district (pl. 2) are exposed in two large outcrops and 10 or 12 smaller outcrops. All exposures appeared massive and no flow boundaries were seen, although the largest area of outcrop comprises a cliff about 1,700 feet long and more than 500 feet high, and the other large exposure is a low knob of rock nearly 900 feet long and 150 feet high. Most of the rock contains conspicuous plagioclase and biotite phenocrysts set in a medium-gray fine-grained structureless matrix, and is similar in appearance to nearby massive rhyodacite flows. Sparse phenocrysts of sanidine, hornblende, and quartz are present, however, and distinguish these rocks from the rhyodacite flows. Microscopic study indicates that the plagioclase is generally intermediate oligoclase, which contrasts with the common andesine-labradorite in the rhyodacite flows.

QUARTZ LATITES UNDERLYING CROPSY RIDGE

A distinctive pyroxene-bearing quartz latite forms massive lava flows under the northern part of Cropsy Ridge and dikelike masses and chaotic breccia under the southern part of the ridge (fig. 5). Although closely related in mineralogy and composition, the rocks from the two areas have slightly different aspects, and the abundance of the phenocrystic minerals differs somewhat. The dikes and breccia have been interpreted as marking a local volcanic vent, perhaps part of a deeply eroded volcanic dome (see "Structure"). The massive flows under the northern part of the ridge seem to rest on the chaotic breccias of the vent area and may represent accumulations marginal to the postulated dome.

The age of the pyroxene-bearing quartz latite relative to other quartz latitic lavas has not been determined with certainty as the pertinent contacts are nowhere exposed (fig. 5). Its composition, however, seems to be intermediate between typical rhyodacitic and quartz latitic lavas; thus they may be intermediate in age between the major eruptions of the two rock types.

The quartz latite in the vent area is a distinctive-appearing rock with a medium-gray aphanitic groundmass enclosing prominent sanidine and plagioclase phenocrysts, minor biotite, pyroxene, and quartz phenocrysts, and local hornblende phenocrysts. The sanidine phenocrysts are characteristically glassy crystals as much as 1 to 2 inches across that commonly have narrow porcellaneous rims. Plagioclase phenocrysts are as much as one-half inch long; they are glassy and poorly twinned, and are difficult to distinguish from the sanidine crystals in hand specimen. The combined feldspar phenocrysts constitute about 20 percent of the rock, the plagioclase being about twice as abundant as sanidine. Biotite is the most conspicuous of the minor phenocrystic minerals, but generally makes up only a fraction of a percent of the rock. Small rounded and embayed grains of green pyroxene are widespread, but generally sparse. The matrix ranges from massive to vesicular, and indistinct flow layers can be distinguished in a few places.

The massive flows marginal to the local vent area are similar in mineralogy to the rocks in the breccia and dikelike bodies, but the contrast in size between sanidine and plagioclase phenocrysts is not marked. Phenocrysts ranging in size from microphenocrysts to the largest sanidine crystals are common. The largest sanidine crystals noted were nearly an inch in diameter, but most are smaller. Quartz is somewhat more abundant in these rocks than in the rocks of the vent area, and the groundmass is darker and nonvesicular.

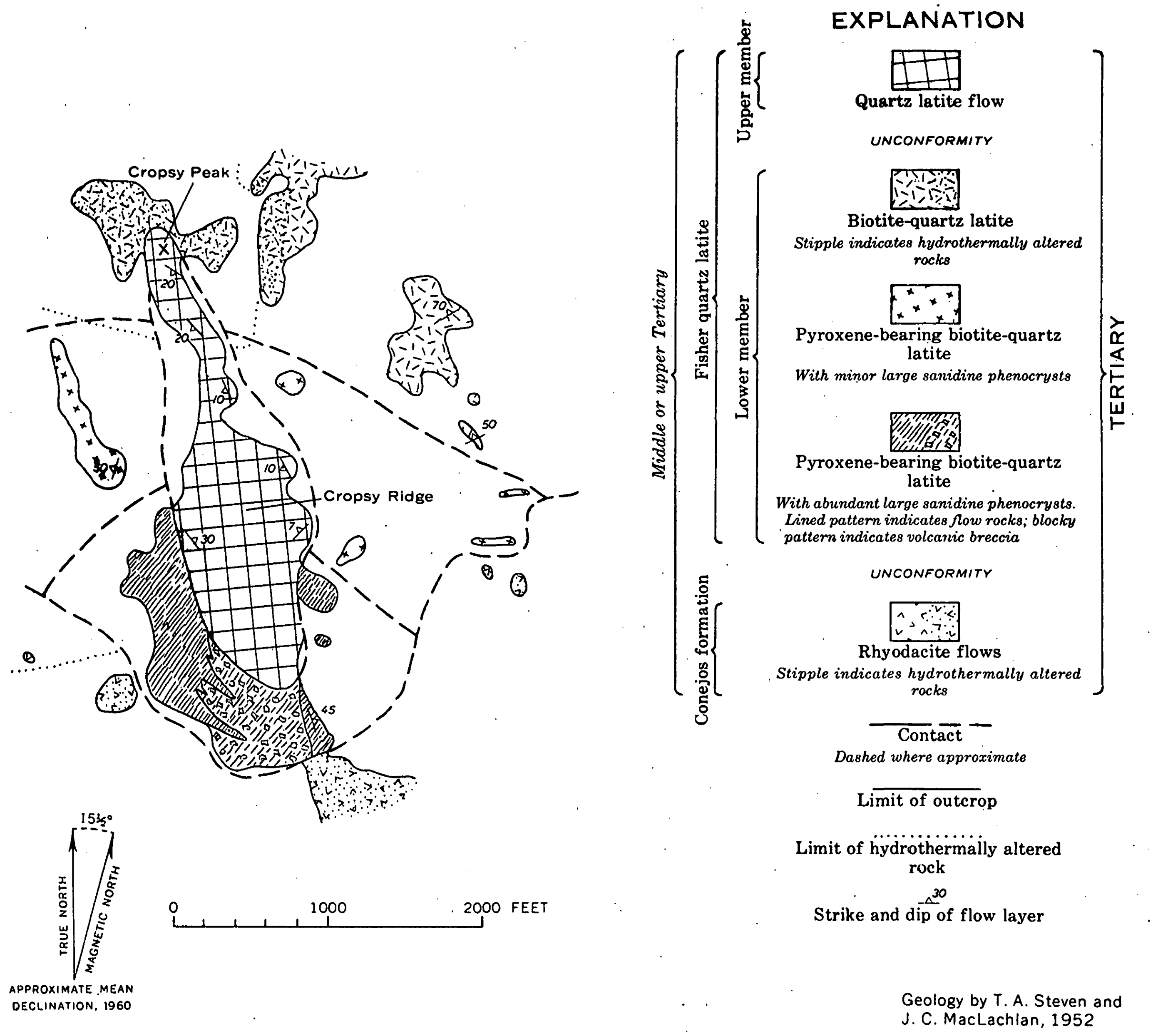

FIGURE 5.—A sketch showing geology of the Cropsy Ridge area

The quartz latites underlying Cropsy Ridge contrast with the other rocks in the lower member of the Fisher by containing phenocrystic minerals characteristic of both the rhyodacitic and quartz latitic lavas. The low percentage of quartz and the widespread presence of pyroxene in a rock containing conspicuous sanidine are particularly distinctive. The general aspect of the rocks in the vent area differs from most of the massive lavas in the lower member of the Fisher probably as a result of the low proportion of the small macrophenocrysts that speckle the groundmass of most lower Fisher rocks. The flows marginal to the vent area, however, are not particularly distinctive in appearance, and closely resemble many of the rhyodacitic flows.

QUARTZ LATITES NEAR SOUTH MOUNTAIN

The quartz latites centering on South Mountain consist largely of massive porphyritic lavas; pyroclastic rocks were seen in only one outcrop where a local tuff unit more than 50 feet thick is exposed. Few flow boundaries were observed in the massive lavas, and according to interpretations that will be outlined in the section on "Structure," the rocks comprising South Mountain proper are probably part of a large volcanic dome. Many rocks in the lower member of the Fisher near South Mountain have been altered hydrothermally and their original appearance destroyed.

The most common quartz latite near South Mountain resembles in general the massive rhyodacitic lavas, including abundant feldspar phenocrysts and sparse but conspicuous biotite phenocrysts set in a variable gray matrix. The feldspars of the quartz latite, however, consist of both plagioclase (oligoclase), and sanidine, rather than plagioclase (andesine-labradorite) alone as in the rhyodacites, and in addition the rocks contain irregularly rounded phenocrysts of quartz. Sparse hornblende crystals occur locally, but pyroxene phenocrysts are generally absent. The aphanitic groundmass, which ranges in color from dark to light gray, is generally structureless, but in places shows conspicuous flow layering.

The sanidine and plagioclase phenocrysts constitute 15 to 20 percent of this common quartz latite; they range from microphenocrysts to crystals half an inch long, and both feldspars tend to be glassy, and have a similar megascopic appearance. Although it is difficult to estimate abundances in hand specimen, plagioclase seems to be about twice as abundant as sanidine. Quartz phenocrysts range from small, nearly indistinguishable grains to rounded or irregular crystals nearly as large as the associated feldspar crystals. The quartz grains rarely constitute more than a few percent of the rock. Biotite is the most abundant and conspicuous ferromagnesian phenocryst, but it generally makes up less than 1 percent of the rock. Most biotite crystals are 0.1 inch or less in diameter, but they are shiny black and easily distinguished. Hornblende or altered hornblende forms widespread but sparse and irregularly distributed phenocrysts that range from small needles to crystals as much as 0.4 inch long and 0.1 inch thick. Much of the hornblende has been altered, and in most rocks its former presence is indicated by earthy-reddish to dark-gray pseudomorphs of the original amphibole prisms.

A common variant of the typical quartz latite described above contains sanidine crystals that are distinctly larger than the other phenocrysts, commonly being 1 or 2 inches across and ½ to 1 inch thick. The rounded to irregular quartz grains in these rocks tend to be larger and perhaps more abundant than in the more normal quartz latites, and many rounded grains are as much as a quarter of an inch across. All gradations exist between the more even grained porphyry and the porphyry characterized by large sanidine phenocrysts, and in many places they form indistinct phases within single massive outcrops. Locally the rock containing the large sanidine phenocrysts is concentrated in poorly defined tabular masses generally parallel to local indistinct flow layers.

The most distinctive quartz latite is a coarsely porphyritic rock exposed in a rudely circular area 3,500 to 4,000 feet in diameter on the northeast face of South Mountain. Large sanidine phenocrysts and prominent rounded quartz grains are so abundant and so widely distributed here that the rock is easily distinguished. Sanidine crystals as much as 1 or 2 inches across, typically showing Carlsbad twins, comprise from 5 to 20 percent of the rock, and many of the large crystals weather free from the matrix and are strewn over the surface of low exposures. Most of the crystals are glassy and range from euhedral to rounded and the borders are commonly marked by white porcellaneous rims an eighth of an inch or less thick. Rounded quartz grains are common in these rocks, and generally are significantly larger than similar grains in other quartz latitic rocks in the Summitville district.

Although the rock on the northeast face of South Mountain grades into the surrounding more typical quartz latites, the transition takes place within a narrow zone, generally 50 feet or less wide, and the coarsely porphyritic rock forms a fairly well defined structural unit that is probably of fundamental importance in interpreting the geology of the Summitville district (see "Structure"). The rock within this mass closely resembles that found in many dikes that cut other rocks in the lower member of the Fisher, as well as rocks of the Conejos formation.

Quartz latite dikes cutting Conejos and lower Fisher rocks are widespread in the Summitville district and surrounding areas. Large sanidine crystals and rounded to irregular quartz grains are common, and most of the intrusive rocks are similar to the local coarsely porphyritic phase of quartz latite on the northeast face of South Mountain. In addition, a northwestward-trending dike that crosses Cropsy Creek (pl. 2) apparently passes laterally into this local phase of quartz latite. These relations suggest that the coarsely porphyritic quartz latite dikes and the quartz latite flows in the vicinity of South Mountain are closely related and resulted from volcanic eruptions and igneous intrusion late in the older period of Fisher volcanism. A few quartz latite dike rocks are fine grained and do not resemble any particular flow rock in the lower member of the Fisher. These rocks may be only remotely related to the more common coarsely porphyritic intrusive rocks.

The coarsely porphyritic quartz latite intrusive rocks vary widely in appearance from dike to dike and from margin to center within some dikes. Most of the rocks, however, contain abundant phenocrysts of plagioclase, sanidine, quartz, biotite, and locally hornblende, set in a variable gray groundmass that ranges from aphanitic to finely granular. The phenocrysts range from about 10 to nearly 50 percent of the rock, and tend to be most abundant where they are coarsest. Feldspar phenocrysts greatly predominate, but plagioclase apparently is slightly more abundant than sanidine. Many of the larger dikes show chilled margins with a few scattered phenocrysts in a fine-grained to aphanitic matrix. Toward the core of such dikes the coarse phenocrysts are more abundant and the matrix tends to be more granular.

PETROGRAPHY

Most quartz latitic lavas in the lower member of the Fisher are similar petrographically; the only significant exception is the pyroxene-bearing quartz latite underlying Cropsy Ridge. All the rocks contain phenocrysts of sanidine, plagioclase, quartz, magnetite-ilmenite, and biotite. Phenocrysts of pyroxene and amphibole are common only in the quartz latites underlying Cropsy Ridge, although some resorbed amphibole and rare pyroxene grains may occur in any of the quartz latitic rocks. Phenocrysts average between 20 and 30 percent of the quartz latites, and range from about 10 percent in some of the lavas and chilled borders of dikes, to about 50 percent in the more coarsely porphyritic rocks. Feldspar and quartz phenocrysts greatly predominate, and mafic crystals generally constitute less than 5 percent of any given rock.

Plagioclase crystals constitute 50 to 75 percent of the total phenocrysts, and range in size from microphenocrysts a few tenths of a millimeter in length to tabular crystals more than 1 centimeter in length. This range in size accounts for a seriate texture in most of the quartz latites, but the rocks of the vent complex under Cropsy Ridge contain few plagioclase phenocrysts of intermediate size. Large tabular plagioclase grains may be roughly euhedral, but commonly the phenocrysts are rounded or embayed and show different degrees of resorption and replacement by the groundmass. Some of the most strongly resorbed plagioclase crystals are in the vent area under southern Cropsy Ridge. The plagioclase phenocrysts in the quartz latite rocks show good albite twinning, and are poorly zoned compared to the more calcic plagioclase in the rhyodacitic lavas.

The plagioclase phenocrysts in most quartz latites in the lower member of the Fisher in the Summitville district have an estimated average composition of calcic oligoclase, which contrasts strongly with the normal andesine-labradorite in the rhyodacitic lavas. The pyroxene-bearing quartz latites in the vent complex under Cropsy Ridge contain calcic andesine phenocrysts similar to those in the rhyodacitic facies, and the crystals are complexly zoned as compared to the oligoclase grains in most of the quartz latitic rocks. The pyroxene-bearing quartz latites marginal to the vent complex, however, contain sodic oligoclase phenocrysts that not only contrast with the calcic andesine in the vent area, but are somewhat more sodic than the average plagioclase of the other quartz latitic lavas. The plagioclase phenocrysts within the rudely circular area of coarse-grained porphyry on the northeast face of South Mountain, and the closely similar rock in the quartz latite dikes are albite-oligoclase, and are somewhat more sodic than average for the quartz latitic lavas.

Some of the quartz latites contain both andesine and oligoclase crystals. The more calcic crystals commonly differ somewhat in form, character of zoning and twinning, or degree of resorption from the more sodic crystals, but none of these criteria was sufficiently distinctive or persistent to be reliable in recognizing the two different plagioclases. These two plagioclase rocks may have resulted from mixing of provincially differentiated magmas, or from partial assimilation of rhyodacitic rocks by quartz latitic magma.

Sanidine and quartz phenocrysts are the distinguishing constituents of the quartz latitic lavas. The sanidine phenocrysts commonly form large crystals with maximum dimensions greater than 5 mm, although small crystals, comparable in size to the associated plagioclase phenocrysts, also are abundant. Sanidine generally is only about half to two thirds as abundant as the associated plagioclase. Carlsbad twins are common in the sanidine crystals, but many of the grains are so rounded and embayed that the original external form cannot be recognized. In thin section, most of the crystals show evidence of some resorption, with the margins marked by reaction rims consisting of mixtures of fine groundmass material and sanidine, or of finely granular albite. The dull white rims around clear sanidine cores noted in many hand specimens consist of well-twinned plagioclase with the same composition as the plagioclase in the adjacent rock.

Quartz phenocrysts make up as much as 5 percent of the quartz latitic lavas, and occur as rounded pellets riddled with irregular embayments filled with groundmass constituents. These quartz pellets are less than 5 mm in diameter in most of the quartz latites, but they attain diameters of nearly a centimeter in some of the more coarsely porphyritic rocks. The pyroxene-bearing quartz latites under Cropsy Ridge have fewer quartz phenocrysts than the other quartz latites; the rock in the vent area contains less than 1 percent of quartz phenocrysts, and the marginal flows north of the vent area contain a maximum of 2 or 3 percent.

Biotite and magnetite-ilmenite are the most abundant mafic phenocrysts in most of the quartz latites, except in the pyroxene-bearing quartz latites under Cropsy Ridge. Biotite rarely exceeds 3 percent of the rock, and in the dikes it is generally less than 1 percent. The shiny black biotite books range from crystals 2 millimeters or more in diameter to microphenocrysts only a few tenths of a millimeter in diameter. Many biotite grains are strongly resorbed with residual accumulations of iron oxide granules as their only remaining vestige. Some virtually unaltered biotite crystals include numerous small crystals of apatite and magnetite-ilmenite.

Magnetite-ilminite in phenocrysts, microphenocrysts, and small disseminated grains, is fully as abundant as all the other mafic minerals combined. Without magnetite-ilmenite to supplement the mafic mineral content, most of these rocks would contain less than 5 percent mafic constituents.

Pyroxene is an important phenocrystic mineral only in the quartz latites under Cropsy Ridge, where pyroxene seems to be nearly as common as biotite. Both augite and hypersthene are in the local vent complex; augite is several times more abundant than hypersthene. The pyroxene in the marginal lavas is entirely augite. Most of the pyroxene phenocrysts are small equant granules less than 1 mm in diameter. Except for minor carbonate, the pyroxene is little altered, and stands in sharp contrast with the strongly resorbed microphenocrysts of biotite that are scattered throughout these rocks. Amphibole is also more common in the pyroxene-bearing rocks under Cropsy Ridge than in the more normal quartz latite rocks; it occurs mainly as altered dark pseudomorphs and only rarely as fresh green hornblende. Even where most abundant, amphibole comprises less than 1 percent of the rock.

Apatite and sphene are common auxiliary constituents in most quartz latites, but rarely occur as phenocrysts. A few small zircon grains occur in most of the rocks.

The matrix of the quartz latitic rocks ranges from slightly devitrified spherulitic glass to cryptocrystalline and microcrystalline aggregates. The more crystalline matrices consist principally of microlitic albite(?), potassium feldspar, and tridymite. Tridymite forms wedge-shaped twinned crystals in the porous parts of some rocks; it possibly may be abundant in the groundmass of the fine-grained rocks. Cristobalite forms sparse microscopic balls on the walls of the minute openings, where it commonly is associated with tridymite. Fine magnetite dust is uniformly present through the groundmass, and colors the unaltered rocks gray. Scattered ferromagnesian granules, particularly microlitic pyroxene, are noticeably more common in the groundmass of the pyroxene-bearing quartz latites underlying Cropsy Ridge than elsewhere in the quartz latitic rocks.

UPPER MEMBER

The lavas of the upper member of the Fisher quartz latite in the Summitville district spread over a hilly topography drained by radially directed streams. The rocks in the upper member of the Fisher that cap Cropsy Peak, Cropsy Ridge, and Lookout Mountain, and the flows that cap the ridge east of Park Creek in the northwest part of the district (pl. 1) filled broad open valleys, whereas the series of flows underlying North Mountain were confined by a more narrow valley.

The quartz latite flows of the upper member of the Fisher quartz latite contrast strongly with the older Fisher and Conejos rocks upon which they rest unconformably. The flows typically have well-defined margins, and many are strongly flow layered. The thicker flows are broken by coarsely textured columnar joints, and steep cliffs mark the edges of the resistant flow remnants that cap some of the higher ridges (figs. 6, 10, and 11). Most of the flows in the upper member of the Fisher in the central and southern parts of the district (pls. 1, 2) are a distinctive pink quartz latite that was erupted from a vent near the west end of South Mountain, and many thinner flows of similar rock underlie North Mountain (pl. 1). The upper Fisher rocks near the northwest corner of the district (pl. 2) consist of several coarsely porphyritic gray to pinkish flows which are cut by a volcanic neck and overlain unconformably by a large flow of vesicular gray porphyry. A few small coarsely porphyritic gray dikes of possible late Fisher age cut the highly altered and mineralized rock near the Little Annie and adjacent veins along the northeast face of South Mountain (pl. 3).

LAVAS CAPPING CROPSY PEAK AND ADJACENT RIDGES

All rocks in the upper member of the Fisher in the central and southern parts of the Summitville district are similar in appearance and they have been recognized for 2¾ miles from the south end of Lookout Mountain (pl. 1) to the nose of the ridge extending west from South Mountain. The rocks underlying Cropsy Peak, Cropsy Ridge, and Lookout Mountain are clearly parts of a single large flow, and locally these remnants are still as much as 400 feet thick. The remnants northwest of Cropsy Peak may be parts of the

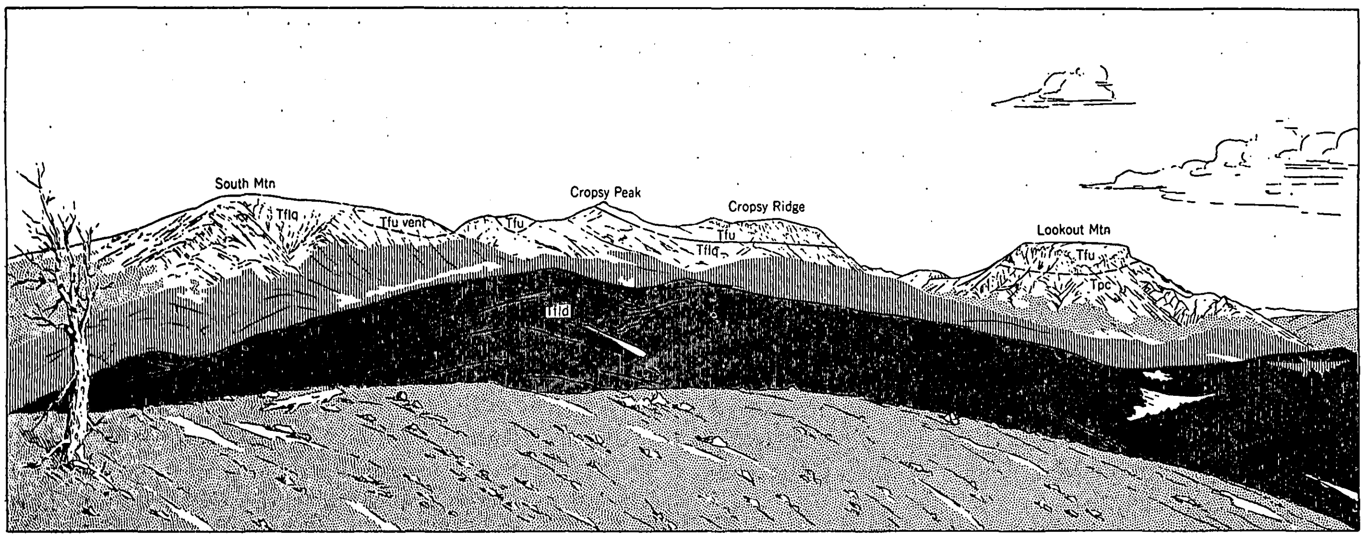

FIGURE 6.—A view of the Summitville district from the west. *Tpc*, altered Conejos flows; *Tfld*, lower Fisher rhyodacitic lavas; *Tflq*, locally altered lower Fisher quartz latitic lavas; and *Tfu*, upper Fisher quartz latite flows with a vent (labelled).

same flow, or may represent other closely related flows. A vent complex 2,500 to 3,000 feet west of the summit of South Mountain is of similar rock, and probably represents the source of these lavas.

Most of the lavas capping Cropsy Peak and adjacent ridges are a dove-gray, pink, or buff porphyry consisting of abundant feldspar and quartz phenocrysts, and sparse biotite and hornblende phenocrysts set in a massive to vesicular groundmass. Fluidal structures are prominent throughout the groundmass; the flow layers generally trend parallel to the margins of the flows, but in detail they show many local irregularities. Most of the rocks have strongly vesicular layers ranging from a fraction of an inch to several inches in thickness and alternating with less vesicular layers of the same general dimensions. The base of the flow underlying Cropsy Peak and Lookout Mountain is marked by a glassy chill phase 5 to 10 feet thick.

The feldspar phenocrysts are typically rounded to rectangular glassy white crystals, and in most of the rock the plagioclase and sanidine are so similar megascopically that they cannot be distinguished with confidence in hand specimen. Combined, the plagioclase and sanidine constitute between 10 and 20 percent of the rock, and an estimate based on thin-section study suggests that the plagioclase is about twice as abundant as sanidine. This estimate may be in error, however, owing to the coarse grain and irregular distribution of the phenocrysts. Most of the feldspar phenocrysts are one-half inch or less in major diameter, but large sanidine phenocrysts as much as 1½ inches long, an inch wide, and three-fourths inch thick occur locally. These large sanidine phenocrysts are similar in size and appearance to the large sanidine phenocrysts that characterize certain lower Fisher quartz latites, and suggest a close genetic relation between the rocks of the upper and lower members of the formation.

The quartz phenocrysts are typically rounded to irregular grains one-fourth inch or less in diameter. Locally, rounded grains as much as one-half inch in diameter are abundant, but these are exceptional. The quartz is unevenly distributed, and ranges in abundance from sparse grains to nearly 5 percent of the rock. In general, however, quartz phenocrysts apparently average only 1 or 2 percent of the rock.

Biotite is the most abundant ferromagnesian mineral that can be identified megascopically and occurs in scattered small flakes a tenth of an inch or less in diameter. It is a minor constituent, however, and rarely exceeds a small fraction of the rock. Reddish-brown prisms of hornblende were noted locally, but these are more sparsely and irregularly distributed than the biotite.

The glassy chill phase at the base of the large flow is a dark-gray to black vitrophyre containing abundant phenocrysts of quartz and white to glassy feldspar, and sparse biotite and hornblende crystals set in a dark obsidian matrix. The phenocrysts comprise about 15 percent of the vitrophyre, and are distinctly smaller than similar phenocrysts in the overlying lava, rarely exceeding a quarter of an inch in diameter. The biotite and hornblende crystals are generally inconspicuous because of the dark glassy matrix that encloses them.

The rocks in the vent complex west of South Mountain are pink quartz latite similar in appearance to the flow rocks to the east and southeast. The flow structures in the vent area stand steeply, however, rather than flat-lying as in the flows.

LAVAS UNDERLYING NORTH MOUNTAIN

Very few of the upper Fisher flows underlying North Mountain are within the area mapped in detail; most of the rocks described in this section were observed during a hurried traverse up the south face and along the crest of North Mountain. Specimens were collected from several representative rock types, but none of the flows was traced nor was any attempt made to establish the chronologic sequence of flows.

The flows underlying North Mountain apparently filled a narrow valley that extended north and northwest from the central part of the Summitville district. The most abundant rock type noted is a pink to gray quartz latite almost identical to the lavas capping Cropsy Peak and adjacent ridges (see previous paragraphs), and probably originated from the same vent.

Layers of black to dark-gray vitrophyre occur at intervals throughout the sequence of flows under North Mountain; these may be chill phases on the more abundant pink lava flows, or they may represent separate flows. White to glassy feldspar phenocrysts comprise 10 to 15 percent of most of the vitrophyres; quartz is next in abundance and makes up several percent of most of the rocks. Small biotite and hornblende crystals are widespread, but generally are surrounded by dark glass and are inconspicuous. The groundmass of the vitrophyres ranges from dull pitchstone to shiny obsidian, and spherulitic structure is locally prominent.

LAVAS CAPPING THE RIDGE EAST OF PARK CREEK

Two distinct types of lava belonging to the upper member of the Fisher quartz latite cap the ridge east of Park Creek, in the northwestern part of the Summitville district. The older of these types is characterized by large sanidine crystals similar to those found in many lower Fisher quartz latites. It constitutes several flows underlying the south end of the ridge, but the rocks are poorly exposed, and the number, extent, or attitudes of the flows is not known. The rocks range from a pink, massive to slightly vesicular quartz latite to a dark-gray scoria with numerous irregular holes as much as 1½ inches across. Glassy sanidine and plagioclase phenocrysts are abundant in all of these rocks, and small rounded grains of quartz a tenth of an inch or less in diameter are widespread but quantitatively rare. Reddish oxidized crystals of biotite and hornblende a few tenths of an inch or less in major dimension are widely scattered, but rarely exceed 1 to 2 percent of the rock.

The younger rock type constitutes a volcanic neck that cuts the older rocks of the upper member of the Fisher, and a large flow that rests unconformably upon them. Only the south end of the large flow has been mapped in detail (pl. 2), but reconnaissance to the north indicates that the remnant still preserved is more than a mile long and apparently consists entirely of a single flow. Present thickness of the flow locally exceeds 300 feet, and the original thickness may have been much more. The rock in the neck and related flow is a vesicular lava with prominent rectangular feldspar tablets one-half inch or less long set in an aphanitic light-gray matrix. All of the feldspar is white and glassy, and the sanidine and plagioclase are almost indistinguishable in hand specimen. Microscopic studies suggest that sanidine is a minor constituent, however, and that most of the feldspar is oligoclase. Quartz is very sparse among the phenocrysts and occurs as small irregular grains that can be seen only locally. Small crystals of biotite and hornblende are widely scattered throughout the rock, but are inconspicuous, and generally can be seen in hand specimen only with a hand lens. The aphanitic matrix is highly vesicular, and the vesicles tend to be flattened and alined subparallel to the tabular feldspar phenocrysts, so that the rock as a whole has a pronounced fluidal structure. Tridymite is common as a lining in the irregular and streaked-out vesicles.

POSSIBLE UPPER FISHER DIKES ON SOUTH MOUNTAIN

Several small dikes cut the altered quartz latites of South Mountain in the vicinity of the Little Annie vein (pl. 3); these consist for the most part of a coarsely porphyritic rock containing abundant sanidine, quartz, and plagioclase phenocrysts, and sparse to moderately abundant biotite phenocrysts, set in an aphanitic gray groundmass. The sanidine phenocrysts typically are large tabular crystals as much as an inch long, and range from euhedral to rounded. The quartz phenocrysts are rounded to irregular grains a quarter of an inch or less in diameter that characteristically are deeply embayed by tongues of the groundmass. The biotite is rare compared to the other phenocrysts, and occurs in small black flakes widely scattered throughout the rock. The groundmass of most of the rock is medium gray and is compact and structureless. The southernmost of the dikes shown on plate 3, however, is composed of a vitrophyre with nearly vertical flow layers.

Most of the rock in the dikes appears nearly fresh in hand specimen, and contrasts strongly with the highly altered host rocks. Locally, however, the dike rocks have been altered somewhat; the feldspar phenocrysts are chalky white or porcellaneous, the biotite is destroyed, and the matrix is light gray and slightly granular. This alteration seems to be most marked in the vicinity of the mineralized veins, and may have resulted from acid supergene solutions derived from oxidation of nearby pyrite.

PETROGRAPHY

The varied rocks in the upper member of the Fisher quartz latite have many petrographic features in common. The phenocrysts are plagioclase, sanidine, quartz, biotite, amphibole, and pyroxene, which are set in groundmasses that range from glassy to cryptocrystalline and microcrystalline. The phenocrysts average about 15 percent, and range from less than 5 percent to about 30 percent of the rock. Minor accessory minerals are magnetite-ilmenite, apatite, sphene, and zircon, in order of decreasing abundance.

Judging from thin-section studies, about 75 percent of the phenocrysts in most of the rocks is plagioclase feldspar. Most of the plagioclase is sodic or intermediate oligoclase, but some rocks contain a second, more calcic plagioclase in the andesine range. The plagioclase crystals are generally a centimeter or less long, and range in form from euhedral laths to rounded grains and broken fragments. Albite twinning is predominant, although other types of twinning are present. The phenocrysts are commonly zoned. Some show progressive zoning either from calcic cores to sodic rims or from sodic cores to calcic rims; others showed oscillatory zoning with alternating more sodic and more calcic shells. Some of the plagioclase crystals are rounded or ellipsoidal as though they had been resorbed somewhat by the surrounding magma and many inner zones of progressively zoned phenocrysts are similarly rounded, and are enclosed in more rectangular outer layers that formed by renewed crystallization.

Sanidine phenocrysts range from the large crystals an inch or more in length to crystals comparable in size to the associated plagioclase phenocrysts. Although many of the sanidine crystals are somewhat rounded and embayed by the groundmass, they are generally less resorbed than the nearby plagioclase phenocrysts. Sanidine is nearly absent in some upper Fisher rocks, but generally constitutes 10 to 15 percent, and locally as much as 25 percent of the feldspar phenocrysts. They are least abundant in the large flow and associated volcanic neck in the northwestern part of the district.

The quartz phenocrysts are typically rounded or ellipsoidal, and commonly are deeply embayed by the groundmass. They are generally only a few millimeters or less in diameter, and although they are widely distributed, they rarely constitute more than a few percent of the rock. They are largest and most abundant in the pink quartz latites in the southern and central parts of the district, and in similar rocks underlying North Mountain; they are small and sparse in the large flow and associated volcanic vent in the northwestern part of the district.

Mafic phenocrysts make up less than 5 percent of the upper Fisher rocks. In order of abundance, these minerals are biotite, amphibole, and pyroxene; they are typically euhedral and unbroken, and are noticeably small in comparison to the feldspar phenocrysts. The biotite grains are commonly 1 to 2 mm or less in diameter, and commonly contain abundant inclusions of fine magnetite-ilmenite, apatite, and some zircon. The amphibole crystals are generally small prisms only a few hundredths to a few tenths of a millimeter long, although scattered larger crystals have been recognized; these prisms range from greenish hornblende in the cryptocrystalline and microcrystalline rocks to brownish oxyhornblende in some of the glassy rocks. Locally, the amphibole is about as abundant as biotite, but generally it is subordinate. Pyroxene, chiefly augite, is much less abundant than the other mafic minerals; it generally occurs as euhedral, colorless crystals about the same size as the associated hornblende crystals. Locally the augite is replaced almost completely by a fibrous material that may be bastite. A few rocks contain sparse small grains of a nearly colorless orthopyroxene, perhaps hypersthene.

The groundmasses of the upper Fisher rocks range from massive glass to pilotaxitic intergrowths of microlites. The glassy groundmasses of the vitrophyric layers generally are speckled with small microlites or crystallites and locally are partly devitrified, whereas the rocks with aphanitic or finely granular groundmasses are fairly uniformly cryptocrystalline or microcrystalline. Many of the strongly flow layered lavas have narrow glassy layers alternating with more crystalline layers and the rock appears heterogenous under the microscope. The indices of refraction of the glass from several vitrophyres ranged from 1.497 to 1.505, indicating a highly siliceous composition (George, 1924).

CHEMICAL COMPOSITION

The rocks in the Fisher quartz latite near Summitville range in composition from rhyodacites to quartz latites; in general the compositions are progressively more silicic toward the younger rocks.

Seven chemical analyses are available for the Fisher rocks near Summitville. Of these, five, by the U.S. Geological Survey, are new analyses reported first in this report; the remaining two are quoted from Patton (1917, p. 31). These analyses are given in table 3.

TABLE 3.—*Chemical analyses and normative compositions, in percent, of rocks from the Fisher quartz latite*

	1	2	3	4	5	6	7
Chemical analyses							
SiO_2	58.7	66.6	65.61	69.45	62.51	70.9	69.13
Al_2O_3	16.8	14.7	14.42	15.21	14.64	14.3	14.31
Fe_2O_3	3.9	2.3	2.40	2.38	.63	1.3	.64
FeO	2.2	1.2	.93	.53	2.93	.51	1.10
MgO	1.8	.68	1.13	.43	1.88	.61	.83
CaO	5.5	2.7	3.12	1.38	3.80	1.6	2.31
Na_2O	3.6	3.9	3.56	4.06	3.01	3.7	4.19
K_2O	2.9	4.2	4.07	4.30	3.78	4.6	4.55
H_2O^-	1.3	1.2	.99	.59	.80	2.5	.06
N_2O^+	--------	--------	.64	.55	1.44	--------	2.45
TiO_2	.86	.52	.53	.48	.73	.28	.50
ZrO_2	--------	--------	--------	--------	.06	--------	.10
CO_2	1.4	1.7	1.99	.00	3.75	.05	Tr.
P_2O_5	.50	.40	.38	.32	.36	.26	.18
SO_3	--------	--------	.00	.00	.15	--------	None
Cl	--------	--------	.00	.01	.02	--------	.02
F^-	--------	--------	.10	.10	--------	--------	--------
S	.2	--------	.00	.00	Tr.	--------	None
MnO	.21	.12	.09	.02	.08	.04	.05
Total	--------	--------	99.96	99.81	--------	--------	--------
Less O	--------	--------	.04	.04	--------	--------	--------
	99.7	100	99.92	99.77	100.57	100.6	100.32

Normative compositions

[CO_2 was disregarded in the calculation of the norms. This procedure leads to certain difficulties exmplified by norm 5. The analysis of this rock shows 3.75 percent CO_2 which when disregarded in the calculation of the norm undoubtedly results in an unreal amount of normative anorthite. Corundum, appearing in norms 4 and 6 is probably due to the presence of secondary clay minerals]

	1	2	3	4	5	6	7
Quartz	14.1	22.4	22.3	26.5	18.6	28.1	21.9
Orthoclase	17.1	24.8	23.9	25.4	22.3	27.1	26.9
Albite	30.4	33.0	30.1	34.3	25.5	30.3	35.4
Anorthite	21.1	10.2	11.4	4.9	15.2	6.3	6.9
Corundum	--------	--------	--------	2.1	--------	1.0	--------
Diopside	2.2	--------	1.3	--------	1.1	--------	2.8
Hypersthene	3.4	1.7	2.2	1.1	8.0	1.5	1.4
Magnetite	5.3	2.8	1.7	.4	.8	1.1	.9
Ilmenite	1.6	1.0	1.0	.9	1.3	.5	1.0
Nematite	.3	.4	1.2	2.2	--------	.6	--------
Apatite	1.2	.9	.9	.8	.8	.6	.4
Zircon	--------	--------	--------	--------	.1	--------	.2

1. (SM 244*; 139604**) Rhyodacite from the lower member of the Fisher quartz latite, collected along the eastern branch of Park Creek due west of the summit of South Mountain. Rapid-type rock analysis (Shapiro and Brannock, 1952); analysts, Paul L. D. Elmore and Katrine E. White. Mar. 4, 1955.
2. (SM 291; 139603) Quartz latite from the lower member of the Fisher quartz latite, collected about 2,400 feet east of the summit of South Mountain. Rapid-type rock analysis; analysts, Paul L. D. Elmore and Katrine E. White. Mar. 4, 1955.
3. (SA-2; A 153) Quartz latite from the lower member of the Fisher quartz latite, collected within 200 feet of the sample represented by analysis 2. Standard rock analysis Mar. 3, 1955; analyst, Lucile N. Tarrant.
4. (SA-1; A 152) Coarsely porphyritic quartz latite from the core of the South Mountain volcanic dome, collected from the nose of the ridge extending east from the Iowa mine workings at an altitude of about 11,700 feet. Standard rock analysis Mar. 3, 1955; analyst, Lucile N. Tarrant.
5. Analysis quoted from Patton (1917, p. 31). Coarsely porphyritic quartz latite from a dike that crosses Cropsy Creek. Analysts, George Roher and Esbon Y. Titus, Colorado Univ.
6. (SM 23A1; 139602) Vitrophyre from the upper member of the Fisher quartz latite, collected from about two-thirds of the way up the south face of North Mountain. Rapid-type rock analysis Mar. 4, 1955; analysts, Paul L. D. Elmore and Katrine E. White.
7. Analysis quoted from Patton (1917, p. 31). "Biotite-hornblende latite vitrophyre, Cropsy Peak type" (upper member of the Fisher quartz latite), collected from Lookout Mountain. Analysts, George Roher and Esbon Y. Titus, Colorado Univ.

* Field number.
** Laboratory serial number.

Norms (table 3) calculated for these analyses were plotted on a Johannsen diagram (fig. 7) to obtain the approximate rock classification for each analysed specimen. The spread of points on the diagram indicates a change in composition with time, in which the younger rocks are progressively richer in normative quartz and potassium feldspar. This change also reflects the phenocryst content of the rocks. Quartz and sanidine crystals are generally absent in the rhyodacitic lavas, but are abundant in the quartz latitic lavas in both members of the Fisher. Although the chemical data are too sparse to be conclusive, the greatest change in composition seems to be between the rhyodacitic and quartz latitic lavas of the lower member of the Fisher.

The progressive change in composition is reflected by the trends of curves obtained by plotting the weight percent of the oxides reported in the analyses against the successive periods of eruption (fig. 8). The actual slope of these curves has little meaning, as the rocks from the different periods of eruption are not equally represented; a few of the specimens analysed were somewhat altered and the time factor is not adequately expressed by the equal spacing between the periods of eruption. The one specimen of rhyodacite contained a slightly more calcic plagioclase feldspar and somewhat more abundant pyroxene phenocrysts than typical rhyodacitic rocks, and thus may not be truly representative. Any correction toward the more probable average rock would have the effect of straightening each curve. Several of the quartz latitic rocks from the lower member of the Fisher contain significant quantities of CO_2, indicating some alteration; one of these (analysis 5, table 3) contained so much CO_2 (3.75 percent) that it was recalculated as CO_2-free before it was plotted on the graph. This partial correction had the effect of grouping the points more closely, but probably introduced other errors that cannot be assessed adequately. The horizontal coordinate also reflects the sequence of eruption only, and not the time elapsed between the different eruptions. In spite of these inherent faults, the general trends of the curves are believed significant, and probably are representative of the direction if not the degree of magmatic differentiation near Summitville during the Fisher period of volcanism.

The norms of the analysed Fisher rocks from near Summitville were plotted on a Johannsen diagram (fig. 9) together with the norms of Fisher rocks quoted by Larsen and Cross (1956, p. 190). The rocks from near Summitville conform to the overall grouping of Fisher rocks, and seem typical of the formation as a whole. The plot of the single analysed rhyodacite from near Summitville is near the more plagioclase-rich margin of the field as it should be to judge from its petrographic character. The quartz latites of the lower and upper member of the Fisher near Summitville are centrally located with respect to the other quartz latites in the formation, and appear typical of the more felsic Fisher rocks.

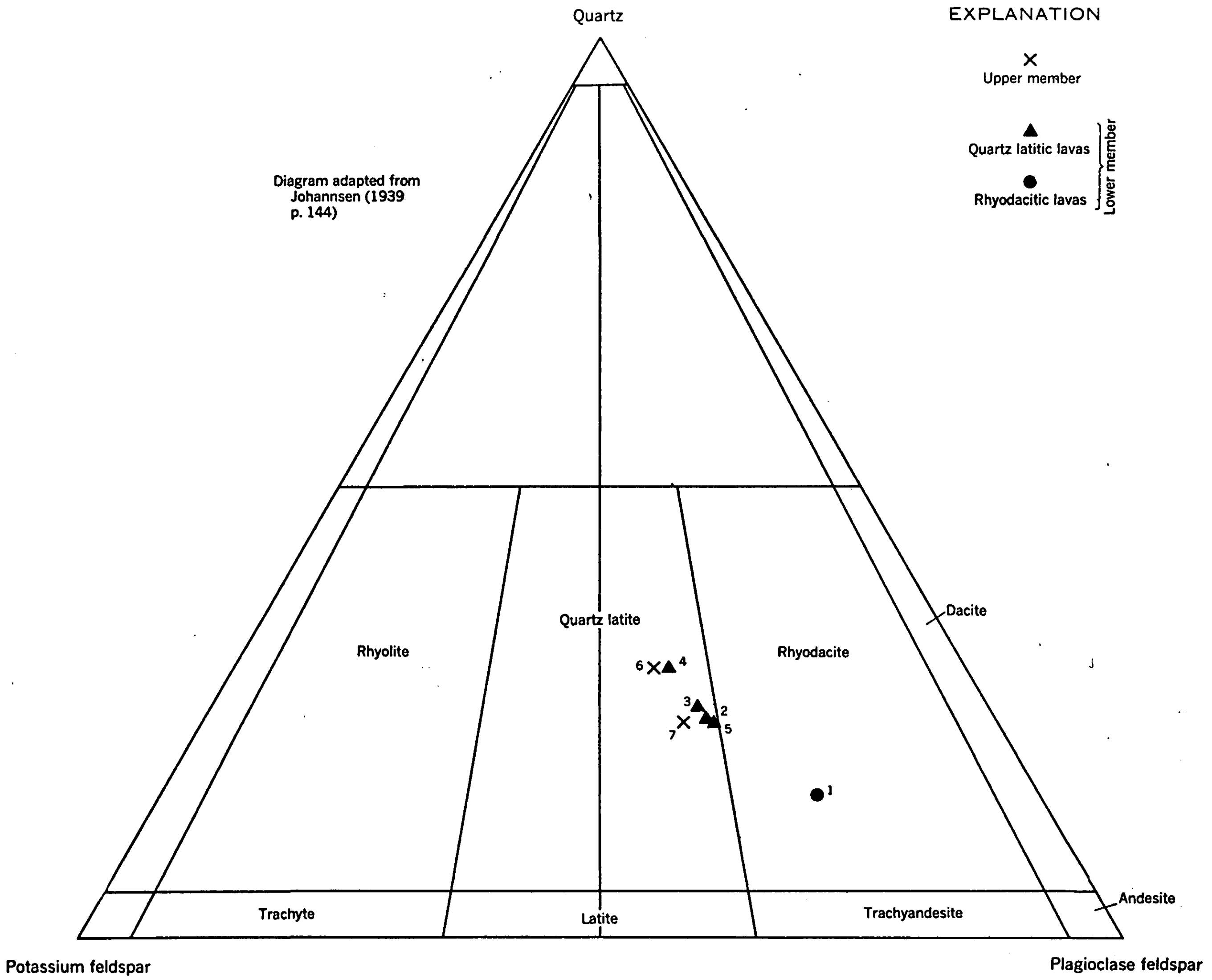

FIGURE 7.—Normative compositions of rocks from the Fisher quartz latite in or near the Summitville district plotted on a Johannsen diagram. Numbers refer to analyses given in table 3.

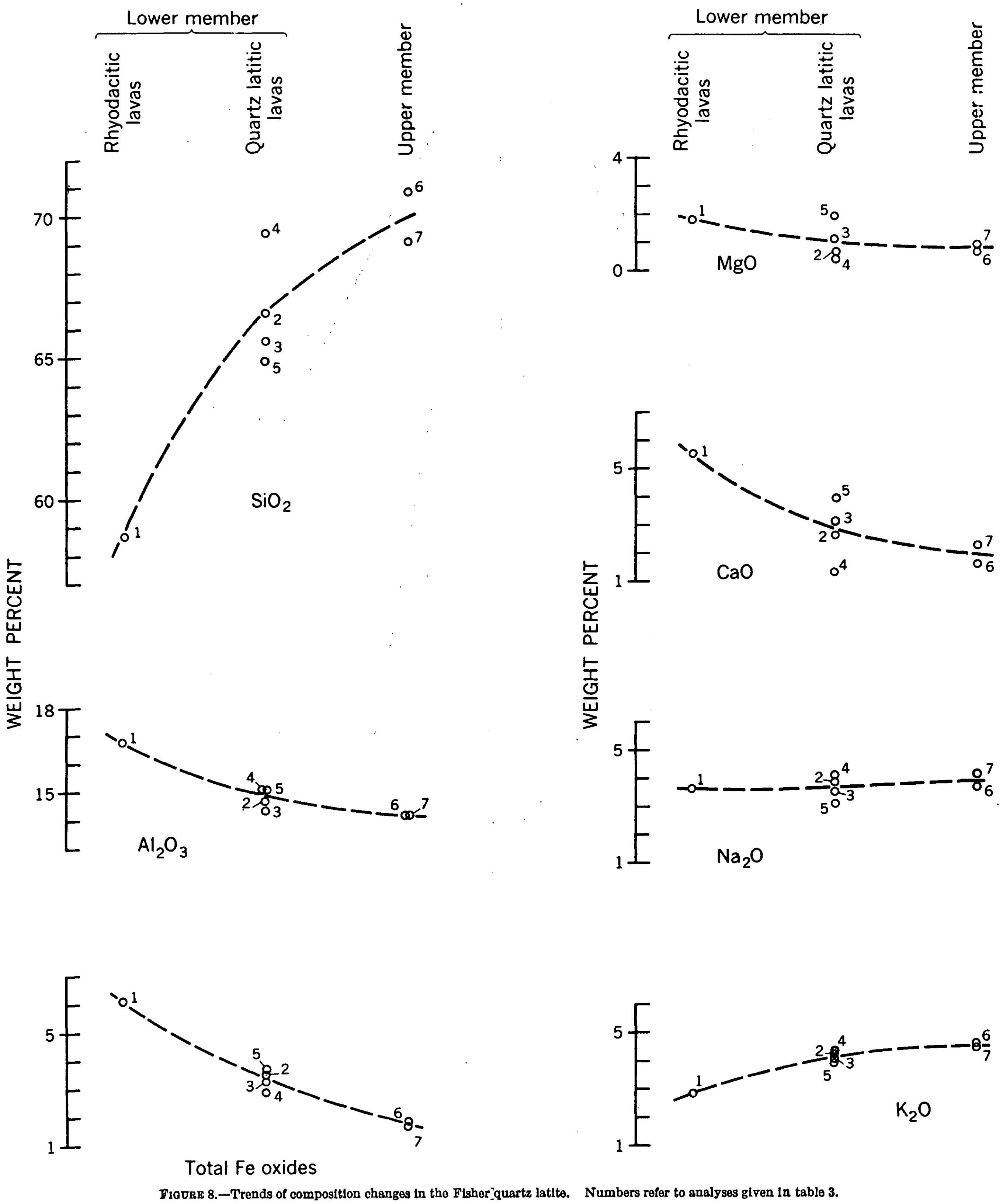

FIGURE 8.—Trends of composition changes in the Fisher quartz latite. Numbers refer to analyses given in table 3.

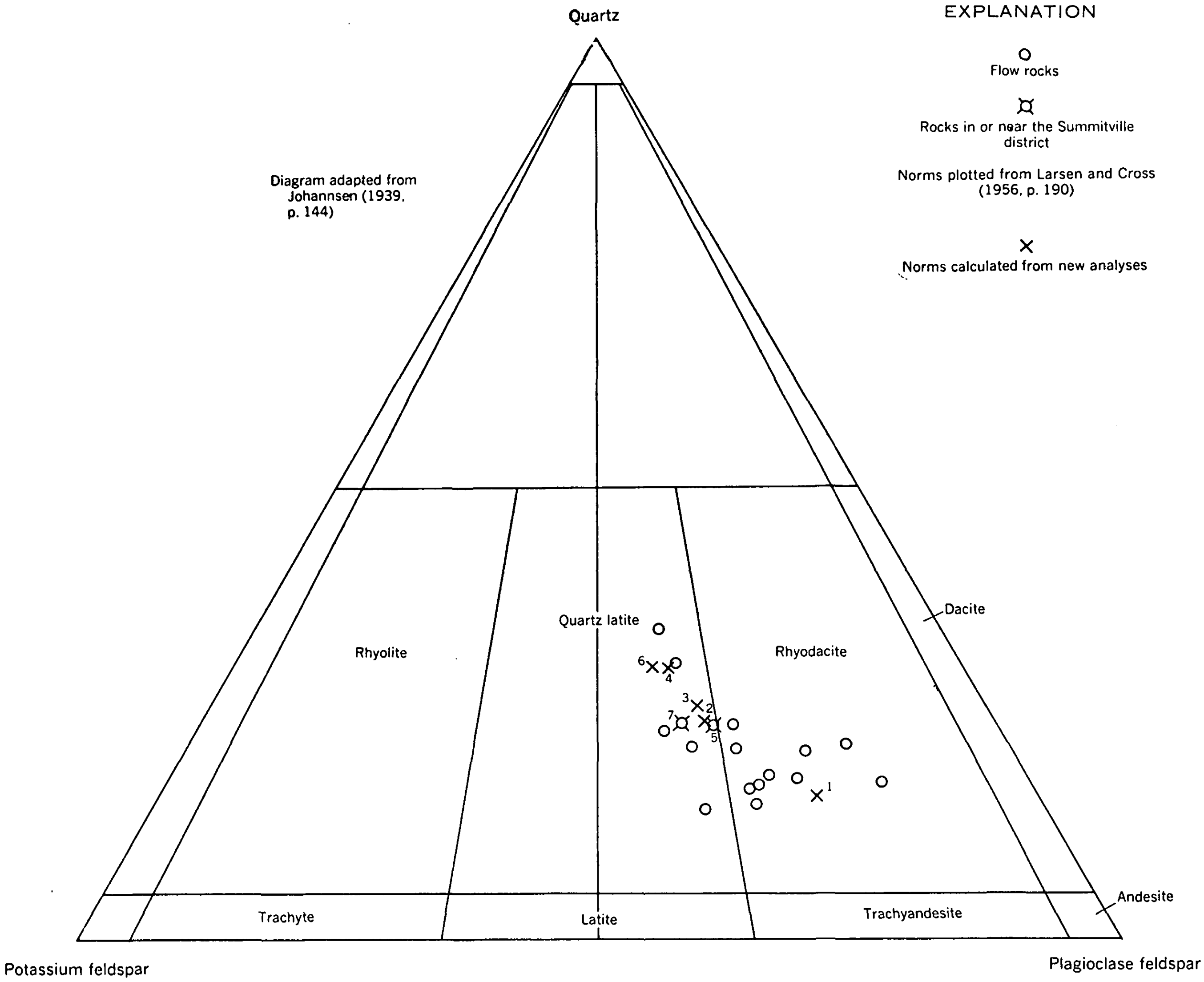

FIGURE 9.—Normative compositions of rocks from the Fisher quartz latite plotted on a Johannsen diagram. Numbers refer to analyses given in table 3.

STRUCTURE

The gross aspect of geologic structure of the Summitville district and surrounding areas is simple. The thick sequence of flat-lying rhyodacitic flows of the Conejos formation provided a platform upon which was built a nested group of volcanoes of Fisher age. Irregularly alternating periods of eruption, quiescence and erosion, and local hydrothermal activity complicated geologic relations locally, and faulting disturbed the pile of lavas at several times during its growth. These processes, however, did not greatly modify the broad general aspect.

The detailed architecture of the broadly simple structure is complex, however. The Conejos flows apparently resulted from flood eruptions that built up a thick local sequence of lava flows. Late in its history, this thick sequence was invaded by quartz monzonite magma and several stocks were emplaced near the southern margin of the Summitville district. At one time several other volcanic formations overlay the Conejos in the Summitville district; these were largely removed before eruption of the Fisher quartz latite when erosion cut an irregular surface across the older rocks.

The rhyodacites and quartz latites of the lower member of the Fisher quartz latite formed largely from viscous lava that heaped up around the vents to form thick massive flows and volcanic domes with marginal accumulations of fragmental debris. Before volcanic eruptions were renewed in later Fisher time erosion modified the external form of these structures to a hilly terrain with radially flowing streams. The quartz latitic lavas of the upper member of the Fisher formed widespread flows whose shapes were controlled by the topography over which they flowed.

Only one major fault cuts the rocks of the Summitville district (pl. 2), but it has had a complex history. Northwestward-trending dikes of coarsely porphyritic quartz latite occur along a zone of en echelon fissures that is closely parallelled by the fault, and at least one of the dikes is cut by the fault. In the central and southeastern parts of the district the fault cuts rocks of the Conejos formation and the lower member of the Fisher quartz latite, but is overlain by unbroken remnants of the upper member of the Fisher quartz latite. In the northwestern parts of the district, on the other hand, a wedge-shaped mass of lava in the upper member of the Fisher was dropped between two branches of the fault, and a later volcanic neck is localized along one of these branches. These relations suggest that the first movements along the trend of the present broken zone produced a set of discontinuous fractures that served to localize some quartz latite dikes. The first major displacement took place between eruption of the lower and the upper Fisher lavas, and the fault so formed was reactivated in the northwestern part of the district in later Fisher time. No post-Fisher movements have been recorded by the rocks.

SHIELD VOLCANO(?) OF CONEJOS AGE

Many features of the Conejos formation near the Summitville district are typical either of lava plateaus or of shield volcanoes built up by many successive flood eruptions of fluid lava. Most of the dips in the thick succession of rhyodacite flows of the Conejos near the Summitville district are low to moderate, generally toward the north or northwest. The porphyritic rocks in the flows are fine-grained and fairly uniform. Pyroclastic rocks intervene between flows in only a few places. According to Cross and Larsen (1935, p. 72–74; Larsen and Cross, 1956, p. 97), the thick succession of uniform flows in and adjacent to the Summitville district is characteristic of the central and thickest parts of the Conejos volcanic pile; the rocks of border areas are typically bedded tuff breccias and volcanic gravels with minor intercalated flows.

The detailed structure of individual flows is difficult to determine, for exposures are generally small and discontinuous, the boundaries can rarely be distinguished, and the internal structures are generally lacking or inconspicuous. Commonly adjacent flows are identical in appearance, and only locally can individual flows be traced for more than a few hundred feet along the surface. Many rocks are locally cut by closely spaced joints, but this jointing has no consistent relation to the attitude of the flows; in some places the joints are nearly parallel to flow boundaries, in other places they are nearly at right angles to the boundaries, and at still other places the joints are oriented at random to the boundaries or are curved and irregular. Many of the strikes and dips shown within the Conejos formation on the geologic map (pl. 2) are based on crude estimates made from discontinuous exposures of one or a series of flows on irregular topography. Other estimates were made by measuring the inconspicuous flow layers or local jointing where these seemed to parallel the general layering of the rocks. Measurements made on actual boundaries were obtained only locally, and even these appeared to be reliable for only small areas.

The general impression gained during fieldwork was that the thick pile of Conejos lavas is made up of many flows that are wide-spread relative to their thickness, but are local with respect to the total area underlain by similar flows. Although generally flat lying, the flows vary abruptly in thickness and attitude, probably as a result of the local irregularities in the terrain over which the lava flowed. These features probably account in large part for the wide divergence in attitude of measurements taken within small areas.

The two intrusive bodies of quartz monzonitic composition that cut the Conejos flows near the southern and eastern margins of the Summitville district (pl. 1) have been interpreted by Cross and Larsen (1935, p. 74; Larsen and Cross, 1956, p. 102), as volcanic necks marking the vents from which the Conejos flows were erupted. No evidence was found during the reconnaissance survey to prove or disprove this hypothesis, and it may be true for some of the smaller bodies. The large intrusive body along the south flank of Alamosa Creek (pl. 1), however, is about 5 miles long and as much as 2 miles wide; it seems much too large to be the vent from which many successive but thin flows were erupted. Insofar as it was observed during a few widely spaced traverses, this intrusive body consists of a fine- to medium-grained equigranular rock that appears uniform throughout the area of exposure. Where seen, the contact with the adjacent rocks is sharp. It seems more plausible that this intrusive mass is a hypabyssal body that was intruded into the earlier flows of the shield volcano or volcanic plateau late in the Conejos period of volcanism, perhaps at the site of earlier vents, and that it cooled slowly enough under moderate cover to produce a generally uniform holocrystalline rock.

The stock along Alamosa Creek may expand northward at depth as a large area of intensely altered rocks borders the intrusive body on the north and seems related to it in space (pl. 1). These rocks were altered before the eruption of lower Fisher rocks, and probably shortly after the intrusion of the stock in the Conejos.

RHYODACITIC FLOWS AND DOMES OF EARLY FISHER AGE

The rhyodacitic lavas in the lower member of the Fisher quartz latite are characteristically massive, and flow structures are local and inconspicuous. The rocks are interpreted to represent thick local accumulations formed by viscous lava heaping up above or near the vents through which they were erupted. This interpretation is based upon only fragmentary evidence because the original pile of lavas is now so deeply eroded that all original constructional forms have been destroyed, but it is in accord with other volcanic terrains consisting predominantly of massive dacites. Although only two areas of pyroclastic rocks large enough to be mapped occur within the area of rhyodacite flows, smaller bodies are abundant and widespread. Much of this material probably represents marginal accumulations along the flanks of massive flows.

Although some of the flows in the vicinity of Schinzel Meadow (pl. 2) are thin—about 10 to 20 feet thick—most of the rhyodacite flows are thicker and more widespread than any of the outcrops that expose them. Some areas of nearly complete outcrop in the low hills between Schinzel Meadow and the headwaters of Park Creek are as much as 1,000 feet long, several hundred feet wide, and 20 to 200 feet high. These areas are virtually homogeneous throughout and are parts of thick individual flows. Some of the flows may be 500 or more feet thick and may extend laterally for at least several thousand feet and perhaps much more.

Most of the exposed rhyodacitic rocks are nearly devoid of flow structures. A few outcrops, however, show obscure layers a few inches thick that differ slightly from the adjacent layers. The differences in the layers generally is the result of a subparallel orientation of tabular feldspar phenocrysts along thin layers in otherwise massive rock. Commonly the flow layers are more apparent if viewed from a distance of 10 feet than from 1 to 2 feet, or through a hand lens. The flow layers dip in all directions, and the few measurements that could be made are so widely scattered that no interpretation is warranted. The dips vary widely, from nearly horizontal to nearly vertical, but most of those measured range from 20° to 60°.

The mass of bedded tuff and breccia along the east flank of Park Creek in the northwest corner of the Summitville district is underlain by typical rhyodacitic flow rocks, and is overlain by a massive quartz latitic flow that may be interlayered with the rhyodacitic lavas. Individual beds within the mass of pyroclastic rocks strike northwest and dip about 30° NE. Many of these rocks are well bedded and fairly well sorted, and are perhaps water-laid deposits. Such rocks are probably too far removed from their place of origin to have any structural significance with respect to the adjacent flows, and probably mark only a local area of deposition.

The larger mass of pyroclastic rocks along the ridge crest east of Park Creek rests in part on the basal vitrophyre flow that filled a local valley cut in the older rocks, and in part on Conejos rocks that projected as low hills through the vitrophyre. The pyroclastic rocks are succeeded and in part overlain on the east by a typical massive rhyodacite flow; on the west they are in fault contact with younger quartz latite flows of the upper member of the Fisher. Chaotic volcanic breccia comprises thick, poorly defined beds that are complexly interlayered with tuffaceous rocks and local flows. Individual beds strike north to northwest and generally dip eastward at angles ranging from 15° to 75°. The steep dips and the coarse, unsorted, and commonly subangular fragments in the breccia suggest that much of this mass is an accumulation of fragmental debris marginal to one of the thick massive flows.

None of the small outcrops of pyroclastic rocks scattered through the rest of the rhyodacitic lavas could be traced beyond the actual areas of outcrop. They are widely distributed, however, and occur through a large range in altitude, and it seems likely that they characterize many flow margins.

As noted by Williams (1932, p. 133–145) in his comprehensive review of volcanic domes, these, and the closely related short thick flows are most common among intermediate to silicic lavas. Most domes tend to grow symmetrically around their vents, but the actual form according to Williams depends on local factors such as the "volume of magma extruded, the rate of its upheaval and solidification, and the topography of the enclosing crater." The thick flows and domes are typically flanked by great banks of fragmental debris that locally almost cover the associated mass of lava. Most rocks in domes and related flows are markedly porphyritic, and commonly show little internal structure (p. 145). Most domical eruptions are preceded by intense pyroclastic activity, but some, such as Lassen Peak, are not.

Although the rhyodacitic flows in the lower member of the Fisher show most of these typical characteristics of domical eruptions, they lack the common basal pyroclastic debris and known preexisting craters. The absence of abundant pyroclastic debris does not invalidate the interpretation, however, for many exceptions to the general rule are known. The great predominance of massive lavas over fragmental debris within most of the rhyodacitic lavas seems somewhat anomalous were the lavas extruded as typical volcanic domes. It seems probable that most of the lava flows, although viscous enough to attain local thicknesses of at least several hundreds of feet spread sufficiently so that the areas covered by marginal talus were small compared to the areas covered by the associated flows.

The root of a vitrophyre dome or flow was seen in a cliff exposure on a ridge about 0.4 mile west of the area mapped in detail (pl. 2). As shown in figure 10, a

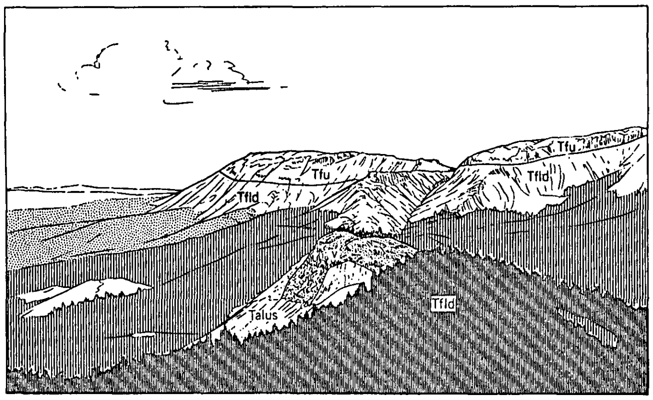

FIGURE 10.—A view looking north-northeast across Park Creek from a point near the center of the western margin of the Summitville district. *Tfld*, lower Fisher rhyodacitic lavas with the roots of a local vitrophyre flow or dome (*v*) shown in the middle distance; and *Tfu*, upper Fisher quartz latite flow.

dark vitrophyre flow remnant passes downward into a neck that cuts a typical massive rhyodacitic flow. The original form cannot be reconstructed because so little of the surface flow is still preserved. However, it spread laterally from the vent in all directions and the eruption probably had characteristics of a domical protrusion.

STRUCTURES UNDERLYING CROPSY RIDGE

Cropsy Ridge is outstanding in the Summitville district for the number and variety of geologic relations shown, and for the degree of exposure which enables many of the relations to be interpreted with fair confidence (fig. 5). An assemblage of volcanic breccia, lava, and dikelike masses of pyroxene-bearing quartz latite at the south end of Cropsy Ridge (fig. 4) has been interpreted as a vent complex, perhaps at the root of a volcanic dome. The rock is easily distinguished in the field, and all phases—the breccia, the massive lava, and the dikelike bodies—are of the same material. The breccia is a completely chaotic assemblage of fragments that range from very fine fragments to huge boulders as much as 30 feet in diameter. This mass of breccia is cut by irregularly curved and swelling dikelike tongues that merge farther west into a large mass of strongly sheeted rock. This sheeted rock is cut by locally abundant, closely spaced, curved to irregular fractures that range from nearly vertical to nearly horizontal, and in places several sets of fractures intersect. Several steeply dipping tabular "breccia dikes" from 5 to 10 feet thick cut the sheeted rock; the fragments in these broken zones are identical to the adjacent wallrocks. This complex is overlain on the east by a massive lava flow of identical rock, in which obscure flow layers near the base dip east at moderate to steep angles.

The eruption and concurrent partial disintegration of a steep-sided dome or spine of viscous lava may explain these complex relations. With continued extrusion, the viscous column of lava would have tended to form local intrusive relations toward the developing cone of rubble through which it was being forced. The strong irregular sheeting in the lava west of the volcanic breccia may have formed as cooling fractures or as the result of shear in viscous lava as it was extruded; in either case, the sheeting probably caused much of the disintegration that resulted in the chaotic breccia. The explosive character of some of the disintegration is indicated by the tabular masses of breccia (breccia dikes) that locally cut the sheeted lava and dikelike tongues. Disintegration of spines and steepsided domes of viscous lava has been observed in many volcanic areas (Williams, 1932a, p. 54–62; 81–85); in all of these places the disintegration was in part concurrent with extrusion and took place both by piecemeal crumbling and by explosive disruption.

The overlying lava east of the volcanic breccia may have resulted from continued extrusion of lava from the same vent, or may mark a satellitic eruption; in either case, the lava appears to have heaped up into a bulbous flow or dome that in part covered the earlier complex of breccia and lava.

The pyroxene-bearing quartz latite that crops out on both sides of Cropsy Ridge north of the probable vent complex differs slightly in phenocryst content and texture from that in the vent area, and probably represents a separate eruption of closely related lava (see "Quartz latitic lavas"). Most of the exposed rock is massive, and faint flow layers were seen at only one place on the west flank of the ridge where the strike was slightly east of north and the dip was about 50°W. (fig. 4). All of the exposures consist of virtually identical rock, and appear to be parts of a single thick local flow or volcanic dome. Exposures are too poor to determine the age of this flow relative to adjacent masses of quartz latite. Presumably it could be older than the adjacent vent complex and be cut by it, or it could be younger and have formed as a satellitic eruption on the north flank of an earlier accumulation of related rock. Relations with the biotite quartz latite to the north are even more nebulous; the pyroxene-bearing quartz latites are intermediate in composition and mineralogy between typical rhyodacitic and quartz latitic lavas of the lower member of the Fisher, and thus may be intermediate in age also (see "Quartz latitic lavas"), but this suggestion is not supported by any known field evidence.

QUARTZ LATITE DOME OF SOUTH MOUNTAIN

Most of the lower Fisher quartz latites in the vicinity of South Mountain and Cropsy Peak are highly altered and the original structures of the rocks are so obscured that they cannot be reconstructed in many areas. The broad distribution and detailed interrelations of rock types on South Mountain, however, suggest that the rocks are remnants of a large volcanic dome of composite origin. This concept is fundamental in all of the following discussions of alteration and ore deposition, and will be elaborated on in detail in this section.

No flow boundaries or other sharp discontinuities were seen in the scattered exposures of massive quartz latite near South Mountain in an area nearly a mile in diameter and more than 1,000 feet high. The most apparent feature in the distribution of rock types here is a subcircular area about 4,000 feet in diameter on the northeast face of South Mountain where the rocks are characterized throughout by abundant large euhedral sanidine crystals and rounded and embayed quartz grains. The rock in this subcircular area grades into the marginal rock by an abrupt decrease in the size and abundance of the sanidine crystals and a slight general decrease in the size and abundance of the rounded quartz grains. Where exposed near the summit of South Mountain, the transition between the coarsely porphyritic core and the adjacent lavas takes place within a horizontal distance of 10 or 15 feet, but at no place was a sharp contact seen. The adjacent rocks locally contain abundant large sanidine phenocrysts, but generally these are sparse and the plagioclase, sanidine, and quartz phenocrysts are all nearly comparable in size. All of the rocks in the core, and most of the rocks in the adjacent areas are massive. Indistinct flow layers were noted sporadically in the rocks along the south flank of South Mountain, and most of these dip moderately to steeply toward the core (pl. 2).

At one place along the southeastern margin of the subcircular core, a dike of coarsely porphyritic rock similar to that in the core seems from scattered outcrops to cut the adjacent massive quartz latite, and it definitely cuts the underlying Conejos flows in the vicinity of Cropsy Creek. Exposures within the area of lower Fisher rocks are too poor to determine the nature of the contact of the dike against the adjacent quartz latites.

The southern and southwestern margins of the South Mountain quartz latite mass seem to have been restricted by preexisting thick flows and breccias formed earlier in the early Fisher period of volcanism. The massive lavas underlying South Mountain are interrupted by an exposure of tuff and breccia in the headwaters of Cropsy Creek, about 3,000 feet south of the center of the subcircular area of coarsely porphyritic rock. The tuff is rudely layered and has an exposed thickness of 50 feet or more; actually it may be several times this thick. The layering in the tuff strikes about N. 75° E. and dips 60° N., and seems to project under the massive lava of South Mountain. The tuff is underlain directly by a massive quartz latite containing locally abundant large sanidine crystals. Similar rock crops out sporadically on Cropsy Peak and apparently underlies all of the ground between the local mass of tuff and the pyroxene-bearing quartz latites under Cropsy Ridge. It is nearly identical to the marginal quartz latite on South Mountain.

The quartz latitic rocks west and southwest of the summit of South Mountain are so highly altered that few original structural features can be recognized, and it was not possible to estimate even within broad limits the extent of the South Mountain lava mass in these directions. North and northeast of South Mountain all of the lower Fisher lavas marginal to the subcircular area of coarsely porphyritic rocks have been removed by erosion.

Where the margin of the subcircular area of coarse-grained porphyry is exposed, near the summit of South Mountain, the transitional zone into the adjacent quartz latites seems to be very steep—virtually vertical as far as indicated by the trace of the zone on irregular topography. On the northeast flank of the mass of coarse-grained porphyry, however, Newmont Mining Corp. in 1953, drilled a test hole intended to cut the Missionary vein (marked on pl. 2 by the sharp outward projection of the Fisher-Conejos contact at the north base of South Mountain) at depth. The hole began in Conejos flows a few hundred feet north of the Missionary vein, and was inclined southward at about 25° from the horizontal; the hole cut through about 400 feet of highly argillized and pyritized Conejos but found no Fisher, indicating that the contact in this vicinity is not steep.

Although the margin of the coarsely porphyritic core is transitional at all places where it was observed, microbreccia is common near the margin of the core and is sparse in similar rocks elsewhere. As seen in thin section, this microbreccia consists of small angular fragments a few millimeters or less in diameter which are separated by more finely broken material. The brecciation generally cannot be discerned in hand specimen, but at one place near the summit of South Mountain a few short discontinuous sheared zones 1 to 2 feet long and as much as half an inch wide were seen in coarsely porphyritic rock within 10 to 15 feet of the most abrupt change in the transitional margin. Although curved and irregular, the minor sheared zones tend to parallel the trace of the transition zone as it was mapped.

The concentric arrangement and great thickness of gradational rock types suggest that the massive lava was erupted during a single period of volcanic activity, and was heaped up around and above the vent to form a large volcanic dome. The character of the lava extruded must have changed during growth to account for the abrupt transition between the coarsely porphyritic core and the adjacent rocks. The gradational nature of the contact indicates that the marginal rocks were still soft when the coarsely porphyritic core was extruded, so the time lapse between eruption of the two rock types cannot have been long. On the other hand, the widespread microbreccia near the transitional contact indicates some difference in physical state between the rock types at the time the core rocks were extruded, as does the apparently intrusive relations of the dike of coarsely porphyritic rock on the southeast flank of the subcircular core toward the adjacent quartz latite. Perhaps these relations indicate that eruption of quartz latite took place in successive pulsations, some of which were separated by intervals long enough for the earlier lavas to cool and become more viscous before the new and slightly different lavas were forced up into the core of the dome.

The brecciated rock along the margin of the coarsely porphyritic core apparently marks a zone of structural weakness that controlled the injection of several small dikes in the vicinity of the Esmond and Little Annie workings (pl. 3). Although the dikes are younger than the period of hydrothermal activity that altered large volumes of lower Fisher rocks, they are closely localized near the margin of the core. Four of the five known dikes were injected within 150 feet of the margin as mapped, and two of these four are immediately adjacent to it. The transitional margin of the coarsely porphyritic core thus probably has a counterpart in the underlying rocks that guided the upward passage of the dike-forming materials; if the interpretation is correct that the quartz latite of South Mountain is part of a large volcanic dome, this underlying zone of weakness may be the margin of the vent through which the lavas of the dome were erupted.

Although the eruption of most volcanic domes in other regions are known or are reasonably inferred to have been preceded by intense pyroclastic activity (Williams, 1932a, p. 142), there is no evidence for any significant accumulation of tuff or other pyroclastic debris beneath the South Mountain mass. In this it is similar to the massive lower Fisher rhyodacite flows discussed previously.

The concept of a composite dome is illustrated by plate 2, a cross section showing the possible general shape and size of the body of quartz latite postulated to have stood above South Mountain. The depth of erosion, lack of exposures, and intensity of hydrothermal alteration have so obscured structural details that this cross section is of qualitative value only. The radius of the dome was drawn to conform fairly closely to the 3,000-foot distance that separates the local mass of northward-dipping tuff in the headwaters of Cropsy Creek from the approximate center of the subcircular area of the coarsely porphyritic core. The height was established by determining the approximate average ratio of diameter to height for the several large volcanic domes described by Williams (1932a). The surface width of the core is measurable; the downward constriction on the other hand, is based in part on the evidence for a flat contact on the northern margin of the core near the Missionary vein, and in part on interpretations given in detail later in the sections on ore deposits, suggesting that the localization of the mineralized veins and pipes may be related in part to the position of the margin of the vent at depth. The diameter of the vent was made intermediate between the major and minor diameters of the exposed volcanic vents in other parts of the Summitville district.

The restored parts of the dome were reconstructed by analogy with other large volcanic domes, chiefly with those in the Lassen area, California (Williams, 1932a; 1932b). Indistinct fan-type structure in otherwise massive lava similar to that in many of the Lassen domes is indicated by the few flow layers south of South Mountain that dip steeply toward the core. The marginal volcanic breccias are characteristic of most domes, and the generally flattened or truncated top is nearly as widespread. As drawn, the dome has nearly the same dimensions as the dome of Lassen Peak, about 7,000 feet in diameter and about 2,500 feet in height.

VOLCANOES OF LATE FISHER AGE

Almost all of the rocks of the upper member of the Fisher quartz latite can reasonably be inferred to have been erupted from one or the other of two vents of late

Fisher age that are exposed in the Summitville district (pl. 2). Eruptions from the two vents were separated by a period of faulting and erosion. The vent in the northwestern part of the district was drilled up along a fault that offsets lavas probably derived from the vent in the central part of the district, and the younger vent definitely cuts some of the earlier flows. The large flow related to the younger vent lies unconformably on older upper Fisher flows near its south end, and on rocks of the lower Fisher farther north.

OLDER VOLCANO

Only scattered remnants of lavas derived from the vent in the upper member of the Fisher near the center of the Summitville district are now preserved within the Summitville district (pl. 2), and it has proved almost impossible to reconstruct much of the original form of the volcano. A thick flow extended southeast across the sites of Cropsy Ridge and Lookout Mountain (pl. 1), and related flows accumulated nearer the source. A thick sequence of similar flows filled a northwestward-trending valley under present day North Mountain (pl. 1). The remnants of the older quartz latites of late Fisher age near the northwest corner of the district are so poorly exposed that their structural relations are little known.

Within the vent area, strongly flow layered pink quartz latite crops out along the precipitous upper edge of the steep slope at the west end of the South Mountain ridge. In outcrop, the rock appears to form a curved dike several hundred feet wide and more than 1,000 feet long, interrupted near the north end by another dikelike mass of somewhat similar quartz latite. The flow layers in the larger dikelike mass strike parallel to the length of the mass and dip 70°–80° E. Exposures in the eastern and southern parts of the vent complex are very poor and structural relations are obscure; the limits of the vent were estimated largely from the distribution and abundance of pink quartz latite float.

Flat-lying lava flows predominate in the remnants of lava erupted from the vent in the upper member of the Fisher near the center of the Summitville district. The remnants near the vent represent only the basal flows, which generally spread radially, and do not indicate the form or composition of the higher parts of the volcano. Flows also predominate in the thick sequence of upper Fisher lavas under North Mountain, but these are too far from the source to indicate the structure above the central vent.

The volcano apparently broke out in a hilly area near the headwaters of many radially flowing streams whose valleys guided the flows that were erupted first. The headwater area centers on the quartz latitic rocks that probably are the youngest rocks of the lower member of the Fisher quartz latite, and the hills probably are residual remnants of the last domes and flows erupted during the older period of Fisher volcanism. The South Mountain dome apparently stood high at this time, as the base of the flow remnant just north of the vent in the upper member of the Fisher is inclined northward and reaches levels well below the present summit of South Mountain (pl. 2). The upper Fisher flow remnants east and southeast of the vent are inclined generally southward, away from the area of the South Mountain dome, again suggesting that this area stood high. This conclusion is of notable geologic importance in reconstructing the possible ground-water conditions at the time the ores were deposited in the Summitville district (see "Altered and mineralized rocks").

The large flow now represented by the caprock on Cropsy Ridge and Lookout Mountain apparently filled a broad, generally southward-trending valley. At Cropsy Ridge, the base of the valley trended southeastward diagonally to the length of the present ridge so that a partial cross section of the old valley is shown. The maximum preserved relief across the valley, from Cropsy Peak to the lowest part of the valley beneath the caprock, is about 400 feet within a horizontal distance of 2,000 feet. Between Cropsy Ridge and the probable originating vent are several flow remnants of similar rock whose basal contacts show local relief as much as 300 feet within 1,000 feet. The base of the flow on Lookout Mountain was not traced carefully in the field, but from a distance it looks much flatter than is has proved to be beneath Cropsy Ridge (fig. 11).

To the north, the flows underlying North Mountain filled a northwestward-trending valley whose flanks slope 10° to 15°, as near as can be estimated from plate 1. The remnants near the northwest corner of the district are too poorly exposed and too highly faulted (see following section) for discussion of the character of the basal contact.

YOUNGER VOLCANO

All that remains of the volcano of late Fisher age centering near the northwest corner of the Summitville district is a vent complex and a remnant of a single thick flow. The vent complex is well exposed along the upper edge of a cirquelike basin near the crest of the ridge; the flow, on the other hand, is not well exposed within the area studied in detail (pl. 2), but forms a bare cliff several hundred feet high a short distance farther north (fig. 10).

Both the flow and the vent complex are made up of identical rock—a distinctive vesicular gray porphyritic rock with well-defined flow layers. The vent complex seems to be made up of many dikelike masses that formed by lava filling fissures, congealing, refissuring, and erupting again. All the rocks are closely similar and in most of the vent the individual "dikes" are difficult to distinguish by casual inspection. The flow layers within the vent area dip steeply and the strike and directions of dip vary widely within short distances. Layers and masses of obsidian are common throughout the vent area and probably formed by local chilling as the several fissures opened and were filled.

FAULTS

The main fault in the Summitville district trends diagonally northwestward across the full width of the district (pl. 2). Across South Mountain the fault is so obscured by later hydrothermal alteration that it could be traced only with difficulty, but to the northwest and southeast it can be bracketed closely. The trace of the fault on irregular topography indicates that the fault surface generally dips between 60° and 80° SW., although poor exposures along the southeastern part of the zone show the fault here to be nearly vertical. The only measurement of the inclination of the fault was made in a prospect pit in the northwestern part of the district where the dip is 60° SW. Although the amount of displacement is difficult to determine, for most of the mapped length of the fault zone the southwestern block seems to have been displaced downward several hundred feet.

Fault breccia and gouge are not abundant in most of the places where the fault can be bracketed closely. The widest zone of broken rock noted was in the prospect pit where the 60° dip was measured; at this place the fault is marked by several feet of gouge and finely granulated rock, and the walls are cut by many thin sheared zones. Elsewhere evidence suggested that a few inches to a foot of finely broken rock is more characteristic of the actual zone of displacement, and that wallrock brecciation is insignificant.

The fault breccia is locally cemented by siliceous vein material, particularly in the southeastern part of the district near the large mass of altered rocks. Several vitrophyre dikes follow both branches of the fault near the northwestern part of the district; a few of these are granulated in some degree, but others are unbroken and have healed the fault fissure.

Smaller sheared zones were seen sporadically throughout the Summitville district, but with few exceptions these could not be traced beyond the limited areas of outcrop, and their significance and general displacement could not be determined. One exception is the small northwestward trending fault that crosses Cropsy Gulch about 3,000 feet from its mouth; the base of the Fisher quartz latite here shows a vertical offset of about 100 feet, but the fault could not be traced far on either side of the displaced contact.

The main fault zone apparently has had a complex history, which will be discussed in more detail in the following paragraphs.

FISSURES FILLED BY QUARTZ LATITE DIKES

Although no single major fracture seems to have existed at the time the quartz latite dikes were injected late in the older period of Fisher volcanism, their general distribution indicates that a zone of structural weakness extended across the northwest quadrant of the district. The quartz latite dikes are largest and most abundant in a broad zone extending from near the center to the northwest corner of the district. All the larger dikes and some of the smaller ones strike northwest, whereas many of the smaller dikes and local protrusions on the larger dikes strike between west and southwest. The northwestward-trending dikes are irregular, discontinuous bodies that tend to be arranged en echelon, and most are nearly paralleled by the later major fault zone (pl. 2).

The westward- to southwestward-trending dikes also are discontinuous and locally arranged en echelon. These dikes are few and small and the fissures they follow apparently opened only during the period of dike injection as no evidence of later reactivation was seen. As some of the larger, northwestward-trending dikes show prominent southwesterly protrusions, the two sets of fissures apparently were open and active at the same time.

EARLY PERIOD OF FAULT MOVEMENT

The earliest major period of faulting clearly took place after the eruptions and igneous intrusion that formed the lower member of the Fisher quartz latite, for the massive flows are offset in the central and southeastern parts of the district, and one of the larger northwestward-trending dikes is truncated in two places by the fault. The displacement, on the other hand, preceded the major period of hydrothermal activity that altered large volumes of rock on South Mountain and the area to the south, for the altered rocks are not displaced and locally the alteration was guided by the fault zone. Rocks of late Fisher age rest undisturbed across the trace of the major fault zone on South Mountain.

The amount of displacement during the early period of movement on the major fault zone is difficult to determine because of the irregular surface at the base of the Fisher, and the complete lack of horizon markers within the lower Fisher lavas. Intersecting trial cross sections were drawn through South Mountain, and these suggest that the displacement here is about 400 feet, and that the southwest block dropped.

LATE PERIOD OF FAULT MOVEMENT

The major fault zone was reactivated in the northwestern part of the Summitville district during late Fisher time. The late movement followed at least some and perhaps all of the eruptions from the vent in the upper member of the Fisher near the center of the district, and preceded eruptions from the volcano in the northwestern part of the district. The fault zone near the northwest corner of the district split into two very steep branches, and a wedge-shaped block of pinkish quartz latite in the upper member of the Fisher was faulted down between walls of older rocks. A downward displacement of more than 600 feet is indicated for the block by the geologic map (pl. 2), but this may be somewhat in error as there are no exposures in the lower 100 feet of the area shown within the block. Thus a known displacement of at least 500 feet and a possible displacement of more than 600 feet is indicated for the younger period of fault movement.

Discontinuous black vitrophyre dikes follow both branches of the main fault zone in the northwestern part of the district. These dikes are poorly exposed, but one outcrop along the eastern branch fault indicates that the dike was injected while the fault was still active. In places the vitrophyre is massive with abundant inclusions of pinkish quartz latite; in other places long spindles of vitrophyre are strung out in the fault breccia; yet in still other places, angular fragments of vitrophyre occur in the breccia along with more abundant fragments of pink quartz latite.

The vent of the younger volcano of late Fisher age was drilled up along the eastern branch of the main fault and clearly postdates all movement on that branch. The western branch is healed in places by black vitrophyre dikes, indicating that it, too, has had no movement since late Fisher time.

ALTERED AND MINERALIZED ROCKS

Hydrothermally altered rocks are widespread in the general area embracing the Summitville district; the areas underlain by these rocks are characterized by scant vegetation and highly colored outcrops, and commonly are the most prominent features of the landscape. Bright yellowish and reddish clayey rocks are particularly apparent along the north wall of the Alamosa Creek canyon south and southeast of Summitville, where gully erosion and landslides have exposed large areas of the soft rocks on the steep slopes. Lookout Mountain (figs. 6, 11) is a particularly prominent

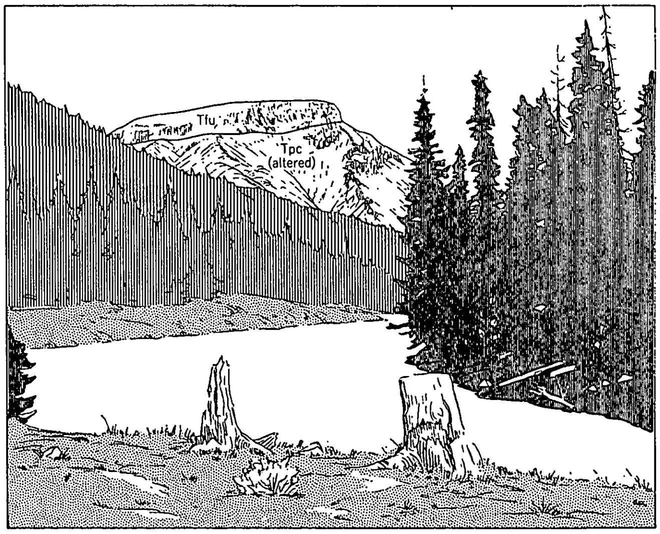

FIGURE 11.—A view of Lookout Mountain from the west. *Tpc*, highly altered Conejos flows; *Tfu*, unaltered upper Fisher flow.

landmark in this area, and has a resistant cap of unaltered lava in the upper member of the Fisher overlying bare slopes of soft highly altered Conejos rocks. South Mountain and Cropsy Peak, within the main Summitville district, also are conspicuous as they are composed largely of altered and highly colored rocks and project well above timberline and the surrounding terrain. These readily apparent areas of altered rocks attracted the earliest prospectors to the area, and old test pits, shafts, or adits can be found on almost every iron-stained outcrop in the region.

Apparently Patton (1917, p. 46–53) and others before him did not recognize that two periods of hydrothermal activity were involved in altering the large masses of rock in the general Summitville region. The present investigation has shown that the areas of altered Conejos rocks south of the Summitville district are overlain unconformably by unaltered lower Fisher rocks and thus must have been altered earlier, probably during the Conejos period of volcanism. The altered rocks underlying South Mountain and adjacent areas, however, clearly were altered during the Fisher period of volcanic activity, between eruption of the lower and the upper members.

The alteration during both periods of hydrothermal activity was of the "solfataric" type, in the sense that term was used by Burbank (1950, p. 291) for a dormant or decadent stage of volcanic activity characterized by the emission of gases and vapors. This type of alteration is characteristic of shallow volcanic environ-

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ments where escaping volatile constituents, mixed in different degrees with meteoric waters, change the original rocks to various aggregates of sericite, chlorite, clay minerals, sulfates, quartz, opal, and other minor alteration products. Metallic minerals containing gold, silver, copper, lead, and zinc are commonly deposited in association with the altered rocks, and locally form high-grade concentrations of the bonanza type.

ROCKS ALTERED DURING CONEJOS TIME

The large masses of intensely altered rocks flanking Alamosa Creek and its tributaries along the southern margin of the Summitville district (pl. 1) were clearly altered prior to the eruption of the Fisher quartz latite for unaltered lower Fisher lavas rest directly upon them. The largest of these masses of altered rocks, with a surface area of slightly more than 6½ square miles, is localized along the northern margin of a quartz monzonite stock of presumed Conejos age (Cross and Larsen, 1935, p. 74; Larsen and Cross, 1956, p. 102), and it seems likely that the alteration resulted from emanations given off by the intrusive body as it cooled and crystallized. Most of the areas underlain by rocks altered during Conejos time are outside the area mapped in detail (pl. 2), and the altered rocks were studied carefully at only a few places in the field and not at all in the laboratory.

Most of the rocks are soft and highly colored, and lack the highly silicified bodies that characterize some areas of rocks altered during Fisher time (see following sections). According to Patton (1917, p. 46–53), kaolin, sericite, alunite, and quartz are the most common constituents in the altered rocks along Alamosa Creek and under Lookout Mountain, although he recorded no information on the general distribution or relations of the different products.

Exposures near the old caved mine workings in the Stunner and Gilmore districts and at the Pass-Me-By mine indicate that local concentrations of pyrite are disseminated through both soft clayey rocks and slightly silicified rocks and constitute the most common mineral deposits. At places, particularly near the margins of the large mass of altered rocks, the pyrite seems to be more concentrated along joints or other fractures, and locally seams of pyrite were noted in cracks in virtually unaltered rocks several feet from bleached and clayey zones. The pyritic rocks weather to blotchy reddish rocks at the outcrop, and limonitic spring deposits are abundant in the same general areas.

The small tributary streams that drain from the highly altered areas to Alamosa Creek have a high mineral content, and the boulders in the stream beds are commonly coated by limonitic crusts. The mineral content in many of the waters is apparent to the taste, which led the early prospectors to apply such names as Alum Creek and Bitter Creek to some of the streams. Four analyses of water from these tributaries were given by Patton (1917, p. 49), and are shown below:

TABLE 4.—*Analyses of waters from streams tributary to Alamosa Creek*

[Analyses given in parts per million; from Patton, 1917, table 1]

	Alum Creek	Branch of Alum Creek	Iron Creek	Bitter Creek
Volatile [1]	240. 75	1, 189. 0	48. 5	44. 6
SiO_2	70. 5	328. 0	29. 5	29. 5
Fe_2O_3	244. 6	1, 784. 6	87. 1	14. 9
Al_2O_3	63. 0	439. 0	19. 0	31. 4
CaO	43. 8	91. 0	15. 5	21. 7
MgO	7. 5	87. 0	8. 1	16. 0
SO_3	633. 5	3, 813. 0	145. 1	129. 3
Total	1, 303. 65	7, 731. 6	352. 8	287. 4

[1] The constituents represented by this item are not known.

The high mineral content in Alum Creek and its tributaries reflects the fact that these streams derive most of their waters from areas underlain by highly altered rocks, whereas Iron Creek and Bitter Creek head in areas of unaltered rocks and pass through more highly altered terrains along their lower courses. The mineral content in all of the streams, including Alamosa Creek, is so high that they are virtually devoid of fish within and for long distances below the areas of altered rocks.

ROCKS ALTERED DURING FISHER TIME

The largest mass of rocks altered during Fisher time in the Summitville district is exposed over an irregular area of about 1⅓ square miles, extending from the north base of South Mountain south to Cropsy Ridge and southwest to the lower slopes above Schinzel Meadow (pl. 2). The alteration was limited largely to the area underlain by the quartz latitic lavas of the lower member of the Fisher quartz latite and took place during an intravolcanic solfataric stage that was of long enough duration to permit intense alteration of large masses of rock and for erosion to cut deeply in the older volcanic pile, but still sufficiently brief for the succeeding upper Fisher lavas to show definite resemblances to the older presolfataric rocks.

The northern lobe of the area of altered rocks is nearly coextensive with the large volcanic dome that is postulated to comprise most of the mass of South Mountain (see "Structure"), and the most intensely altered and mineralized rocks lie near one margin of the coarsely porphyritic core of this structure. The detailed discussion of altered and mineralized rocks in the following sections refers almost entirely to this center of hydrothermal activity.

Other local centers of hydrothermal activity occur in the central and southwestern parts of the area of rocks altered during Fisher time (pl. 2). The ridge crest extending northwest from Cropsy Peak is underlain by some of the most intensely altered rocks in the Summitville district. Much of the rock here was converted to a soft yellowish to white clay that retains little of the original texture of the rock. Locally, masses as much as several hundred feet across were replaced almost entirely by opal, and the original rock texture can still be recognized in parts of these masses. No structural control was discerned for this local center of intense alteration.

Much of the rock in the southern and southwestern parts of the large mass of altered rocks is soft and clayey, similar to but perhaps somewhat less intensely altered than the rock along the ridge crest northwest of Cropsy Peak. The irregularly lobate enlargement at its southwest end of the area of altered rock contains some intensely silicified and mineralized rocks similar to those in the metal-bearing quartz-alunite bodies on the northeast face of South Mountain. These are poorly exposed and their detailed geologic relations are virtually unknown.

Two smaller areas where alteration has affected rocks of Fisher age were noted in the western part of the area covered by the reconnaissance survey around the Summitville district (pl. 1). In each of these places the alteration has modified both Fisher and older rocks belonging to the Potosi volcanic series, and the altered rocks are associated with small intrusive bodies of coarsely porphyritic quartz latite similar to the rock in the core of the volcanic dome of South Mountain.

The northernmost of these marginal areas of altered rocks is located near the western margin shown on plate 1 almost due west of Summitville. The altered rocks occur along and near a fault, and the alteration of Fisher age evidently was superimposed in part at least, on rocks that already were altered, presumably some time during the period of eruption of the Potosi volcanic series. Relations are complex, and, as the area was mapped hurriedly, the following account may be incomplete in some respects. Toward the west, Potosi rocks are thoroughly and pervasively bleached and altered on both sides of the fault, but are overlain by and are in fault contact with virtually unaltered Fisher quartz latite (pl. 1). To the east, pervasively altered rocks cut indiscriminately across formation boundaries, and Fisher quartz latite on both walls of the fault has been modified. At one place a small intrusive mass of Fisher quartz latite is located on the trend of the fault, but poor exposures in critical places obscure its relations. Silicified and pyritized vein material was noted at several places along the fault, even in areas where the nearby Fisher quartz latite is virtually unaltered, and in most such places the veins in turn are sheared and slickensided in some degree. These relations suggest that the first fault movements took place during or after eruption of the Potosi series, and in part guided an early period of hydrothermal alteration which affected only Potosi rocks in this vicinity. Lower Fisher lavas covered an erosion surface cut across the older rocks, and were in turn displaced by reactivated movements on the fault. Hydrothermal activity of Fisher age caused renewed alteration near the east end of the fault, and deposition of vein materials locally farther west. Minor fault movements continued after most of the alteration and vein deposition ceased.

The southernmost of the marginal areas of altered rocks is southwest of Summitville, near the west margin of the area shown on plate 1. The rocks in this area are generally less intensely altered than those in the northernmost mass, and they seem to have had a less complex history. Although most of the altered rocks now exposed belong to the Potosi volcanic series, the alteration definitely modified Fisher rocks along the north edge of the altered area, and small intrusive bodies of typical Fisher aspect are located near the west margin.

Vuggy silicified and pyritized masses similar to the gold- and copper-bearing quartz-alunite bodies in the Summitville district were noted in both of these marginal areas of altered rocks. Although most of the bodies seen are small—only a few feet wide and a few tens of feet long at the most—they are intensely altered and appeared from casual observations to warrant closer inspection than time permitted during the reconnaissance survey. Small pits have been dug on many of these silicified and mineralized masses, but no evidence of intensive prospecting was seen.

LIMITS AND SCOPE OF ALTERATION STUDY

The detailed field study of the altered and mineralized rocks in the Summitville district was confined to the main productive area on the northeast face of South Mountain (pl. 3), and was limited to observations of surface exposures and rock materials from the mine dumps. The inaccessibility of the underground workings and consequent lack of information regarding changes in alteration and ore mineralogy with depth, constitutes an important limitation on this study. In addition, less than 10 percent of the area shown on the retailed geologic map of the vein zone (pl. 3) is outcrop; the remainder is covered by soil and vegetation, talus, and mine dumps.

The detailed field mapping has been supplemented by microscopic studies of thin sections of the altered rocks, and of polished sections of ore specimens. X-ray identification of alteration minerals and ore minerals has been utilized where necessary. Some information on the altered rocks and mineralogy of the ores has been taken from Patton's report (1917) on the geology of the Summitville district.

Emphasis in this study therefore has been focused on the description of the altered and mineralized rocks, their mineralogy and gross paragenetic relations. Without data on the composition and behavior of the altered rocks in depth, the discussion of the processes and physical-chemical conditions of the alteration environment is of necessity conjectural.

STRUCTURAL SETTING

The ore deposits in the main productive area of the Summitville district occur in a series of irregular pipes and veinlike masses of quartz and alunite (pl. 3) that formed largely by replacement of the original quartz latite. The gross distribution of the mineralized bodies suggests that the replacement took place locally along a zone of intersecting fissures within the postulated volcanic dome of South Mountain. Most of the more tabular veins trend northwest, about parallel to the regional trend of fracturing in the Summitville district, and they probably are localized closely above the buried conduit through which the dome was extruded.

The larger elongate quartz-alunite bodies follow two northwestward striking trends (pl. 3). The Little Annie, Tewksbury, Black Wonder and related veins strike generally N. 25–35° W. whereas the Hidden vein and the large mass of highly silicified rock extending northwest from the Copper Hill knob trend about N. 55° W. Some of the more prominent projections on the larger quartz-alunite bodies suggest local control by northeastward-trending fissures, and many smaller bodies appear somewhat elongate along this same trend. Replacement along all of these fractures was spotty and irregular, and the discontinuous quartz-alunite bodies that were formed have extremely complex shapes.

The distribution of the elongate quartz-alunite bodies does not indicate that any single fissure was dominant, and the transitional boundary between the coarsely porphyritic core of the South Mountain volcanic dome and the marginal quartz latites shows no apparent offset where transected by the mineralized zone. Evidently little if any displacement took place along the fractures that later guided the altering and mineralizing hydrothermal solutions.

Several lines of evidence suggest that the mineralized quartz-alunite bodies are further localized above one margin of the buried conduit that fed the South Mountain volcanic dome. As shown on plate 3, the zone containing these bodies extends diagonally across the southwest margin of the coarsely porphyritic core of this dome. The zone centers within this core and the larger masses of quartz-alunite do not extend far beyond the margin of the core. The concentric arrangement of rock types within the postulated dome suggests that the feeding pipe is centrally located beneath the coarsely porphyritic core, and the sparse centripetally arranged flow structures in the adjacent quartz latites suggests that the pipe may have a smaller diameter than this core. A restricted diameter for the pipe is further suggested by the flat contact beneath the coarsely porphyritic rocks at the north base of South Mountain, as indicated by the hole drilled by Newmont Mining Corp. beneath the Missionary vein (see "Structure"). The transitional margin of the coarsely porphyritic core shows evidence of structural weakness that occurred several times during Fisher volcanism. The microbreccia found near this margin probably marks a poorly defined structural discontinuity that formed during the development of the dome, and probably reflects slight differences in the consistency of the material extruded at different times through a centrally located vent. The latter introduction of dikes of probable late Fisher age along the west margin indicate that this zone of structural weakness extends deep enough to have guided igneous intrusion.

These interpretations are illustrated diagrammatically on plate 2, which shows the mineralized quartz-alunite bodies within the body of the South Mountain volcanic dome. The Copper Hill knob, near the middle of the mineralized zone, is located above the postulated southwest margin of the conduit through which the dome was extruded, whereas other vein locations are not so closely controlled. The primary hydrothermal solutions responsible for altering and mineralizing the rocks in the main productive area in the Summitville district thus may have been guided at depth by the volcanic neck through which the quartz latites of South Mountain were erupted. At higher levels they reached the northwestward-trending fissures and spread out along them, altering and mineralizing the adjacent rocks.

DESCRIPTION OF ALTERED ROCKS

The most intensely altered rocks in the main productive area of the Summitville district form resistant quartz-alunite masses that mark the veins in the district. Parts of the resistant veins have been strongly leached and consists of vuggy, porous quartz; elsewhere compact quartz has replaced most of the constituents in the original rock. Ore minerals, largely pyrite and enargite, are generally concentrated in the leached, porous rock.

The resistant quartz-alunite bodies are commonly surrounded by irregular envelopes of soft highly argillized ground. Although locally absent, these envelopes generally range from a few inches to 10 feet or more in thickness. Illite [2] and montmorillonite are the most common alteration products in the argillized envelopes, and in places greatly predominate. Locally, however, the innermost parts of the envelope contain abundant kaolinite and the argillized rocks can be split into poorly defined illitic and kaolinitic subzones. The strongly argillized rocks grade outward into the generally less altered marginal rocks.

The intensely altered quartz-alunite bodies and their argillized envelopes are surrounded by creamy yellow or greenish-gray, slightly to moderately altered rocks that form the bulk of South Mountain. These rocks weather to slabby blocks that form extensive talus piles on all of the steeper slopes. The rocks in this marginal area of alteration are characterized by the fresh appearance of their phenocrysts and the dominance of montmorillonite and chlorite minerals among the alteration products of the groundmasses.

QUARTZ-ALUNITE ZONE

The quartz-alunite zone as here defined consists of all the resistant quartzose bodies that mark the veins in the Summitville district. These bodies clearly formed by replacement of the original quartz latite, and relict textures can be recognized almost everywhere. In places the rocks consists of compact aggregates of quartz and alunite (quartz-alunite rock) (pl. 6) with the quartz largely in the matrix of the original quartz latite, and the alunite as pseudomorphs of the feldspar phenocrysts. Elsewhere quartz greatly predominates. It locally forms solid, fine-grained aggregates (compact quartz rock) that have replaced both the groundmass and the phenocrysts of the original rock, but elsewhere it forms porous, vuggy masses (vuggy quartz rock) in which spongy quartz represents the replaced matrix and most of the vugs are casts of the original phenocrysts (pl. 6). The sulfide minerals are commonly concentrated in the porous, leached rock (primary ore deposits) where they form spongy aggregates and encrustations within the voids.

[2] In this report, illite is used as a general term in the sense defined by Grim (1953, p. 36; 68–69) for "a mica-type clay mineral with a 10-*A* *c*-axis spacing which shows substantially no expanding-lattice characteristics" (p. 36). Most of these materials are apparently intermediate in composition between montmorillonite and muscovite or biotite (p. 68–69). Yoder and Eugster (1955, p. 253–254) have shown that many of the materials within this general group have mixed-layer structures and are not members of a specific solid-solution series.

DISTRIBUTION OF ROCK TYPES

The distribution of the several rock types within the quartz-alunite zone is erratic, but a few generalizations can be made. The larger bodies of strongly leached vuggy quartz rock are generally surrounded by less porous quartz-alunite rock. In the more elongate bodies, such as the Little Annie vein and the Hidden vein (pl. 3), the vuggy quartz rock greatly predominates, and the bodies have only a thin layer of quartz-alunite rock along the margins; irregular, erratically distributed masses of quartz-alunite rock are common within the strongly leached rock, however. Quartz-alunite rock is generally more abundant in the larger silicified masses, and locally is the predominant rock type. Within the large silicified mass extending northwest from the Copper Hill knob, the vuggy quartz rock occurs as irregular local masses that in places are centrally located but elsewhere occur near one or the other margin of the enclosing quartz-alunite rock. In the large knobby exposure of the Tewksbury vein, on the other hand, the vuggy quartz rock forms a centrally located elongate mass that generally parallels the trend of the silicified mass as a whole. Strongly leached and vuggy rock is common along joints in most of the masses of quartz-alunite rock, and many small local bodies of it occur at joint intersections.

Compact quartz rock is found chiefly in the large silicified masses such as the Copper Hill knob and the outcrop of the Tewksbury vein. The distribution in outcrop suggests that these masses may form discontinuous siliceous caps above more normal quartz-alunite and vuggy quartz rocks. A brief examination was made of the Copper Hill tunnel late in the summer of 1953 when the ice at the portal had melted sufficiently to permit entrance. Although this level passes directly beneath an area where nearly solid quartzose rocks are abundant at the surface, these rocks were not seen in the walls of the tunnel, which are composed largely of quartz-alunite and vuggy quartz rocks containing local zones of soft argillized rock. At the surface the compact siliceous rocks are most abundant toward the center of the large siliceous masses where they are commonly associated with the strongly leached, vuggy rocks.

The ore deposits are closely associated with the vuggy quartz rocks. Most of the original sulfides have been oxidized near the surface, where the "ore" appears as limonite-stained and encrusted vuggy quartz. The fragments of primary ore seen on dumps show pyrite, enargite, and locally native sulfur as fillings and encrustations in the pores and vugs. Although the ore deposits are closely associated with the leached, vuggy quartz rocks, not all of the vuggy quartz is strongly mineralized. Much of the vuggy quartz seen at the surface is virtually devoid of limonite, and the mine dumps show considerable unoxidized vuggy quartz rock that has only minor associated sulfide minerals. So little ore was seen in place that no quantitative estimates can be made of the proportions of strongly mineralized and barren vuggy quartz, nor can anything be postulated about their distribution.

QUARTZ-ALUNITE ROCK

The quartz-alunite rocks preserve many features of the original coarsely porphyritic texture of the quartz latite (pl. 6). The matrix is a fine-grained gray siliceous aggregate composed largely of quartz but also containing variable quantities of fine-grained alunite, and the feldspar phenocrysts commonly are pseudomorphed by pearly pink to white alunite aggregates. The original rounded quartz phenocrysts are preserved almost intact. These rocks grade into the strongly leached, vuggy quartz rocks toward the central parts of the quartz-alunite zone, on one hand, and into the soft rock of the surrounding argillic envelopes on the other.

The matrix of the original quartz latite has been changed to variable mixtures of quartz and alunite, and subordinate amounts of pyrite, rutile, zircon, and local opaline silica (pl. 6). Weathered quartz-alunite rocks commonly contain in addition abundant limonite and jarosite, as well as smaller quantities of diaspore and allophane. As seen in thin section, irregularly interlocking quartz grains are always present and generally range between a few hundredth and a tenth of a millimeter in diameter. Numerous irregular patches of somewhat coarser grained quartz occur locally, and under the microscope the matrix appears uneven.

In some rocks, alunite is intimately intergrown with the granular quartz in the matrix, but more commonly it occurs as tiny rectangular laths irregularly interspersed with the mosaic of quartz grains like sticks of wood among the cobbles of a beach. In many rocks, alunite is virtually absent from the matrix, but it is abundant in the replaced feldspar phenocrysts.

Pyrite is widely disseminated in the matrix of the quartz-alunite rock; in places it appears to be pseudomorphous after magnetite-ilmenite grains or it forms local concentrations near former ferromagnesian phenocrysts, but many of the grains show no evidence of their origin. Sparse fine grains of rutile occur sporadically in the matrix, but are in greatest concentration near former biotite, amphibole, or sphene crystals.

Fine grains of zircon occur in the silicified matrix; these have the same general appearance, abundance, and distribution as the zircon in unaltered quartz latite, and apparently have persisted through chemical alteration.

Among the former phenocrysts, only the rounded and embayed quartz grains have withstood the hydrothermal alteration without apparent change. The original ferromagnesian phenocrysts are now reflected by concentrations of secondary minerals which commonly preserve the original crystal outlines. Former sphene and amphibole crystals can be detected under the microscope in thin or polished sections by lacy skeletons of rutile, leucoxene, or pyrite; original biotite, and less commonly amphibole, have altered largely to alunite, pyrite, rutile, and quartz. The feldspar phenocrysts have been altered chiefly to alunite, which forms pseudomorphic aggregates that clearly reflect the shapes of the original crystals (pl. 6). Individual crystals in the alunite aggregates are long tapering rhombohedrons, bounded sharply by basal pinacoidal planes, and commonly arranged like jackstraws within the confines of the replaced phenocrysts (pl. 6). The alunite crystals commonly contain numerous tiny inclusions of quartz(?) and barite(?), and the triangular-shaped interstices between the intersecting, jackstrawed laths may be filled with quartz, opaline silica, or rarely with illite, kaolinite, or diaspore. Locally, particularly near masses of strongly leached, vuggy quartz, the alunite laths may project into open holes, or form porous aggregates of bladed crystals.

The alunite in the quartz-alunite rock is sodium bearing, although it does not contain enough to be called natroalunite. A chemical analysis of typical quartz-alunite rock (table 7) indicates 0.58 percent Na_2O, and alunite is the only mineral present that can contain it in any significant quantity. The Na_2O (0.58 percent), K_2O (1.80 percent), and SO_3 (8.34 percent) detected by the analysis are nearly in the proportions required by alunite, and the relative proportions of the alkalies indicate about 25 percent substitution of sodium for potassium. Possible errors derived from SO_3, contained in jarosite or other sulfates, or K_2O in illite or related minerals, have been neglected in these rough calculations as these minerals are generally sparse in the quartz-alunite rocks, and the errors would tend to be compensating. An analysis of impure alunite from one of the pseudomorphic feldspar casts (table 5) contains Na_2O and K_2O in the approximate ratio of 28 : 72, which accords closely with the approximate ratio of 27 : 73 obtained from the spectrographic analysis of a duplicate sample (table 6). The only minerals known to be present in this sample were alunite, quartz, kaolinite, and probably minor pyrite and jarosite, and it is likely that most of the alkalies are contained in the alunite. Other Na_2O–K_2O ratios indicated by the analyses of alunite from the Summitville district are 40 : 60, 29 : 71, and 14 : 86 (table 6). The indices of refraction of the alunite with the Na_2O–K_2O ratio of 28 : 72, as determined in sodium light, are $N_o = 1.578 \pm 0.002$ and $N_e = 1.597 \pm 0.002$.

TABLE 5.—*Chemical analysis of an impure specimen of alunite from the Summitville district*

[Standard rock analysis; field No. Sd-Sci 1; laboratory No. C501; analyst, Lucile N. Tarrant]

	Percent
SiO_2	39.00
Al_2O_3	23.21
Fe_2O_3	.16
MgO	.00
CaO	.00
Na_2O	1.19
K_2O	4.53
H_2O-	.00
H_2O+	7.92
TiO_2	.05
SO_3	[1] 23.36
BaO	.07
Total	99.49

[1] Calculated from total sulfur. It was assumed that all sulfur is present as SO_3.

Many alunite crystals and aggregates contain very small inclusions believed to be barite. These form square to rectangular colorless crystals only a few thousandths of a millimeter across that are best seen under very high magnification using an oil immersion lens; their index of refraction is above that of the enclosing alunite, and their birefringence is masked by that of the host. Spectrographic analyses of four specimens of alunite scraped from pseudomorphic aggregates after feldspar (table 6) detected 0.15 to 0.7 percent Ba. These figures are probably not precise, as a duplicate of one of the samples (Sd–Sci 1) was analyzed chemically (table 5) and only 0.07 percent BaO was detected in contrast to the 0.15 percent Ba indicated by spectrographic methods. However, both the chemical and spectrographic analyses indicate that sufficient barium is present to support the suggestions from crystal form and meager optical data that the minor inclusions are barite. A quantitative spectrographic analysis of an unaltered sanidine phenocryst showed 0.3 percent barium, indicating a readily available source of this element (table 6).

Table 6.—*Quantitative spectrographic analyses of alunite and sanidine from the Summitville district*

[General spectrographic analyses; analyst, Paul R. Barnett]

Material analyzed	Field No.	Laboratory No.	Na	K	Ba	Approximate ratio $Na_2O:K_2O$
Alunite	Sd-Sci 1	C497	1.5	4	0.15	27:73
Do	Sd20A	C498	2	3	.6	40:60
Do	Sd28	C499	2	5	.7	29:71
Do	Sd148d	C500	.8	5	.3	14:86
Sanidine	Sa-1	C535			.3	

VUGGY QUARTZ ROCK

Typical vuggy quartz rocks have been flushed clean of all constituents other than quartz, pyrite, rutile and a few zircon grains. The rocks are cavernous where leaching has removed most of the material from the casts of the original feldspar phenocrysts (pl. 6). The matrix ranges from porous to compact, and the textures closely resemble those shown by the fine-grained quartz mosaic in the matrix of quartz-alunite rocks.

Most of the larger voids in the vuggy quartz rocks are modified rectangular casts of former feldspar crystals. These depart from idealized casts by irregular corrosion of the adjacent quartzose matrix; by linings, irregular growths, and skeletal fillings of euhedral quartz crystals; or more commonly, by both. In addition, the quartzose matrix commonly is somewhat spongy and contains abundant irregularly distributed small pores and holes. As seen under the microscope, these small pores are very complexly shaped, and have cuspate margins and irregularly attenuated projections that do not resemble casts left by leaching of individual mineral grains. Where the matrix is particularly porous, many of the holes are lined and partly filled with euhedral quartz crystals similar to those found in the feldspar casts. Locally the vuggy quartz rocks show the effects of recurrent brecciation and rehealing, and several specimens showed breccia fragments that contain abundant feldspar casts contained in a compact siliceous matrix, which in turn is corroded and vuggy along later fracture zones.

Euhedral to subhedral pyrite crystals commonly are widely disseminated through the matrix of the vuggy quartz rocks. Rutile ranges from erratically disseminated granules to lacy skeletons and outlines of former sphene and amphibole crystals. Sparse, apparently relict zircon grains also are widely scattered.

Although the vuggy quartz rocks typically have voids in the same places where alunite crystals are common in the quartz-alunite rocks, the available evidence seems inconclusive that any given piece of vuggy quartz rock once had alunite in the voids. Many of the smaller pores in the matrix, as well as some of the margins of the feldspar casts, are irregular in minor detail, presumably from the effects of chemical leaching. At no place were we able to agree that the pores reflected casts of former alunite crystals.

Although we are not in complete accord as to the detailed time-space significance of certain of the textural features of the vuggy quartz rocks, we both believe that some of the voids probably represent leaching of the original phenocrystic materials, and other voids probably once contained alunite. These interpretations will be discussed more fully in subsequent sections on the course of the solfataric alteration.

COMPACT QUARTZ ROCK

Compact rocks consisting largely of quartz are most abundant in the upper parts of the larger bodies in the quartz-alunite zone, where they commonly are closely associated with leached, vuggy quartz rock. The compact quartz rocks range from mottled rocks that generally reflect the original porphyritic texture of the unaltered quartz latite, to nearly massive finely granular gray quartz rocks, and to irregularly layered aggregates of fine-grained quartz along joints or fissures. Most of the larger masses of compact quartz rock are erratically vuggy where silicification was locally incomplete.

In thin section, the texture of the compact quartz rocks closely resembles that of the matrix in vuggy quartz rocks. The fine mosaic of quartz grains in the matrix is similar to that in the other rocks in the quartz-alunite zone; that in the replaced feldspar phenocrysts is commonly somewhat coarser, however, giving a slight contrast in appearance in hand specimen as well as thin section. Besides quartz, only the more inert minerals such as rutile and zircon have persisted through alteration. As in the other rocks in the quartz-alunite zone, the rutile commonly reflects the crystal outlines of the original ferromagnesian crystals, from which it apparently represents the insoluble residue. The zircon grains appear virtually the same as those in unaltered quartz latite, and probably are relict.

The compact quartz rocks are the only ones within the area of altered rocks studied in detail (pl. 3) that show much evidence for introduction of rock-forming constituents other than water, sulfur, iron, and copper during hydrothermal alteration. Where the original porphyritic texture can still be recognized, compact, finely granular quartz forms the matrix, and either replaced or filled casts of the original feldspar phenocrysts, indicating a positive addition of silica. The layered granular quartz found along many of the joints apparently was deposited as successive encrustations along fractures, also indicating movement and deposition of silica during alteration.

PRIMARY ORE DEPOSITS

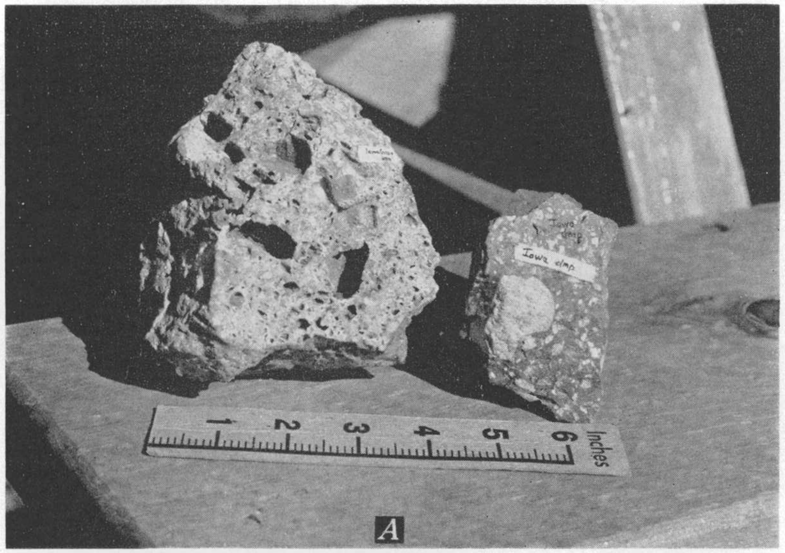
Except for the disseminated pyrite found in most rocks of the quartz-alunite zone, the primary ore minerals are closely associated with vuggy quartz rocks. Pyrite and enargite are the most abundant ore minerals; native sulfur, barite, galena, sphalerite, and gold are minor accessory ore minerals. They occur largely in voids and along fractures; the minerals show complex paragenetic relations and are erratically distributed.

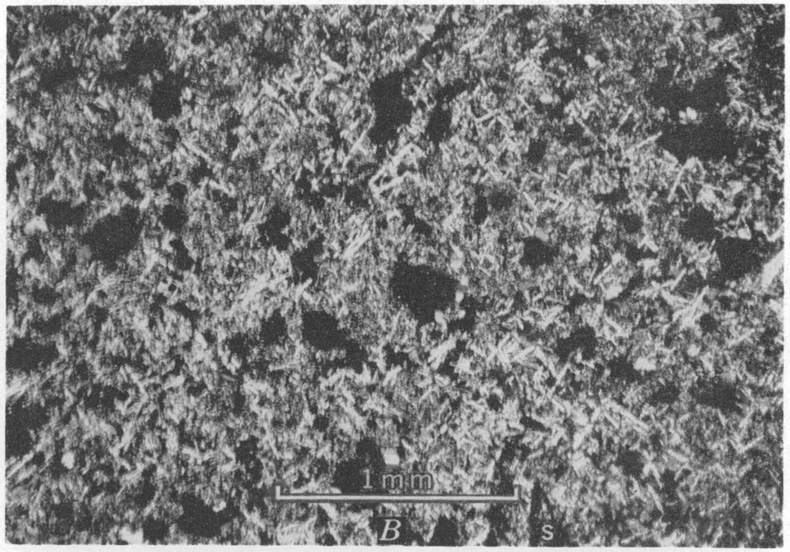
As the present investigation was limited almost entirely to surface exposures, no comprehensive study of the distribution of the ore minerals has been possible. Ore specimens were collected from many of the mine dumps, and 26 polished sections of the ore were studied under the microscope. The limited number of specimens probably does not provide a representative sample of the ore deposits as a whole, and without specific information on the individual specimens only limited interpretations can be drawn from them. The minerals identified probably include the main constituents of the ores, but certainly cannot be presumed to be a complete list. More important, the character of our information precludes generalizations concerning the distribution of the various constituents in the ores.

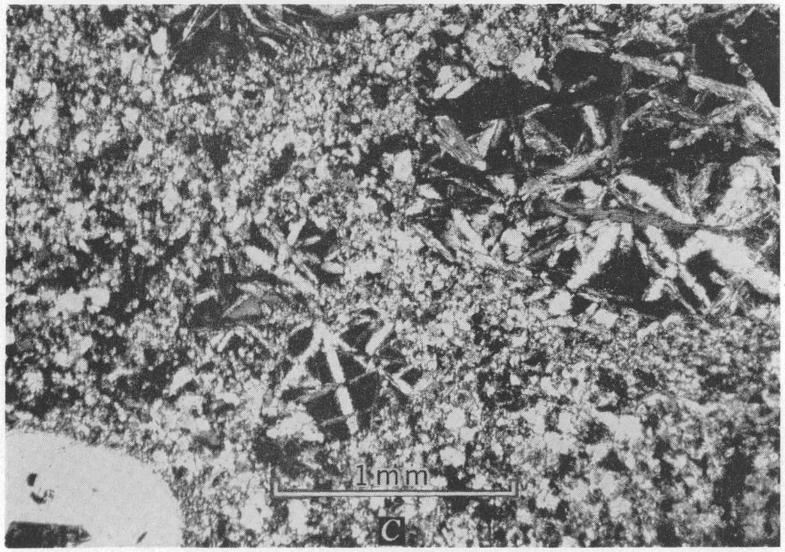
Pyrite seems to be the most widespread ore mineral; it occurs as widely disseminated grains tightly enclosed in the fine-grained quartzose matrix of the different rocks in the quartz-alunite zone, and in addition it forms massive to granular aggregates that fill or partly fill voids in much of the leached, vuggy quartz rock. Enargite, native sulfur, and other less common ore minerals, on the other hand, were seen only in voids and along fractures in vuggy quartz rock. Hypogene barite was seen in many of the ore specimens where it is associated with the ore minerals as fillings in voids and fractures. Covellite, chalcopyrite, and some of the barite are probably of secondary origin, and will be discussed in the section on supergene alteration.

The most fundamental distinction made with respect to the ore minerals was between the grains tightly enclosed in the quartz matrix, and those deposited in the open spaces in the vuggy quartz rock. This distinction is not everywhere easy to make as pyrite, which is the dominant ore mineral in the first class is also the most common in the second, and in many specimens the pyrite grains cannot be assigned with confidence to either. More commonly, however, the gross distinction is clear cut as indicated by the occurrence and associations of the various ore and gangue minerals.

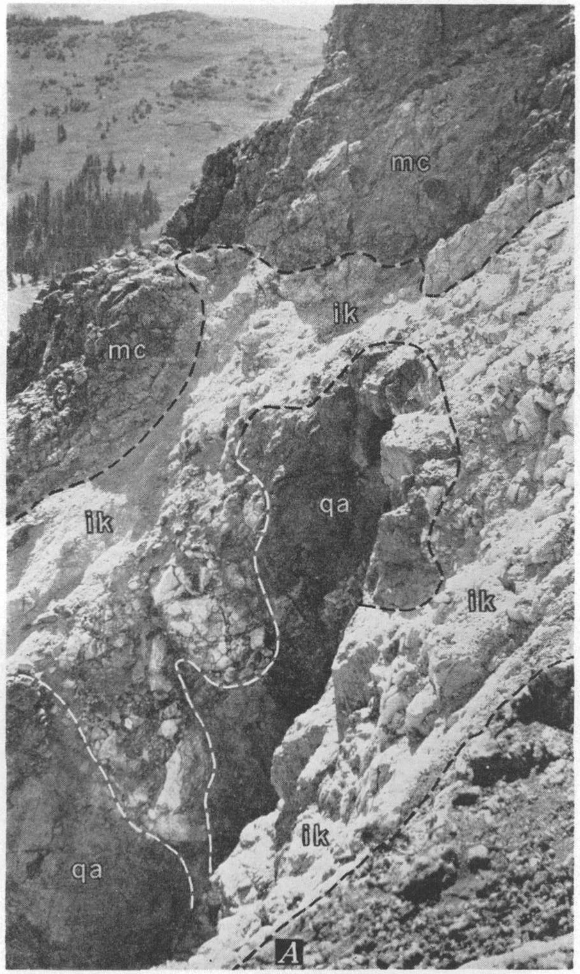
Pyrite crystals tightly enclosed in the quartz matrix generally are widely disseminated, and locally form concentrations that reflect the outlines and internal structures of former biotite and hornblende crystals. Some disseminated grains may be pseudomorphs of original magnetite-ilmenite grains, but no positive evidence for this was seen; more commonly the grains form a random pattern with sporadic concentrations along the margins of fractures or other locally more permeable zones. Pyritohedrons and octahedrons can

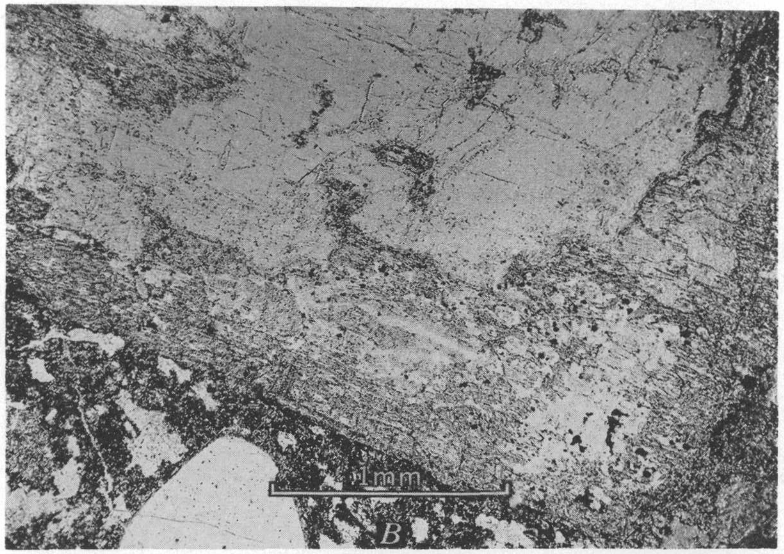


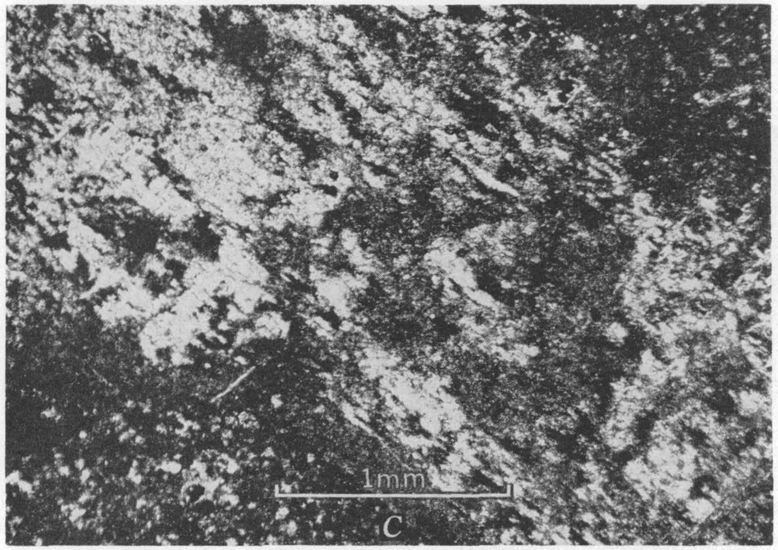




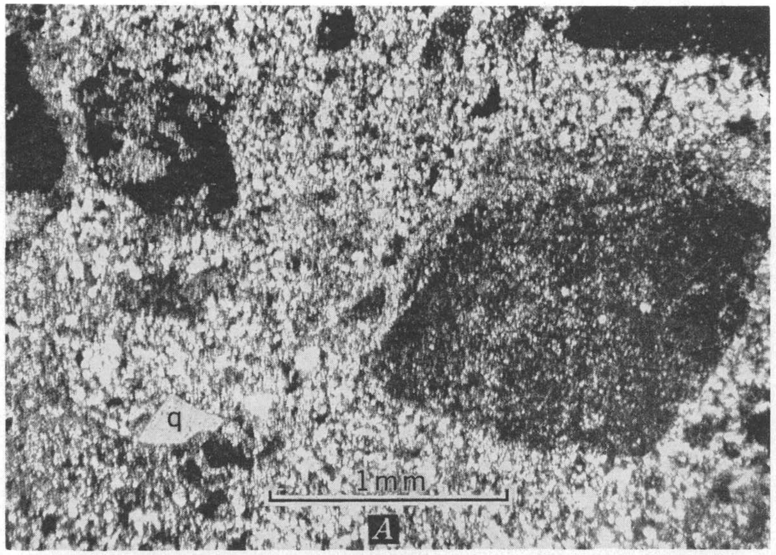
A. Typical rocks of the quartz-alunite zone. Specimen at right is quartz-alunite rock containing alunite pseudomorphs of feldspar phenocrysts enclosed in a matrix of fine-grained quartz and alunite. Specimen at left is vuggy quartz rock; original feldspar phenocrysts are represented by empty casts and the matrix by a porous aggregate of fine-grained quartz. Ore minerals commonly occur in the voids in this type of rock. *B*. Photomicrographs cf fine-grained quartz-alunite rock. The rock consists of finely granular quartz (gray) and tabular crystals of alunite (white). The dark crystal(s) at bottom of picture is an altered sphene crystal consisting of quartz and alunite and a drak border of "leucoxene" and rutile. Other dark areas are pores in the rock. Crossed nicols, × 31. *C*. Photomicrograph of quartz-alunite rock showing relict porphyritic texture. Aggregates of tabular alunite crystals mark former feldspar phenocrysts. Matrix consists chiefly of interlocking quartz grains and minor alunite (white or gray); dark patches in the matrix represent irregular aggregates of "leucoxene," rutile, limonite, and jarosite. Rounded quartz phenocryst in lower left corner is unaltered except for a thin recrystallized border. Crossed nicols, × 31.

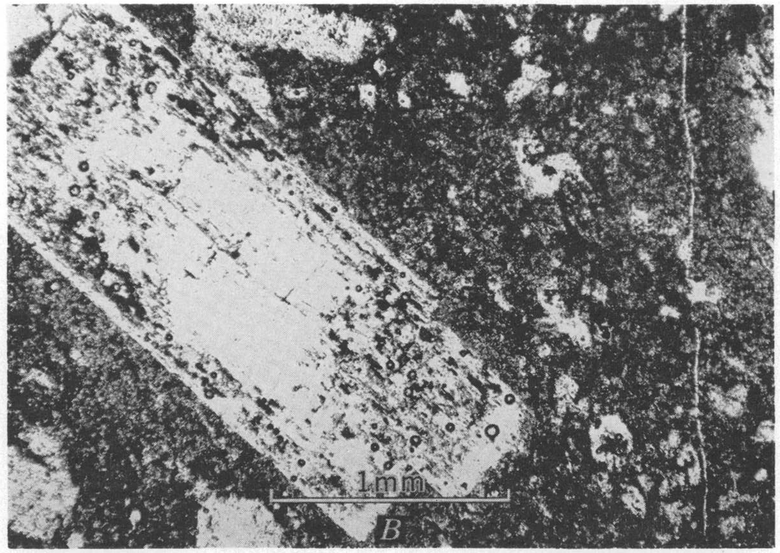


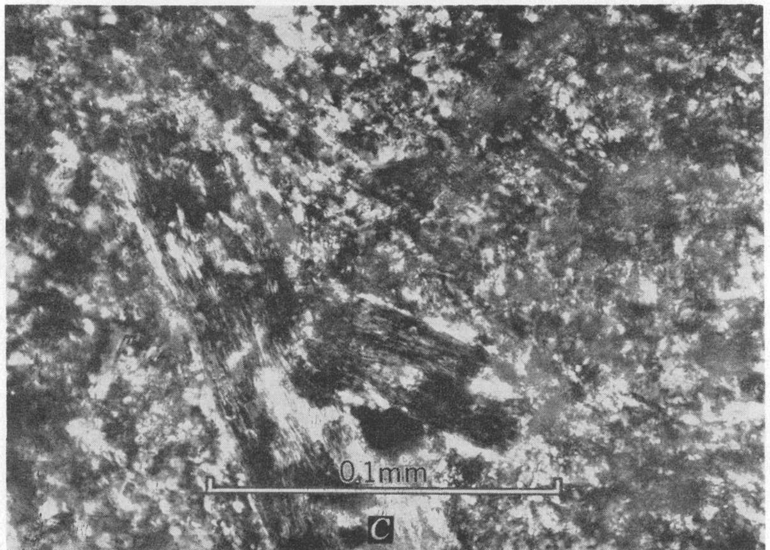




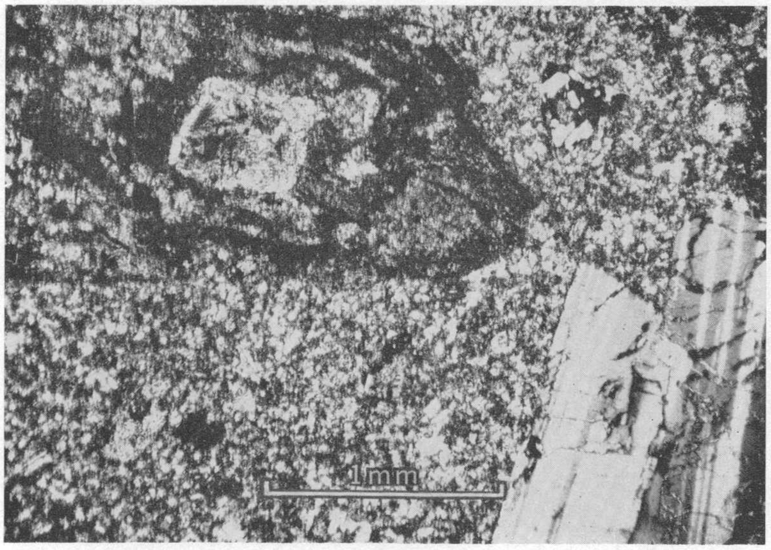
A Aztec glory hole. A narrow rind of quartz-alunite rock (*qa*) lines most of the glory hole, and is surrounded successively by soft bleached rock of the illite-kaolinite zone (*ik*), and by less altered rocks of the montmorillonite-chlorite zone (m_c). The illite-kaolinite zone ranges from about 2 to 4 feet in width. *B*. Photomicrograph of rock from the illite-kaolinite zone, showing altered phenocryst. Center of phenocryst is unaltered sanidine; border was plagioclase now replaced by illite. Matrix consists of granular patches of quartz and illite (white) enclosed in a finer grained aggregate of quartz and cloudy montmorillonite (gray). Rounded quartz phenocryst is unaltered. Plain light, $\times$ 31. *C*. Photomicrograph of an altered feldspar phenocryst in the illite-kaolinite zone. Illite (white) and montmorillonite (gray) are the main alteration products; the illite appears to have replaced much of the montmorillonite. The matrix (upper right and lower left) consists largely of quartz (white) and montmorillonite (gray). Crossed nicols, $\times$ 31.







A. Photomicrograph of kaolinitic rock from the illite-kaolinite zone. A former feldspar phenocryst is pseudomorphed by kaolinite (gray) and quartz (white). A small quartz phenocryst (q) is unaltered. Matric consists of granular quartz (white) and patches of kaolinite (gray). Crossed nicols, × 31. *B*. Photomicrograph of a rock from the montmorillonite-chlorite zone. Dusty-appearing parts of plagioclase crystals are partly altered to montmorillonite; clear parts are virtually unaltered. Matrix consists of tiny grains of quartz (white) showing through a dark cloud of montmorillonite. A veinlet of quartz appears near the right margin. Round blebs are air bubbles in the thin section. Cross nicols, × 31. *C*. Photomicrograph of a rock from the montmorillonite-chlorite zone. Former biotite phenocrysts are now represented by illite-sericite pseudomorphs. Matrix consists of patches of granular quartz (white) showing through a nebulous cloud of montmorillonite. Crossed nicols, × 480.



A. PHOTOMICROGRAPH OF CHLORITIC ROCK FROM THE MONTMORILLONITE-CHLORITE ZONE

Plagioclase phenocrysts are virtually unaltered. Former mafic phenocryst, now a cloudy "ghost" outlined by dark bands of montmorillonite-chlorite and irregular light areas of illite and quartz. Matrix consists of quartz and feldspar somewhat altered to fine clay minerals. Crossed nicols, × 31.

B. SMALL SILICIFIED PIPE ABOUT 130 FEET SOUTHEAST AND ALONG TREND OF HIDDEN VEIN

Detailed view, looking northwestward. Hard, silicified rock of the quartz-alunite zone (*qa*) is surrounded by soft, highly argillized rock of the illite-kaolinite zone (*ik*), and by less altered rock of the montmorillonite-chlorite zone (*mc*). Owing to its small size in relation to the argillized envelope, this pipe has no surface expression, although it consists of rock as hard as that in the highly silicified Copper Hill knob appearing in the right background.

be recognized in a few places, but more commonly the crystals show complex combinations of many forms. Simple cubes apparently are rare. These grains are tightly enclosed in the finely granular quartz mosaic that constitutes the matrix of most of the rocks in the quartz-alunite zone, and presumably formed almost contemporaneously with the silicification by sulfidization of the iron contained in the original quartz latite (see following sections on the solfataric environment).

The relations of the ore minerals that were deposited in the pores and phenocryst casts in the vuggy quartz rock are much more complex than are those of the pyrite crystals sealed in quartz. The minerals obviously fill or partly fill holes that formed by leaching of all but the most insoluble rock constituents, and, in addition, many ore specimens show evidence of recurrent corrosion of both the ore minerals and the quartzose gangue during and subsequent to cavity filling. These relations, described in detail in the following paragraphs, form the basis for many of the interpretations on the place and time of ore deposition in the period of solfataric alteration that affected many of the rocks in the Summitville district.

The ore minerals show a diversity of paragenetic relations. Pyrite ranges in age from the oldest to the youngest mineral in any local assemblage, and in some specimens it shows several distinct periods of deposition. Other ore minerals, as well as the quartz, sulfur, and barite, similarly show no consistent sequence of deposition, but show contradictory relations from specimen to specimen, and from place to place within some individual specimens. The most abundant ore minerals, pyrite and enargite, and the associated native sulfur are not coextensive, but most commonly occur in local concentrations in which one or another is alone or greatly predominates within the voids. Even where the minerals occur in the same specimen, they commonly are erratically distributed among the voids, and where two or more occur within the same hole they tend to encrust one another. Less commonly, pyrite and enargite form complex granular aggregates that seem to have formed by contemporaneous deposition, but at no place was native sulfur seen to form mutual intergrowths with the other minerals.

The pyrite within the cavities ranges from granular masses that nearly fill the associated holes, to small individual crystals or porous aggregates of crystals that show many crystal faces. Cubic, pyritohedral, and octahedral forms have been recognized at different places, but most of the crystals show complex combinations of forms. In a few places the pyrite forms botryoidal crusts with columnar structure and some of this may be marcasite. Pyrite lines some cavities, where it may be overgrown with quartz, enargite, barite, or sulfur; it commonly is mutually intergrown with quartz or barite, and less commonly with enargite; and in places it forms crustified masses that coat all the other cavity-filling minerals. Mutually intergrown aggregates commonly are porous and form skeletal fillings in which the individual grains tend to show crystal form and apparently grew freely into open spaces. The granular aggregates and encrustations also show crystal faces toward adjacent cavities, but for some reason grew as compact layers rather than as the more common loose aggregates.

Enargite occurs in tabular to prismatic black crystals and in sooty to compact aggregates. Most of the enargite in the holes and phenocryst casts consists of well-formed crystals in loose jackstrawed aggregates. Many of these cavity fillings were deposited on encrustations of euhedral quartz, yet in many other specimens the enargite is mutually intergrown with similar quartz or even is crusted in turn by quartz. Where associated with pyrite, the enargite is commonly the younger, although examples were seen where enargite and pyrite are closely intergrown, or where late stringers of pyrite cut enargite or botryoidal crusts of pyrite cover earlier enargite. Sooty or compact enargite is most common along fractures or in brecciated and recemented zones where it may coat or be coated by pyritic layers, or may be closely intergrown with fine-grained pyrite.

Native sulfur has been found on mine dumps and in outcrop at all altitudes from the Chandler level at the northwest end of the vein zone to the outcrop of the Tewksbury vein high on the flank of South Mountain near the southeast end of the zone (pl. 3). Judging from surface exposures and from fragments seen on mine dumps, the sulfur generally is sparse and occurs only locally as cavity fillings in the vuggy quartz rock. Most of the sulfur observed is massive and tends to fill most of the holes in which it occurs. Locally, however, scattered crystals of sulfur were seen projecting out into partly filled or virtually unfilled voids. Most of the sulfur is not closely associated with the ore minerals, but is in casts by itself or with marginal rims of euhedral quartz crystals. Locally, however, some sulfur was seen in association with both pyrite and enargite, and in all such examples the sulfur is younger than either of the associated sulfide minerals.

Barite is a minor but widespread mineral in the ore-bearing rocks, and shows complex paragenetic relations similar to those of pyrite and enargite. Most commonly it is closely associated with pyrite and euhedral quartz crystals in the cavity fillings, and in most hand specimens no relative order of deposition could be determined. Some barite crystals, however, fill in the centers of holes lined with aggregates of quartz and pyrite, whereas one crystal of barite seen was clearly coated by a thin layer of quartz and pyrite. Enargite and barite were not seen together in any of the hand specimens studied, and in polished sections all of the barite observed was along fracture zones that cut pyrite and enargite. The complex relations shown by all of the main cavity filling minerals, however, suggests that they all were deposited discontinuously during the same general period.

Minor primary ore minerals such as galena and sphalerite were seen only in polished section. Sphalerite was the more common and was seen as small grains within pyrite, and as larger crystals associated with a barite stringer cutting pyrite and enargite. The only galena noted was in the same barite stringer, but the complex relations shown by the other ore minerals suggests that this may not be its only association.

The distribution of gold in the primary ores is a major problem that has not been solved satisfactorily by this investigation. Only one small speck of gold was seen in the polished sections studied, and this was along a contact between enargite and pyrite grains. According to stories told by former miners in the district, some native gold in the unoxidized ores occurred as granules, leaves, and stringers in quartz, but more commonly it was contained in the sulfide-rich ore and could not be seen in hand specimen (see "Distribution of metals in the ore").

The relation of the ore minerals and the cavities is of particular interest in interpreting the relation of ore deposition to the general solfataric alteration. The euhedral crystals of quartz, pyrite, enargite, barite, and sulfur that grew freely into many of the pores and phenocryst casts clearly indicate that most of the holes were in existence before this suite of minerals was deposited. In polished section, however, many crystals and aggregates that fill or partly fill the cavities show evidence of subsequent corrosion. In places several periods of corrosion alternated with deposition are suggested. These relations are most apparent in the smaller voids where the margins of pyrite and enargite cavity fillings are irregularly corroded. In places, earlier pyrite crystals have been differentially leached along concentric growth lines so that only shreddy skeletons now exist.

As near as can be ascertained from general appearances, this late leaching was not restricted to the sulfide cavity fillings, but affected the siliceous matrix as well. The margins of some of these late cavities are most irregular toward the sulfide minerals and holes project erratically into them; elsewhere the opposite is true and in a few places the late cavities are confined largely to the quartzose matrix and sulfides are corroded only incidentally as the irregular holes reached them.

ILLITE-KAOLINITE ZONE

The highly silicified reefs comprising the quartz-alunite zone are commonly surrounded by discontinuous thoroughly argillized envelopes (pls. 7, 9) that are characterized by abundant illite and kaolinite as well as other alteration products. These envelopes range from a few inches to 10 or more feet in thickness, and grade abruptly into the centrally located rocks of the quartz-alunite zone on the one hand, and somewhat less abruptly into rocks of the surrounding montmorillonite-chlorite zone on the other. As seen in mine workings and other man-made exposures, the illite-kaolinite zone is always closely associated with the margins of the quartz-alunite zone, and it occurs throughout the length of the main mineralized area.

The highly argillized rocks of the illite-kaolinite zone are not distinguished on the detailed geologic map of the vein zone (pl. 3), as the rocks are characteristically soft and poorly exposed and the zone cannot be mapped adequately in the field. In addition, the zone is not everywhere present and commonly is so narrow that in many places it would be difficult to show at the scale of 1 inch to 100 feet.

Rocks in the illite-kaolinite zone vary widely in appearance and hardness. In places, particularly toward the inner parts of the zone, the rocks are nearly as hard as those in the quartz-alunite zone; whereas in other places some of the rocks are so soft that even in recent mine cuts the walls are highly slaked and good exposures are scarce. Laboratory studies indicate that the differences result largely from variations in the proportions of the different minerals formed during alteration. The firm rocks adjacent to many quartz-alunite bodies and characteristically forming transitions into them contain abundant finely granular quartz and lesser quantities of clay in the matrix, and have most of their clay minerals in pseudomorphic aggregates replacing the former feldspar phenocrysts. These rocks closely resemble many quartz-alunite rocks, except that clay minerals occur in the place of alunite. In the softer rocks, the different clay minerals predominate, and the less abundant quartz does not form a coherent mosaic in the matrix.

Illite and kaolinite are both found in most rocks in the argillic envelopes, but they are not uniformly distributed. Kaolinite is generally more common toward the transition to the quartz alunite zone, whereas illite is generally more common in the middle and outer parts of the zone. In places, however, very little kaolinite is present and abundant illite persists to the transitional contact with the quartz-alunite zone. In addition to illite and kaolinite, the argillic envelopes contain abundant quartz and montmorillonite, as well as minor but widespread rutile and leucoxene.

Where the argillization in the illite-kaolinite zone has not been complete, a progressive increase in the intensity of alteration is apparent from the outer to the inner margins of the zone. In the outer parts of the zone where illite is the dominant characterizing mineral, most of the mafic phenocrysts are completely altered, but many of the plagioclase phenocrysts are only partly altered and the large sanidine crystals and scattered accessory minerals are only slightly altered. Preferential replacement of plagioclase over sanidine in the middle and outer parts of this zone is graphically shown by clear sanidine phenocrysts whose margins once were marked by a rim of plagioclase, but now are mantled by illite and montmorillonite (pl. 7). The groundmass of these rocks is commonly an anisotropic mess consisting of illite, montmorillonite, kaolinite and quartz, with rutile (leucoxene) and minor quantities of other clayey minerals. Paragenetic relations, as seen in thin section, are generally inconclusive. Illite seems to have replaced montmorillonite in some places (pl. 7), and kaolinite apparently has replaced illite in others, but textures suggesting reverse sequences also were observed.

In the inner parts of the illite-kaolinite zone where kaolinite is locally more common, the sanidine as well as the plagioclase is commonly completely altered to clay. Illite, montmorillonite, and quartz are common in these rocks, too, and they show inconclusive paragenetic relations similar to those in the more illitic rocks. Locally, illite is either very inconspicuous or lacking within the kaolinitic subzone, and the rocks consist largely of a granular quartz-kaolinite matrix and fine-grained kaolinite pseudomorphs of feldspar phenocrysts (pl. 8). These rocks strongly resemble those of the adjacent quartz-alunite zone where alunite rather than kaolinite occupies the space of the old feldspar phenocrysts. The transitional rocks between the illite-kaolinite zone and the quartz-alunite zone locally have kaolinite in the interstices between alunite crystals in the pseudomorphic aggregates that have replaced the feldspar phenocrysts.

Kaolinite and illite are widely scattered in all zones of the pervasively altered rocks in the vicinity of Summitville, and in many places they probably are of supergene origin (see following sections). Within the illite-kaolinite zone, however, these minerals probably are largely of hypogene origin. The zone conforms to the zonal pattern of the other products of solfataric alteration, as it occupies an intermediate position between the more intensely altered rocks of the quartz-alunite zone and the slightly to moderately altered rocks in the surrounding montmorillonite-chlorite zone, and the rocks show a progressive destruction of the original minerals toward the more altered core. The illite-kaolinite zone does not occur immediately adjacent to the limonitic vuggy quartz rocks that once contained abundant sulfides, as would be expected were it derived by reaction involving sulfuric acid of supergene origin; rather it is almost always separated from vuggy quartz rocks by quartz-alunite shells that reflect intermediate stages of hypogene alteration.

MONTMORILLONITE-CHLORITE ZONE

Most of the Fisher quartz latite surrounding the strongly altered rocks of the quartz-alunite and illite-kaolinite zones on South Mountain is only slightly to moderately altered. The most common rock type in this marginal area is a bleached, creamy yellow to white rock in which many of the feldspar phenocrysts are nearly fresh but the matrix has been altered to mixtures of quartz and clay minerals. This rock weathers to light-colored slabby blocks that form characteristic talus slopes and boulder fields on most of the higher slopes. Less common but locally prominent is a medium- to dark-greenish gray rock that contains abundant chlorite in addition to the alteration products found in the bleached rocks. Exposed surfaces and cracks of the chloritic rocks are stained dark with coatings of limonite and manganese oxide.

As seen in thin section, the major phenocrystic minerals are little changed in the bleached rocks. Quartz is completely unaltered, and sanidine is nearly so. The oligoclase is locally altered to fine clay minerals (pl. 8), but many of the crystals are virtually unaltered. The minor ferromagnesian phenocrysts, on the other hand, are characteristically partly to completely altered to mixtures of muscovite-sericite, illite, rutile (leucoxene), iron oxide, and other minor fine-grained alteration products (pl. 8). Where biotite is only partly altered, white mica generally is interleaved with less altered biotite within the original phenocrysts. The accessory minerals apatite, sphene, zircon, and magnetite-ilmenite still persist for the most part.

In most thin sections studied, the original quartz-feldspar aggregate in the microcrystalline groundmass is practically obscured by a brownish cloud of montmorillonite (pl. 8). Small areas of finely granular quartz are common locally, and a few small quartz stringers cut the phenocrysts and altered groundmass, but the rocks generally are not silicified. Yellowish crystalline aggregates with high relief and moderately high birefringence, probably jarosite, are widespread. Disseminated pyrite is locally present, but for the most part is a very minor constituent of the bleached rocks. Montmorillonite, mixed-layer montmorillonite-chlorite, kaolinite, and illite, in the relative order of abundance, have been identified by X-ray methods from specimens of the bleached, pervasively altered rocks.

The slightly to moderately altered rocks characterized by abundant chlorite are particularly conspicuous on the upper slopes of the northeast face of South Mountain. In outcrop these dark rocks stand out in contrast to the nearby bleached rocks, but all gradations exist between the two types. Although both rock types have many alteration products in common, the chloritic rocks have additional minerals more characteristic of propyllitic alteration, and perhaps some of these may have formed during a late stage of cooling of the original quartz latite rather than as a phase of the general solfataric alteration.

The quartz and sanidine phenocrysts in the chloritic rocks are virtually unaltered. The oligoclase phenocrysts in the chloritic rocks range from fresh to thoroughly altered (largely to montmorillonite), and locally they have been replaced in some degree by a carbonate mineral. Many fresh biotite and hornblende phenocrysts have persisted through alteration, but conversely, where one of these minerals has been altered the change has been nearly complete (pl. 9). Chlorite is the most common alteration product of the ferromagnesian minerals, but sericite and illite also have been identified. Pyrite is more common in the chloritic rocks than in the bleached rocks, but even here it is a minor local constituent.

As in the bleached rocks, montmorillonite is the most common alteration product of the groundmass of chloritic rocks. Chlorite is also widespread and X-ray determinations indicate that mixed-layer montmorillonite-chlorite is more common in these than in the bleached rocks. The general index of refraction of montmorillonite in the chloritic rocks is somewhat higher than that of the mounting medium of the thin section, whereas in the bleached rocks it is slightly less than that of the mounting medium. Illite and kaolinite are widespread minor constituents in the matrix of the chloritic rocks, and rutile (leucoxene) is a common alteration product of the biotite, hornblende, sphene, and magnetite-ilmenite. Silicification is minor—even less than in the bleached rocks.

SUPERGENE ALTERATION

Many secondary minerals in the highly altered rocks in the Summitville district may be produced readily by weathering as well as by hypogene alteration. Problems associated with alteration include distinguishing between products of hypogene and supergene origin. This investigation was conducted wholly within the domain of ground water and currently oxidizing conditions, so some modification of the primary altered rocks by weathering must be assumed. Without the aid of control specimens from below the zone of oxidization, it is impossible to give specific answers for many individual mineral grains or many individual specimens. However, the gross field relations, the zoning and areal distribution of the secondary minerals, and the textural relations seen in thin sections, indicate a hypogene origin for most of the altered rocks. The association of sulfide ores with the quartz-alunite zone clearly shows that the alunitization and silicification are hypogene, and the zonal arrangement of progressively less altered rocks around these highly altered cores suggests a contemporaneous origin.

Although the gross zoning reflects hypogene alteration, the origin of certain common minerals in the different zones is less certain. The widespread jarosite, limonite, and manganese oxide along cracks and staining surfaces of the rocks in outcrop are easily attributed to weathering, and much of the minor but widespread kaolinite found throughout all zones of the altered rocks appears younger than other main alteration products, and thus may be either late hypogene or supergene. The local strongly kaolinized rocks in the inner parts of the illite-kaolinite zone commonly bear more resemblance to the rocks of the quartz-alunite zone than they do to the more illitic rocks surrounding them, and the possibility that some or all of the kaolinite may have been produced by supergene alteration of alunite and clay minerals cannot be summarily dismissed. On the one hand, the kaolinitic rocks seem to reflect the hypogene zoning of alteration products, but on the other hand they are located near the rocks that originally had abundant sulfides and thus near a possible source of supergene acidic solutions. The common occurrence of quartz-alunite rock between the limonitic vuggy quartz rock that once contained the sulfides, and the kaolinitic rocks marginal to the quartz-alunite zone was the evidence most impressive to the authors. If supergene in origin, the kaolinitic rocks would more likely occur along the margins of the vuggy quartz rocks rather than consistently along the outer margins of the quartz-alunite zone where they conform to the hypogene zonal pattern. In our opinion, however, the possibility of widespread supergene kaolinite must be assumed until the mines are reopened and comparative studies are made at different depths both within and beneath the zone of oxidation.

All of the mineralized vuggy quartz rock near the surface is thoroughly oxidized, and most of the material of ore grade has been mined out. Only thin remnants of vuggy quartz rock remain along the margins of opencuts, and these all show limonitic material in the vugs. In places porous aggregates of limonite and barite fill the phenocryst casts and minor fissures, and the barite in these occurrences seems to be contemporaneous with the limonite. According to Patton (1917, p. 82), Hills (1885, p. 23), and others, free gold was disseminated through the limonite, and only locally formed nuggets of an ounce or so in weight. In places the gold occurs with abundant secondary barite or in rusty quartz, and a few selected specimens of quartz with disseminated gold shown the writers by Mr. G. H. Garrey are exceedingly rich. Copper apparently has been almost completely removed from the oxidized ores, and silver is a minor constituent.

Selected ore specimens collected from the mine dumps show that secondary deposition of copper took place near the base of the oxidized zone. Covellite is the most common secondary copper mineral, and it occurs as encrustations and fillings in the cavities in vuggy quartz rocks. The covellite ranges from powdery coatings on the margins of crystal casts, to bladed euhedral crystals and aggregates of crystals extending into the openings, and to massive aggregates that nearly fill the holes in which they occur. As seen in polished sections, none of the covellite showed the effects of alternating deposition and leaching displayed by many of the primary sulfides. In all places where covellite and enargite are associated, covellite is definitely the younger. In a few sections studied, the covellite contains small inclusions of chalcopyrite that also seem to be secondary; in places the chalcopyrite blebs are most common along and near the contacts between covellite and pyrite, and seem to have formed by reaction between them. A few specks of chalcopyrite were seen within and along the margins of pyrite grains without any associated covellite, but these are rare.

Most reports on the secondary deposition of gold cite the oxidized ores from the Summitville district as examples. The ultimate source for most of these references seems to have been the original report by R. C. Hills (1885). Patton (1917, p. 87) cites an example of limonite stalactites and stalagmites formed in old mine workings that assayed $2.40 and $7.20 per ton. Although we were unable to gather any data on this subject in the field, a high-grade specimen of limonitic gold ore from the Summitville district on display at the Denver Museum of Natural History, Denver, Colo., shows relations that almost certainly indicate secondary deposition of gold. Granules of gold are concentrated in a narrow layer within porous limonite. The layer shows many irregularities and rounded, cuspate protuberances similar to those shown by diffusion rims commonly seen in weathered rocks. Considering that most of the primary gold in the Summitville district is contained within other ore minerals and is rarely visible to the unaided eye, the evidence seems conclusive that the gold in this specimen moved during supergene alteration and was concentrated in a narrow layer where conditions were right for precipitation.

CHEMICAL CHANGES DURING ROCK ALTERATION

The chemical changes during rock alteration in the Summitville district involve progressive leaching of the more soluble constituents and residual enrichment of the more insoluble constituents. The only materials added in significant amount were water in the rocks showing intermediate degrees of alteration, and sulfur, iron, and copper in the more intensely altered and mineralized rock. Chemical analyses of typical rocks from the different zones of altered rocks are given in table 7. These analyses represent samples collected throughout the main mineralized area, and thus are representative of the compositions of the zones in general rather than of a given local sequence. As most of the different rock types are represented by single analyses only, we cannot be sure that truly representative compositions are shown; in this respect we have had to rely on hand specimen and thin-section studies to indicate that typical samples of the different rocks were collected.

The relict textures preserved in all the zones of altered rocks have indicated that the gross volume of the effected rocks was not changed appreciably during alteration. Thus the weight per unit volume of the various constituents in the different types of altered rocks should provide a means whereby the chemical changes in the different zones can be compared directly. This comparison has been made on plate 5, where a hypothetical sequence from unaltered quartz latite through intermediate stages to the intensely leached and mineralized vuggy quartz rock is represented.

Table 7.—*Chemical analyses of rocks from the main metal-producing area of the Summitville district, in percent*

	[1] 1	[1] 2	[1] 3	[1] 4	[1] 5	[2] 6	[1] 7	[2] 8
SiO_2	69.45	65.74	69.03	65.33	72.14	73.73	65.53	80.43
Al_2O_3	15.21	15.05	15.30	17.36	14.87	17.30	13.93	.33
Fe_2O_3	2.38	.27	2.04	2.46	.81	.06	.09	.00
FeO	.53	[3] 2.50	.03	.09	.04	.09	[3] 1.93	[3] 10.58
MgO	.43	1.13	.12	.34	.79	.01	.00	.00
CaO	1.38	2.82	1.19	.28	.04	.11	.11	.00
Na_2O	4.06	3.85	4.30	.60	.20	.01	.58	.02
K_2O	4.30	3.94	4.53	5.94	5.49	.09	1.80	.01
H_2O-	.59	.76	.48	1.15	1.37	.15	.12	.06
H_2O+	.55	.99	.94	3.73	2.48	6.07	4.76	.42
TiO_2	.48	.50	.52	.58	.60	.60	.48	.43
CO_2	.00	1.22	.04	.03	.01	.01	.01	.02
P_2O_5	.32	.41	.15	.25	.28	.49	.48	.00
SO_3	.00	.03	1.14	1.48	.48	[4] .63	8.34	--------
Cl	.01	.01	.00	.00	.00	--------	.00	--------
F	.10	.10	.03	.08	.10	--------	.12	--------
S	.00	.72	.01	.00	.00	--------	1.64	9.34
MnO	.02	.08	.01	.01	.02	.00	.01	.00
BaO	--------	--------	--------	--------	--------	.13	--------	.17
	99.81	100.12	99.86	99.71	99.72	99.48	99.93	101.81
Less O	.04	.22	.01	.03	.04	--------	.46	2.34
Total	99.77	99.90	99.85	99.68	99.68	99.48	99.47	99.47
Powder density	2.58	2.63	2.59	2.59	2.56	2.60	2.70	2.88
Bulk density	2.34	2.52	2.18	2.14	2.07	2 03	2.66	2.75

[1] Analyst, Lucile N. Tarrant.
[2] Analyst, Faye H. Neuerburg.
[3] A calculated correction was made for the FeO present in pyrite.
[4] Calculated from total sulfur. It was assumed that the sulfur is present as SO_3.

1. (SA-1*; A 152**) Slightly weathered but otherwise unaltered quartz latite from the core of the South Mountain volcanic dome. Collected from the nose of the ridge extending east from the Iowa mine workings at an altitude of about 11,700 ft. [Asterisk (*) indicates field No. ** indicates rock analysis laboratory serial No.]
2. (SA-5; A 156) Chlorite-rich rock from the montmorillonite-chlorite zone. Collected from a bulldozer cut about 100 ft. north of the Science adit.
3. (SA-6; A 157) Montmorillonite-rich rock from the montmorillonite-chlorite zone. Talus block from south of the Copper Hill knob.
4. (SA-4; A 155) Illitic rock from the illite-kaolinite zone. Collected from bulldozer cut about 200 ft. north of Science adit, between bulldozer trenches Nos. 9 and 10.
5. (SA-7; A 158) Illitic rock from the illite-kaolinite zone. Collected from the wall of a glory hole along the southwest margin of the Copper Hill knob.
6. (SD-161h; C-496) Kaolinitic rock from argillized zone of Aztec glory hole. Several tenths of a percent of lead noted by analyst in addition to materials given here.
7. Quartz-alunite rock from quartz-alunite zone. Collected from bulldozer cut about 200 ft. north of Science adit, between bulldozer trenches Nos. 9 and 10. Specimen located near center of vein 3-4 ft. east of SA-4.
8. Vuggy quartz rock from quartz-alunite zone. Collected from dump of Aztec Pit No. 2.

The bulk density of the different rock types is shown, as is the approximate percent porosity which was calculated from bulk density and powder density measurements according to the formula

$$\left(1-\frac{\text{bulk density}}{\text{powder density}}\times 100\right).$$

The grams per cubic centimeter of the major rock-forming constituents was determined by

$$\left(\frac{\text{weight percent}}{100}\times\text{specific gravity}\right)$$

and plotted on bar graphs for comparison.

The inherent inaccuracies owing to possible nonrepresentative samples and errors in bulk density measurements probably are significant only for the mineralized vuggy quartz rock represented by analysis 8. This rock is composed of porous vuggy quartz and contains abundant pyrite in the holes; the larger vugs are sanidine casts as much as 1 inch or more in diameter. Many of these vugs are too large in relation to the size of the specimen submitted for analysis to be sealed off effectively during bulk density measurements, and only the smaller pores are adequately accounted for in the figures obtained. Thus the bulk density given for analysis 8 in table 7 and plate 5 is much too high and the percent porosity is much too low. This inaccuracy increases the apparent weight per unit volume of all the constituents in the mineralized vuggy quartz rock by a significant but undetermined factor.

The nearly stable weight per unit volume of silica in the different zones corroborates the conclusion reached from hand-specimen and thin-section study that most of the quartz in the altered zones is residual from the breakdown of glass and silicate minerals by hydrothermal action. The content in grams per cubic centimeter of SiO_2 shows little change through most of the zones of altered rock; the only marked deviation is in the vuggy quartz rock where the SiO_2 shows an apparent marked increase. In hand specimen, the vuggy quartz rock showed no indication of the positive addition of quartz noted in many of the compact quartz rocks, and the apparent increase in SiO_2 in this specimen may provide a measure of the effect of the inaccurate bulk density measurements.

The Al_2O_3 changes little from one rock type to another, except for the strongly leached vuggy quartz rock. This change indicates that the original alumina in the rock was largely retained under all but the most intense conditions of alteration, but that here it was almost completely removed.

The behavior of iron is more difficult to interpret. Although some of the altered rocks had much of the iron removed, the plots of total iron oxide indicate that a large quantity of iron remained in the rock throughout alteration. The generally inverse variation of ferric and ferrous oxides, however, indicates that this residual iron changed oxidation state from one rock type to another. The high ferrous iron content in the chloritic rocks (table 7, analysis 2), reflects the iron contained in the chlorite and in the irregularly disseminated pyrite, the high ferrous iron in the quartz alunite rock and vuggy quartz rock, on the other hand, results from a high content of pyrite. The high ferric iron in the samples of montmorillonitic rock (analysis 3) and illitic rock (analyses 4 and 5) can be accounted for by the common presence of jarosite and finely disseminated iron oxides which seem to be largely of supergene derivation, as well as a minor amount of iron contained in montmorillonite and illite.

MgO shows a marked increase in the chloritic rocks (analysis 2) where it probably is held largely in the chlorite. Additional MgO could have been supplied by the adjacent altered rocks which generally were depleted in this constituent. MgO is present in minor but significant quantities in the montmorillonitic rocks (analysis 3) and illitic rocks (analyses 4 and 5) where it is probably held in montmorillonite, illite, and chlorite. It was almost completely leached in the more strongly altered rocks represented by analyses 6, 7, and 8.

The variation in CaO content was influenced by at least two factors. The higher content in the chloritic rocks (analysis 2) reflects the widespread presence of carbonate, probably calcite, but probably an additional factor is that the plagioclase phenocrysts show only minor alteration in many of these rocks. The progressive destruction of plagioclase with more intense alteration is shown by the progressive decrease in CaO content toward the right in the diagram (pl. 5). In addition, montmorillonite commonly contains absorbed calcium, and the progressive decrease in montmorillonite and increase in illite and kaolinite toward the more intensely altered rocks may account for some of the decrease in CaO.

The variations in content of Na_2O also probably reflect the destruction of plagioclase closely. Nearly fresh plagioclase crystals commonly persist in rocks of the montmorillonite-chlorite zone, whereas they are commonly destroyed in the more strongly argillized rocks of the illite-kaolinite zone. The sodium content of alunite in the quartz-alunite rock (analysis 7) is clearly shown on the diagram.

The stability of K_2O in the less altered rocks of the montmorillonite-chlorite zone is related to the stability of sanidine and much of the plagioclase in the weaker phases of alteration in the Summitville district. Nearly fresh sanidine commonly is present even in some of the less strongly argillized rocks in the outer parts of the illite-kaolinite zone. The relative increase in K_2O in the illitic rock (analyses 4 and 5) probably indicates the sum of potassium contained in whatever residual sanidine remains plus the additional potassium displaced outward from the more intensely altered zones, and probably held largely in the illite. Although most of the K_2O was removed from the kaolinitic rocks (analysis 6), large quantities remain in the adjacent quartz-alunite rock (analysis 7) where it is fixed in alunite.

The gain in H_2O^+ is a measure of the progressive hydration in the more intensely altered rocks. Secondary hydrated minerals are common in the montmorillonite-chlorite zone, but the ground masses of many of the rocks are only partly altered, and many of the feldspar phenocrysts are nearly fresh, so the content of H_2O^+ is low. In the more intensely altered rocks of the illite-kaolinite and quartz-alunite zones, almost all of the original silicate minerals of the quartz latite are broken down, typically to hydrated secondary minerals such as montmorillonite, illite, kaolinite, and alunite, and the corresponding H_2O^+ content is high.

Sulfur in sulfate and sulfide represents the positive addition of a constituent that was nearly absent in the original unaltered rock. The sulfate in the quartz-alunite rock (analysis 7) is easily accounted for by the high alunite content; that in the montmorillonite-chlorite and illite-kaolinite zones may be present in jarosite and other minerals of possible supergene origin. The sulfide is almost entirely contained in pyrite, which is commonly disseminated in the more chloritic rocks of the montmorillonite-chlorite zone, and in the alunitic rocks in the quartz alunite zone. In addition, pyrite is the most common of the ore minerals in the mineralized vuggy quartz rock, where it is reflected by the very high sulfide and ferrous iron contents.

SOLFATARIC ENVIRONMENT

The altered and mineralized rocks in the Summitville district are products of a period of solfataric activity that followed closely after eruption of the quartz latitic lavas of the lower member of the Fisher quartz latite. The alteration was localized in and near the then recently erupted lavas, and the environment in these areas probably was closely similar to that in modern hot spring and fumarolic areas associated with recent volcanic activity. Minerals of the alunite and kaolinite groups, as well as quartz, opal, and chalcedony, are common alteration products where such a solfataric environment is characterized by acid sulfate solutions; a mineral suite consisting of montmorillonitic clays, sericite, illite, and quartz is more common where the solutions are nearly neutral or basic. Important problems associated with these types of alteration include the difficulty in distinguishing between the effects of hypogene and supergene processes in a near-surface oxidizing environment; the relative importance of juvenile and meteoric waters in the hydrothermal solutions; the stability relations between the different alteration products; and the origin of the sulfuric acid and sulfate in the acid solutions.

The depth at which the ores were deposited at Summitville is a critical factor in determining the solfataric environment. Little direct evidence is now available, but it seems improbable that the surface above the main mineralized area was below the present top of South Mountain (altitude 12,530 feet), and more probably it was above the projected base of the unaltered remnant of the upper member of the Fisher shown on the cross section through South Mountain (pl. 2). This surface projects over the vein zone at a present altitude of about 12,800 feet, which is about 500 feet above the highest mine workings at the Aztec glory hole, and 1,500 feet above the lowest workings on the Reynolds level. Maximum figures for the depth of ore deposition are more difficult to estimate, but it seems unlikely that the surface could have been above that shown on the cross section (pl. 2) as the restored surface of the South Mountain volcanic dome. Above the main vein zone this surface has an altitude of about 13,600 feet, and is thus about 1,300 feet above the Aztec glory hole and 2,300 feet above the Reynolds level. The mineralized rock exposed in the highest mine workings, therefore, seems to have formed within 500 to 1,300 feet of the surface at the time of solfataric activity.

The young and possibly still hot quartz latitic lavas that were being altered and mineralized apparently stood high topographically, for stream valleys cut on them were directed radially away from the present South Mountain mass (see "Volcanoes of late Fisher age"). The base of some remnants of these valleys preserved beneath lavas of the upper member of the Fisher are actually below the level of the higher ore deposits on the northeast face of South Mountain. This envioronment is not of the type to favor accumulation and deep circulation of meteoric water, and hypogene constituents possibly predominated in the altering and mineralizing solution.

COURSE OF SOLFATARIC ALTERATION AT SUMMITVILLE

The zones of intensely altered rocks now exposed at Summitville probably have formed by a virtually continuous process involving progressive neutralization of acid hydrothermal solutions by reaction with the wallrocks outward and upward along the fractures that concentrated the flow of the volcanic emanations. The minerals of the quartz-alunite zone, as well as the locally abundant kaolinite in the inner parts of the adjacent illite-kaolinite zone, typically form in modern hot spring environments characterized by acid sulfate solutions. The illite and montmorillonite in the outer parts of the illite-kaolinite zone and the montmorillonite and chlorite in the adjacent rocks generally indicate weakly acidic, neutral or basic conditions of origin.

Except for the general late appearance of the ore minerals, paragenetic relations between the different altered rocks are generally inconclusive. Where local sequences can be determined, they generally involve minerals of an inner zone following those of an outer zone. This is easily explained by the natural tendency of the acidic solutions to encroach outward and upward as the reactive materials in the wall rocks were exhausted by chemical action. The absence of general discontinuities in the sequence of mineral development other than those reflecting the nearly symmetrical concentric zones argues against any marked change in composition of the primary solutions as the alteration progressed. The late appearance of the ore minerals seems more related to changes in the chemical and physical environment as alteration progressed than to any fundamental change in the composition of the solutions (see "Deposition of ores").

The excellently preserved textures of the original quartz latite apparent throughout the quartz-alunite zone make it unlikely that these rocks ever were subjected for very long to a strongly argillic type of alteration such as formed the surrounding illite-kaolinite zone where original textures are commonly destroyed. This would suggest that the zones formed almost concurrently, with only minor lateral encroachment. Vertical encroachment, in the direction of greatest permeability and presumably solution flow, may have been much more pronounced, but evidence for this is lacking in the severely restricted vertical zone available for study in this investigation.

The vuggy quartz rock and quartz-alunite rock within the quartz-alunite zone probably formed simultaneously, with some lateral encroachment, throughout at least the latter parts of the period of solfataric activity for which evidence remains. As a working hypothesis, it is suggested that in the initial stages of alteration, the original acid sulfate solutions were able to leach large quantities of the wallrock constituents, particularly the more soluble bases, from the feldspars and ferromagnesian minerals, and were quickly reduced in strength. With time, fairly fresh acidic solutions persisted farther and farther into the wallrocks, where their leaching capacity was progressively neutralized and the concentrations of soluble ions was progressively increased. At some time during these initial stages, part of the dissolved potassium and sodium combined with the available aluminum of the feldspars, and sulfate and water from the solution to form alunite. The silica from the silicates and the tridymite and quartz in the groundmass were reconstituted to the fine-grained quartz aggregate that still persists. A continuing supply of fresh or nearly fresh acid sulfate solutions following the same general channels completed leaching of the rocks near the channelways to form the vuggy quartz rocks, which encroached progressively on the adjacent quartz-alunite rocks. The encroachment was not everywhere complete, however, as irregular masses of quartz-alunite rock surrounded by vuggy quartz rock still can be seen in many of the mine workings.

The kaolinitic rocks that locally surround the quartz-alunite zone present a problem in the interpretation of the course of solfataric alteration. These rocks are not everywhere present, and locally seem to cut across quartz-alunite rocks. Textures seen in some thin sections suggests that in places kaolinite replaces alunite and appears distinctly younger than the associated alteration products. As indicated in the section on supergene alteration, however, the kaolinite concentrated in the inner parts of the illite-kaolinite zone reflects the hypogene zonal pattern rather than the former distribution of sulfide minerals which conceivably would supply the acid under supergene conditions, and therefore is probably of hypogene origin. Perhaps much of the disseminated kaolinite present nearly everywhere within the weathered, near-surface rocks is of supergene origin, and this material may confuse many local relations.

Implicit in the interpretation that the concentric zones at Summitville resulted from progressive neutralization of acidic hydrothermal solutions is the requirement that the alunite here formed under more acidic conditions than the kaolinite. This is strongly suggested in such places as Summitville and Marysvale, Utah (Willard and Proctor, 1946) where the kaolinite occurs in marginal envelopes between the intensely altered alunitic cores and the surrounding less-altered rocks. Interpretations elsewhere, however, would suggest that the stability fields of alunite and kaolinite may overlap, and that the order of crystallization or relative distribution of the minerals depends on local conditions.

Anderson (1935, p. 243–245) examined a specimen of dacite from a hot spring in the Lassen area in which the core of the specimen was practically unaltered, but the exterior was altered to a soft powdery material consisting chiefly of opal with minor kaolin and less alunite. Between the soft exterior and the core, alunite made up nearly 9 percent of the rock as calculated from the Na_2O and K_2O content of that part of the specimen. If these minerals formed in a stable chemical environment, it would seem logical to assume that the kaolin represents alteration under more strongly acidic conditions than the alunite, and Lovering (1950, p. 244–247) has so interpreted it. This relationship may not be invariable, however, as Noll (Morey and Ingerson, 1937, p. 736; Grim, 1953, p. 318–319) synthesized kaolinite from basic as well as acidic solutions in which the concentration of Na_2O, K_2O, MgO, and CaO was less than 0.02 mole; somewhat greater concentrations of these constituents under otherwise identical conditions had no effect on the formation of kaolinite in acidic solutions, but in basic solutions led to the formation of montmorillonite. Alunite has been synthesized in an acidic environment (Leonard, 1927), but apparently the full range of pH conditions under which it will form or the effect of other constituents in solution were not explored. Parker [8] developed alunite from solutions ranging in pH from 3.5 to 1.5, but these are not limiting figures. The effect of these complex stability relations between alunite and kaolinite may be illustrated at San Manuel, Ariz., where Schwartz (1953, p. 19–24) described local relations in which kaolinite preceded, was contemporaneous with, and followed alunite.

Illite and montmorillonite can form under many conditions, and are characteristic minerals in soils, bentonites, shales, and hydrothermally altered rocks. Although these minerals have long been presumed to form under basic conditions, experimental evidence suggests that they also may form in acidic solutions (Hauser and Reynolds, 1939). Ross and Hendricks (1945, p. 59) suggest that the presence of appropriate constituents is more important than the pH of the system. Whether the illitic rocks at Summitville formed in a basic, neutral, or slightly acidic environment, they probably represent a continuation of the progressive modification of the original acid-sulfate solutions. An increasing concentration of dissolved constituents obtained from the inner zones may have resulted in fixing some potassium in the illite. The depleted solutions were unable to alter many of the phenocrysts in the rocks significantly, however, as fresh sanidine and some plagioclase phenocrysts still persist in the outer parts of the illite-kaolinite zone.

Alteration in the montmorillonite-chlorite zone was general and pervasive, and the distribution of the alteration products does not reflect the concentric arrangement shown by the quartz-alunite and illite-kaolinite zones. No evidence was seen for reactions involving acid-sulfate solutions, and the alteration was of the type considered by Schmitt (1950, p. 214–215) to comprise CO_2 leaching under basic conditions. These differences may reflect greater influence of ground water in diluting or otherwise modifying the primary volcanic emanations as they moved away from their source or from fractures which served as trunk channels.

SOURCE OF THE SULFURIC ACID

The source of the sulfuric acid responsible for intensive leaching in the quartz-alunite and illite-kaolin-

[8] Parker, R. L., 1954, Alunitic alteration at Marysvale, Utah: U.S. Geol. Survey open-file report, p. 62–65.

ite zones at Summitville is of primary concern in determining the course of solfataric alteration. As we lack evidence from vertical changes in the altered rocks at Summitville, we must postulate a source for the acid by analogy with other areas where relations are more amenable to interpretation.

Many workers in the early part of this century recognized such secondary minerals as kaolinite and alunite as products of acidic solutions, but the prevalent theory at that time postulated that basic solutions were ore-carrying magmatic derivatives. Thus the acidic solutions and their secondary products were attributed to weathering processes which produced sulfuric acid by oxidation of pyrite. In more recent times studies of volcanic emanations and furmarolic-hot spring areas have indicated that at least some of the hypogene solutions expelled by cooling magmas may be acidic. Butler (1919) assembled massive geologic evidence favoring a hypogene origin for many of the sulfate minerals associated with ore deposits formed at shallow depths.

The source of the oxygen which permits local development of these sulfates is one of the main problems. Atmospheric oxygen is an obvious source, but where this source is responsible, the zone of sulfate development is limited to depths to which surface waters can circulate readily. Deeper sources of oxygen for the formation of sulfates include oxygenated connate water. Some SO_2 and SO_3 may be present in primary magmatic exhalations, as discussed by White (1957, p. 16–49).

The sulfuric acid that causes the acid-sulfate type of alteration associated with hot springs seems in most places to be derived by superficial oxidation of the sulfurous components contained in the primary igneous emanations. E. T. Allen and A. L. Day in their studies of the thermal areas at Lassen Peak (Day and Allen, 1925, p. 138–140) and Yellowstone (Allen and Day, 1935, p. 100–101) favored shallow oxidation of H_2S as the process whereby the sulfuric acid was formed. The evidence from a borehole in Norris Basin, Yellowstone (Fenner, 1936) supports this conclusion; strongly leached rocks typical of acidic springs areas were found to a depth of about 28 feet and kaolinite was abundant to a depth of about 100 feet, but at greater depths beidellite clay and other minerals characteristic of basic environments were found. White (1955, p. 110–119) noted that acid leaching near the hot springs at Yellowstone National Park; Steamboat Springs, Nev.; Wairakei, New Zealand; and Sulphur Bank, Calif., was restricted to near-surface zones, and died out downward within a few hundred feet. These hot-spring environments, however, are commonly in topographic basins and may not be closely comparable with the environment that prevailed at Summitville.

Many of the better known ore deposits associated with alunitic altered rocks seem to have formed at depths below those cited by White for superficial acidic alteration around modern hot springs. As noted earlier, evidence at Summitville suggests that the highest exposures of quartz-alunite rock are probably between 500 and 1,300 feet below the surface at the time of alteration, and the lowest exposures are about 1,000 feet deeper. At Red Mountain, Colo., Burbank (1941, p. 194–195) states that the surface at the time of ore deposition could scarcely have been less than 3,000 feet above the deepest ore deposits, and perhaps somewhat more than 1,500 feet above the highest now exposed. In discussing the hypogene zoning at Cerro de Pasco, Graton and Bowditch (1936, p. 654, 691–692) state that alunite is exposed in mine workings throughout a vertical range of 2,100 feet or more, and that the topmost exposures are probably several hundred feet and perhaps several thousand feet below the surface at the time of mineralization. The approximately 300 feet of erosion since mineralization suggested by Ransome (1909, p. 174) at Goldfield, Nev., has since been shown to be a theory based on incomplete information (Searls, 1948, p. 12–13), and actually the depth of erosion may have been much greater. The ore shoots at Goldfield generally bottom at depths less than 1,000 feet (Ransome, 1909, p. 173, Searls, 1948, p. 16–17). At the Flathead mine, Montana, Shenon (1935, p. 601) suggested that the present exposure of the ore body is less than 400 feet below the surface at the time of origin; however, we do not believe the evidence cited is particularly conclusive.

White (1955, p. 107; 1957, p. 1648) has shown that only a small part of the sulfate in the Green Dragon spring in the Norris Basin, Yellowstone, can be accounted for by near-surface oxidation of H_2S; the remainder must be supplied by other processes of deeper level oxidation. Reduction of ferric iron oxides, as suggested by Butler (1919, p. 599), was rejected by Graton and Bowditch (1936, p. 685) at Cerro de Pasco because the quantity of magnetite in the country rocks was too low; the same objection probably applies at Summitville and other places where the wallrocks are intermediate and silicic lavas. Oxygenated connate waters seem an even less likely source in the recent accumulations of hot lavas that characterize many solfataric areas.

At Cerro de Pasco, Graton and Bowditch (1936, p. 677–678; 683–691) postulate that the decomposition of water is a source of the oxygen, basing their conclusions on the established reaction:

$$4\ H_2O + 4\ S = 3\ H_2S + H_2SO_4$$

The reaction takes place readily between steam and sulfur at 250°C, and perhaps at 200°C (Day and Allen, 1925, p. 139), and as one product is a volative (H_2S), the reaction is favored by low pressures (Graton and Bowditch, 1936, p. 687). This combination of high temperatures and low pressures is obtained chiefly in volcanic regions where near-surface rocks are abnormally hot. As stated by Graton and Bowditch (p. 689):

> But where temperature is maintained to an abnormal degree in relation to pressure—as by preheating—or where pressure abruptly drops in relation to temperature—as by reopening—then, if either of these tendencies is sufficiently great, the previous liquid may boil in corresponding degree, the more volatile components responding first and the less volatile ones tending to remain liquid. Moreover, whether or not any boiling in the simple sense may go on, any possible reaction in the solution which would be favored by relative reduction of pressure to temperature would tend to take place. The Allen reaction, with its production of H_2S, is such a reaction; H_2SO_4 is its other product.

Krauskopf (1951, p. 511–513), however, has indicated that this reaction is displaced to the left with lowering temperatures unless stabilized by some strong oxidizing agent such as O_2 or Cl_2. As noted above, it seems unlikely that free O_2 was present in the mineralizing solution at Summitville, but halogen gases are common in volcanic emanations and some may well have been present even though we recognized no evidence indicating their presence.

Burbank (1941, 1950) has envisaged a process somewhat similar to that postulated for Cerro de Pasco as acting at the Red Mountain district, Colorado. Presolfataric igneous intrusion and volcanic activity raised the general ground temperatures in the district, and prepared the rock for the later rise of high-temperature emanations near the surface. Burbank postulates two types of solutions: a primary sulfide solution, generally basic, from which the mass of the ore was deposited, and a sulfate solution formed by evaporation and recondensation of volatile emanations from the sulfide solutions at an interface determined by a steep pressure gradient found at shallow depths.

Burbank (1941, p. 202) noted that the specific reaction postulated by Graton and Bowditch at Cerro de Pasco has not been proven experimentally under conditions free from atmospheric oxygen, and could not eliminate to his own satisfaction the possibility of some surface oxidation. He preferred to base his argument on the geologic evidence cited by Butler (1919) that sulfates originate in hypogene environments almost free from surface oxygen.

White (1957, p. 1647-1649; 1651-1652) believes that acid-sulfate-chloride waters probably form in one or another of four different ways: (a) mixing different sodium-chloride and acid-sulfate waters; (b) near-surface acidification of near-neutral sodium-chloride waters by oxidation of H_2S; (c) deep condensation of dense alkali halides and oxidized sulfur; and (d) surficial condensation and oxidation of low-density volcanic gases containing halogen acids and sulfur. He believes acid-sulfate waters containing little chloride formed either by high-temperature magmatic steam and associated volatiles, little diluted by meteoric water, approaching near to the surface and there condensing and oxidizing; or by boiling of acid-sulfate-chloride waters at depth and condensation and oxidation of sulfur compounds nearer the surface. White appeals to near-surface oxidation of volcanic gases to obtain the sulfate in fumarolic environments such as we believe may have existed at Summitville. Possibly near-surface oxidation extends deeper in these circumstances than in hot-spring environments where the maximum depth seems to be a few hundred feet.

In summary, the ore deposits and associated altered rocks at Summitville, in common with other areas with "Goldfield-type" ore deposits, formed at shallow depths and in circumstances where high temperatures and low pressures could have existed. The oxidizing reactions which form sulfuric acid under such conditions may involve some oxygen from the surface, but geologic evidence in many areas suggests that this was not the only source. Fractionation of acid-forming constituents by selective vaporization is one hypothesis that seems to fit the facts as known, but owing to the limited vertical range of our observations at Summitville, we are unable to cite any positive evidence to support it. Lacking data even on these more general phases of the problem, we are unable to comment on the applicability of specific reactions.

DEPOSITION OF THE ORES

Deposition of the ore minerals was an integral part of the process of rock alteration at Summitville, and is the greatest interest to the miner. The ore minerals occupy a special place in the course of solfataric alteration, as they alone among the products of hydrothermal activity formed consistently late in the local sequence of events and under demonstrably different conditions of origin. Whereas the different rock types in the quartz-alunite and illite-kaolinite zones seem to have formed almost concurrently in an oxidizing, acidic environment, the ore minerals were deposited subsequent to the most intense silicification and leaching and formed in a generally reducing chemical environment.

The fine disseminated pyrite grains tightly enclosed in the quartzose matrix of the quartz-alunite and related rocks seem to have formed contemporaneously with the enclosing minerals, presumably by sulfidization of iron contained in the original quartz latite. This origin is particularly suggested by those local concentrations of pyrite that reflect the outlines and internal structures of former ferromagnesian phenocrysts. Pyrite of this habit is considered distinctly older and of a different origin than the sulfides and related minerals that occur in the leached holes in the vuggy quartz rock, and therefore will not be discussed in the following account of ore deposition.

The pyrite, enargite, native sulfur, barite, and local galena and sphalerite that fill or partly fill cavities in the vuggy quartz rock definitely were deposited subsequent to the intense leaching and silicification that formed the host rocks. In many places the vugs containing the ore minerals are lined with drusy coatings of euhedral quartz crystals that clearly grew into open holes, and some of the larger phenocryst casts are crisscrossed with skeletal walls of similar quartz. Pyrite, enargite, and related minerals commonly encrust these drusy quartz linings, and consist in large part of euhedral crystals or loose aggregates of crystals showing numerous crystal faces, also indicating free growth into open spaces. In other places, small veinlets of ore minerals fill minor fractures in the strongly altered host rock and locally seem to have corroded and replaced the walls of the fracture somewhat. Some of these veinlets are layered and crustified, showing several periods of sulfide deposition subsequent to alteration of the walls.

The change from strong leaching and silicification to the deposition of ores and related minerals in the open cavities also marked a change from strongly oxidizing conditions characterized by the formation of sulfuric acid and sulfate minerals to a generally reducing environment favorable for the deposition of the sulfides. The change from oxidizing to reducing conditions was not everywhere complete, and locally conditions seem to have varied from reducing to partially oxidizing. Barite is a widespread associate of the sulfide minerals and shows complex paragenetic relations with them, indicating that conditions were locally favorable for the deposition of sulfates at times during the period of ore deposition. Native sulfur, which commonly forms by partial oxidation of H_2S, was deposited in the same general environment as the sulfides, although normally the sulfur and sulfides are not closely associated and presumably did not form concurrently at any given place. In a few specimens small crystals of sulfur were seen projecting out into the open cores of cavities lined otherwise by enargite, indicating that locally at least partly oxidizing conditions followed the reducing environment favorable for sulfide deposition. The alternation of sulfide deposition and minor leaching suggested by textures seen in many of the polished sections also indicates that conditions varied widely during the period of ore deposition. This local leaching may have resulted from episodic or partial oxidation within the mineralizing solution to form reagents similar to those responsible for the earlier acid-sulfate leaching.

The relations of the ores and altered rocks at Summitville are similar to those observed by Burbank (1941) in the Red Mountain district in the western San Juan Mountains, Colo., where the ore minerals occur in leached holes and caves in highly silicified pipes that clearly formed under acid-sulfate conditions of alteration. Using the pipelike, or "chimney" ore bodies at Red Mountain as a model, Burbank (1941, 1950) has developed a theory of ore deposition that fits the known facts at Summitville closely. Our information on the changes of alteration and ore deposition with depth are too sketchy to permit a critical evaluation of Burbank's hypothesis, but the close agreement between available fact and theory certainly warrants discussion.

According to Burbank (1941, 1950), the pipelike "chimney" ore deposits like those found at Red Mountain and Summitville form in shallow hydrothermal environments where the geothermal gradients are high and volcanic emanations at high temperatures and pressure approach near the surface. Where an abrupt drop in pressure takes place, the condensed hypogene solutions are fractionated by differential vaporization of the more tenuous and generally acidic constituents. These acidic vapors and their condensates react with the wallrock in an oxidizing environment, and cause the intense leaching characteristic of the acid-sulfate type of alteration. Typically, highly silicified and leached pipes or replacement veins similar to those at Red Mountain and Summitville form. Some of the leached constituents, particularly silica, are reprecipitated in the upper parts of the altering column, and the cumulative effect of this precipitation is to form a semipermeable seal above the fractionating and altering column. Back pressures built up below the semipermeable seal inhibit the differential vaporization of the hypogene solution, which penetrates into the leached and porous rock above and is progressively concentrated by the differential escape of the tenuous gases through the semipermeable cap. By this means the hypogene solution becomes saturated in the metallic constituents which are deposited as relatively pure sulfide aggregates in the open spaces previously leached in the silicified pipes. Conditions within the fractionating column are unstable and are sensitive to sudden and wide variations in temperature and pressure which result from any change in the effectiveness of the sealing envelope. These variations cause complex alternations of leaching and reprecipitation.

As applied to Summitville, the time sequence between acid-sulfate alteration and ore deposition indicates that some sort of a fractionating mechanism was active. The early environment was strongly acidic and oxidizing, as required by theory, and this was followed by a generally reducing environment wherein abundant sulfides were deposited in the earlier leached cavities with little associated gangue material. Compact silica is abundant in the upper parts of the Copper Hill knob, whereas none was noted in the Copper Hill adit level that passes beneath this cap. This evidence suggests that sealing the upper parts of the quartz-alunite zone was an effective process that occurred in the Summitville district. The process could have been sufficiently complete to permit the unoxidized hypogene solution to penetrate upward into vuggy quartz formed by earlier acid-sulfate leaching and there to deposit the sulfides that constitute the ore minerals. The alternating sulfide deposition and leaching noted in some of the polished sections, and the irregular alternation of reducing and partly oxidizing conditions indicated by the relations of the sulfides, sulfur, and hypogene sulfates seem the logical results of variations in the sealing mechanism. When the sealing envelope was effective, reducing conditions and sulfide deposition extended upward into the previously leached vuggy quartz rock; with any local failure of the seal, back pressures would have dropped and oxidizing and acid-sulfate conditions would have prevailed to some extent until the leak was repaired and the seal made effective again.

ECONOMIC GEOLOGY

All the lode production from the Summitville district to date has come from the highly mineralized area on the northeast face of South Mountain (pl. 3), and the placer gold recovered from gravels along Wightman Fork in early days of mining probably had its source in the same area. The ore is closely associated with the highly silicified rocks of the quartz-alunite zone, which form many pipes and irregular tabular masses constituting the veins in the district. Other centers of hydrothermal activity are apparent in the area of altered rocks south and southwest of South Mountain (pl. 2) and in similar areas west of the Summitville district (pl. 1), but mineralized quartz-alunite rocks appear sparse there compared to the main productive center.

As our studies were limited almost entirely to surface exposures, it has been necessary to use other sources for information on the mines and ore deposits at depth. Hills (1885), Patton (1917), and Garrey (1950) have been the best sources of published data, and through the courtesy of Mr. G. H. Garrey, we have had available maps of many of the mine workings, including some geologic maps prepared by him and by members of the staff of Summitville Consolidated Mines, Inc.

The data available have enabled us to outline the general features of the mines and ore deposits, but without firsthand information from the underground workings it is difficult to give much of the detailed geologic information desirable to guide exploration or mine development in the Summitville district. We know that the veins in the district are irregular and discontinuous but we cannot predict these irregularities either laterally or vertically. Certain general trends of the vein zones, believed to represent trends of original fracture zones, are apparent at the surface, but our knowledge of detailed structure is too sketchy to determine whether similar favorable zones exist in areas now covered by talus or other surficial debris. Our lack of knowledge of changes in rock alteration and mineralization at depth is particularly serious, as closely similar ore deposits in the Red Mountain district, Colorado, (Burbank, 1941), the Goldfield district, Nevada (Ransome, 1909), and the Flathead mine, Montana (Shenon, 1935), have shown marked vertical changes and have bottomed at shallow depths.

VEIN ZONES

Most of the larger silicified bodies of the quartz-alunite zone exposed at the surface occur along definite trends (pl. 3) that probably reflect an original fracture pattern within the South Mountain volcanic dome; and the composite map of underground workings (pl. 4) shows that most of the mining in the district has been along these same trends. Smaller pipes and replacement veins have been mined to some extent as well, and some, like the one developed by the Pickens cut, have produced extremely rich ore.

The names that have been applied to the different silicified masses and vein zones are confusing. For the most part this seems to have resulted from the belief of the early miners that the silicified masses extended laterally for a considerable distance. The Tewksbury vein and the Little Annie vein were projected for the full length of the known mineralized belt, and any silicified mass that cropped out approximately on trend with one or the other was assigned to that vein. As mining progressed and the discontinuous nature of the veins became apparent, the older names were restricted and new names were applied. The old names were restricted gradually, however, and what was included in a given vein at one particular time commonly differed from what was included either before or after. Thus it is difficult to determine which silicified bodies are being discussed in many of the earlier accounts of the district, and even the several company mine maps we have inspected are not consistent throughout. The names used in this report are those that appear most commonly and consistently on the company maps; the judgment required in places to decide which name to use, indicates that the names we have applied represent one more stage in the evolution of vein names in the district.

TEWKSBURY VEIN ZONE

The Tewksbury vein zone extends N. 30°W. for more than 1,600 feet from the large mass of highly silicified rock south and west of the portal of the Hugh Bly workings (N. 7200; E. 8000) to the Aztec No. 2 working (pl. 3). Although exposures are too poor to indicate with certainty, the Tewksbury vein zone does not seem to be continuous near the surface. The surface above the central and northern segments of the vein zone is largely covered by a smooth talus slope. No mine workings have been developed near the surface in the central part whereas stopes in the northern and southern parts of the zone either are near the surface, or have broken through to form open glory holes (fig. 12). It seems possible, therefore, that a gap in the mineralized rock, and perhaps in the highly silicified rock as well, exists near the surface in the central part of the vein zone. On the Iowa level, on the other hand, geologic maps prepared by Mr. G. H. Garrey show virtually continuous vein material for the entire distance.

Vuggy quartz rock is confined chiefly to the central parts of the large irregular masses of highly silicified rock near the south end of the Tewksbury vein zone. Where the vein zone is narrower and more tabular, however, the vuggy quartz rock makes up nearly the whole width of the vein. In the northern part, the width of vein material shown by Mr. Garrey on his geologic maps of the Iowa and Golconda No. 2 levels is narrow, and, as the vein under this area was extensively stoped, it seems logical that here also most of the zone may consist of mineralized vuggy quartz rock.

The Tewksbury vein zone has been extensively developed down to the Iowa level (portal altitude 11,872 feet), and has been extensively stoped above this level

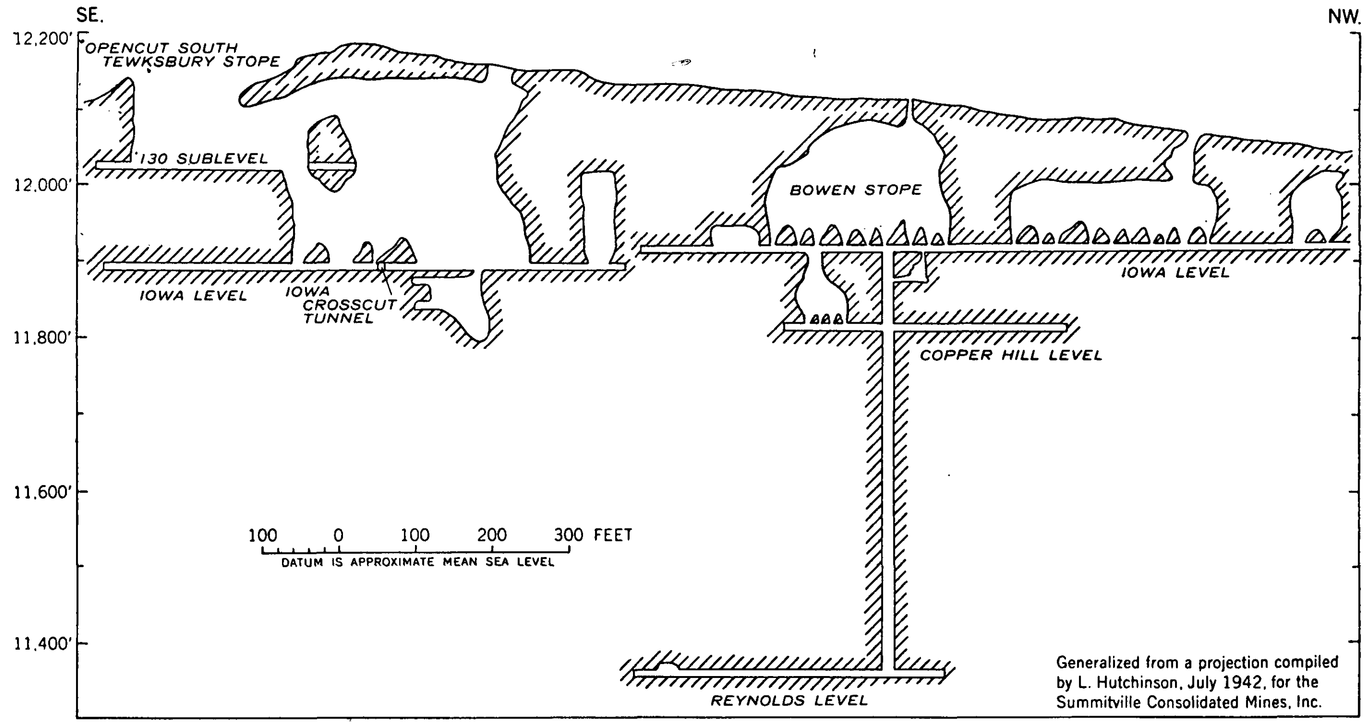


FIGURE 12.—Vertical projection of mine workings and stopes on the Tewksbury vein.

in the northern and southern parts of the zone (fig. 12). The Copper Hill level (portal altitude 11,807 feet) follows the northern segment of the vein zone for several hundred feet, and some stoping has been done between this level and the Iowa level. The Reynolds level (portal altitude 11,318 feet) intersects the northern part of the Tewksbury vein zone and follows south along it for 300 or 400 feet (the different company maps inspected by us were not consistent), and north approximately parallel to it for more than 200 feet. No geologic map of any of these workings was seen, but incidental notations on workings maps indicate that both gold and copper contents of economic interest extend to the Reynolds level.

The closely superposed mine levels on the southern part of the Tewksbury vein zone (pl. 4) indicate that here the zone is almost vertical. The position of the levels in the northern part of the vein zone near where the Golconda No. 2 and Reynolds crosscut tunnels intersect the vein zone indicate a dip of about 75° E. down to the Copper Hill level, and about 85° E. between the Copper Hill and Reynolds levels.

AZTEC-McDONALD-BLACK WONDER VEIN ZONE

This vein zone comprises a group of discontinuous, intersecting veins, pipes, and irregular pods that extend about 800 feet northwest from the Aztec glory hole approximately parallel to the northern part of the Tewksbury vein zone (pl. 3). The only surface exposures along this vein zone are in the Aztec glory hole (pl. 7); elsewhere the trend of the zone is indicated by shallow conical depressions in the talus that reflect caved stopes below. The representation of the vein zone shown on plate 3 was obtained by generalizing the geology mapped by Mr. G. H. Garrey on the Iowa, Golconda No. 1, Golconda No. 2, Aztec No. 1, and Aztec No. 2 levels, and projecting it to the surface. This representation is general and does not reflect the highly irregular and discontinuous character of the vein zone indicated by Mr. Garrey's maps. The vein zone varies so greatly from level to level that it was not possible to predict accurately its upward projection.

At the surface the Aztec vein appears to be an oval-shaped pipe of highly silicified quartz latite, surrounded by a soft white highly argillized envelope (pl. 7). This envelope appears to wrap over the top of the pipe at the southeast edge of the Aztec glory hole, and these exposures may be near the original top of the silicified pipe. Judging from Mr. Garrey's geologic maps of the Aztec No. 1 and Iowa levels, the pipelike form persists through these levels, but between them on the 90-foot level (about 90 feet above the Iowa level) the vein is shaped like a cross defined by major tabular projections extending northwest and southeast along the predominate trend of the vein zone, and northeast and southwest across this trend. These relations suggest that the Aztec pipe was localized at the intersection of fractures, and that the intense alteration represented by the quartz-alunite zone extended out along these fractures away from the main pod localized at their intersection.

The Aztec pod is extensively developed down to the Iowa level, and has been largely stoped above the 90-foot level (fig. 13). Abundant silicified rock appar-

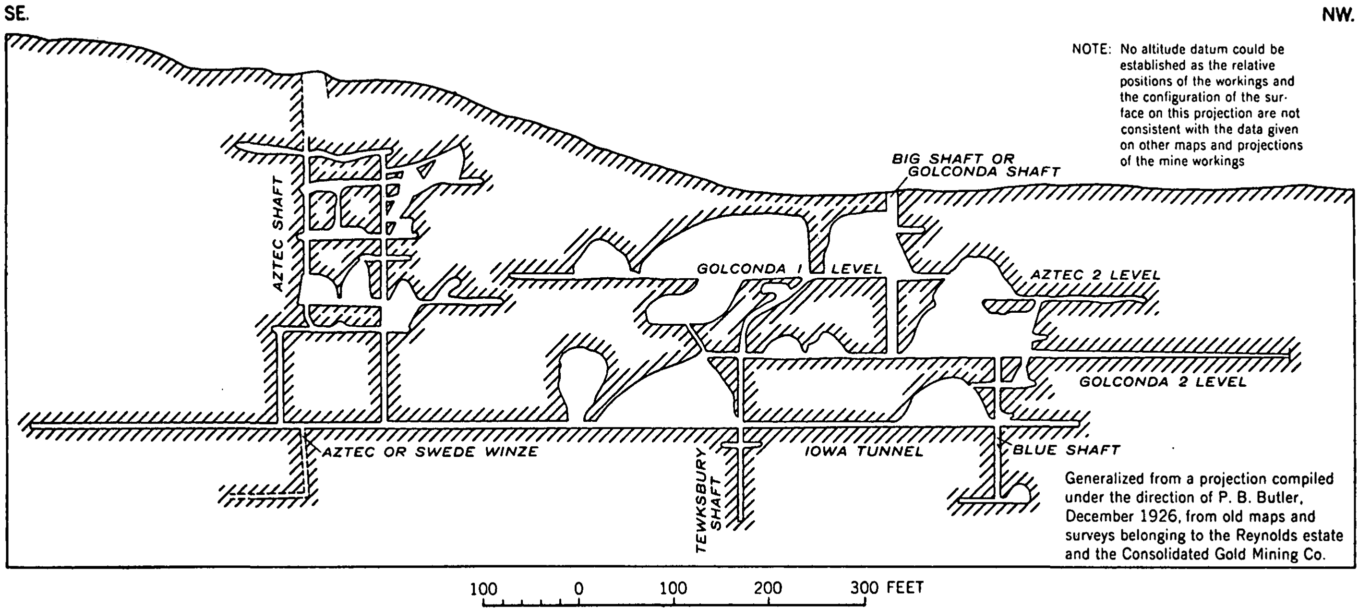


FIGURE 13.—Sketch vertical projection of mine workings and stopes on the Aztec and Black Wonder veins.

ently is still present at the Iowa level, but no known workings cut the vein at greater depths.

The McDonald vein cuts northwestward across the north to N. 30° W. trend of the vein zone as a whole, and forms a link between the slightly offset Aztec and Black Wonder segments of the zone. According to Mr. Garrey's geologic maps of the Iowa and Golconda No. 1 levels, the McDonald vein is joined on the north by the Black Wonder vein. Northwest of the junction it seems to diminish in width and perhaps in degree of mineralization. On the Golconda No. 1 level, tabular projections extend north and south of the main McDonald vein about on trend with the elongate Aztec pipe, again indicating the control of intersecting fractures on the localization of the highly silicified replacement veins. The strike and dip of the McDonald vein changes from place to place, and the vein appears highly irregular and perhaps discontinuous. On the Golconda No. 1 level the vein strikes generally N. 60° W., but on the Iowa level, 180 to 200 feet below, the vein strikes more nearly N. 50° W. This divergence apparently is due to a progressive steepening in dip from near 80° NE. near the intersection of the Black Wonder vein to nearly vertical about 120 feet farther southeast.

Surface depressions are particularly prominent above the McDonald vein, indicating that the shallower parts have been mined extensively. No stope maps of this vein were seen, however, and it is not known just how much ore has been removed. No workings are indicated below the Iowa level.

The Black Wonder vein (Golconda vein according to some maps) extends from the McDonald vein north and northwest to the Aztec No. 2 workings (pl. 3). Although Mr. Garrey's maps indicate that abundant silicified vein material is present, it seems to form irregular and discontinuous bodies. There is little similarity between the shape and distribution of the silicified bodies along the vein zone on the different levels. The Black Wonder and Tewksbury veins may join on the Iowa level near their north ends, approximately beneath the Aztec No. 2 workings. The superposed workings (pl. 4) show the Black Wonder vein to be nearly vertical down to the Iowa level. No geologic maps were seen of the parts of the Copper Hill and Reynolds levels beneath this area, so the character at greater depths is not known.

The Black Wonder vein is developed by the Golconda No. 1, Aztec No. 2, Golconda No. 2, Iowa, and Copper Hill levels, and by two short winzes below the Iowa level. Stoping has been done largely above the Iowa level (fig. 13).

HIDDEN VEIN ZONE

The Hidden vein is a narrow, obscure zone of highly silicified and mineralized rock that trends N. 40–60° W. across the central part of the main mineralized area, approximately parallel to the nearby southwest margin of the highly silicified Copper Hill knob. Although smaller than most of the other vein zones, the Hidden vein is as extensively developed and mined as any in the district. Judging from surface outcrops, which are well exposed in the many pits and open stopes, the Hidden vein is a continuous tabular mass of vuggy quartz from a point about 50 feet southeast of the Elithorpe shaft to about 310 feet northwest of the shaft. The vuggy quartz rock generally has a narrow selvage of quartz-alunite rock, and is flanked by an envelope of soft, highly argillized rock. To the southeast, several small pipelike masses of highly silicified rock completely surrounded by soft argillized rock occur on trend with the Hidden vein (pl. 9).

Geologic maps prepared by Mr. Garrey for the Copper Hill level, Narrow Gauge level, and Narrow Gauge 104-foot sublevel suggest that the vein zone is much more complex at depth, and consists of many irregular, discontinuous and overlapping masses. Judging from the position of the workings on the different levels (pl. 4), the zone as a whole dips about 85° SW.

The stope map of the Hidden vein (fig. 14) shows almost continuous stoping above the Copper Hill level for about 160 feet southeast of the Elithorpe shaft, but on the surface the vein ends about 50 feet southeast of the shaft. This would suggest that the vein pinches out upward and is blind in part; the isolated pipes of silicified rock exposed southeast of the surface termination of the main Hidden vein may thus mark local upward projections of a more continuous vein zone at depth.

The Hidden vein is developed by the Copper Hill level, Narrow Gauge level, Narrow Gauge 104-foot sublevel, and the Reynolds level, and is extensively stoped from the Narrow Gauge 104-foot sublevel to the surface (fig. 14). A winze has been sunk more than 100 feet from the Narrow Gauge 104-foot sublevel, and two raises and two stopes have been started above the Reynolds level. Incidental notations on several of the company mine maps indicate that gold and copper concentrations of commercial grade are exposed, in places at least, on all of these lower workings.

COPPER HILL-ESMOND VEIN ZONE

The largest mass of highly silicified rock of the quartz-alunite zone in the Summitville district extends

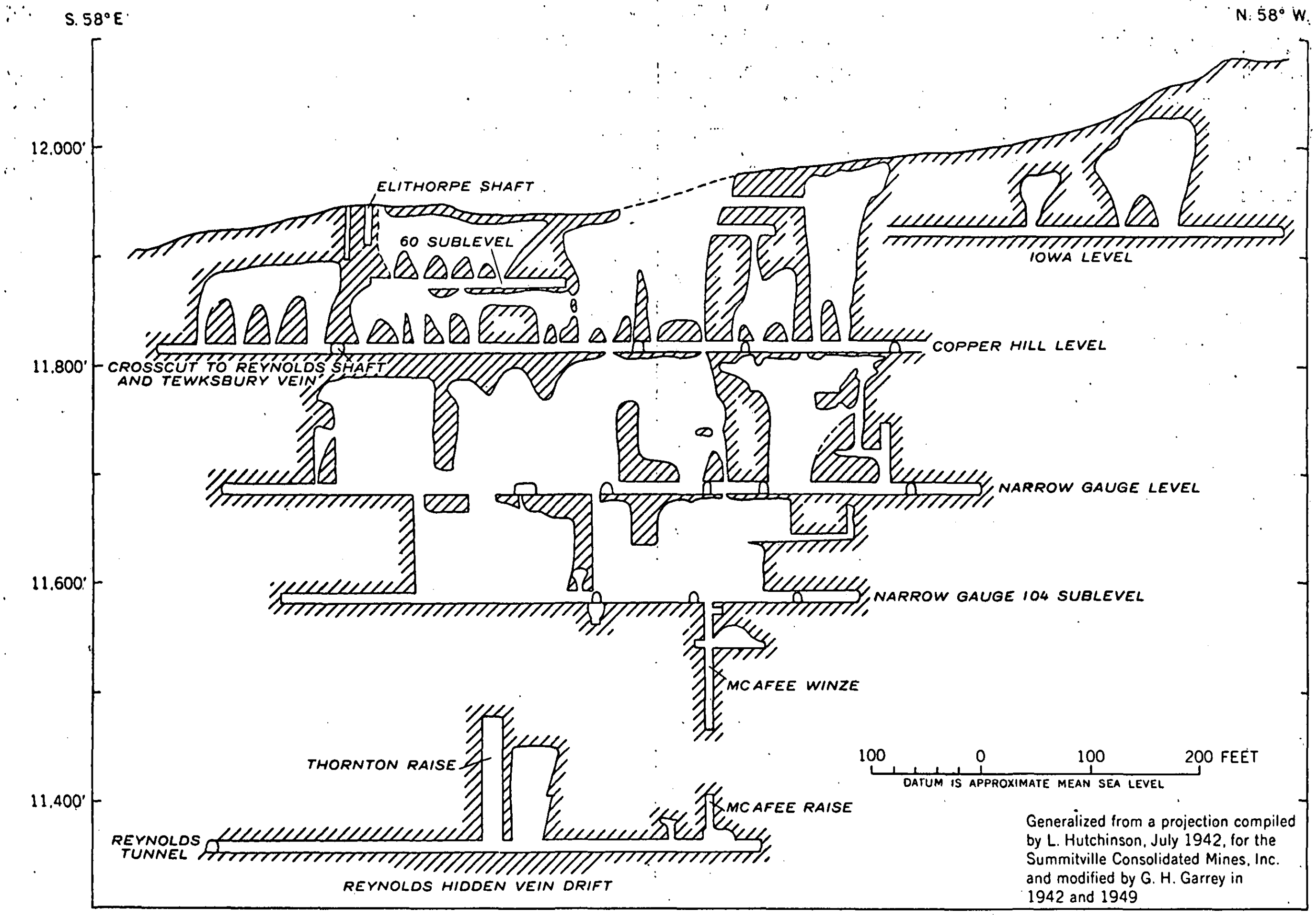


FIGURE 14.—Vertical projection of mine workings and stopes on the Hidden vein.

northwest across the center of the main mineralized area from the Copper Hill knob to the Esmond vein (pl. 3). Mineralized vuggy quartz rock is erratically distributed within this mass, and many mine workings have been driven into it to develop the irregular and pipelike ore bodies. The complex pattern of these mine workings, including the Copper Hill, Narrow Gauge, Upper Highland Mary, Lower Highland Mary, Bob Tail, Del Norte, Winchester, and Esmond levels, is shown on the composite level map (pl. 4). These in conjunction with the many small glory holes and stopes that open to the surface reflect the irregular shape, size, and distribution of the ore bodies.

Many names have been applied at different times to parts of this large silicified mass. These reflect the evolution of ideas regarding the extent or correlation of vein zones and ore bodies, and changed from time to time as continued mining proved one or another of these ideas wrong. The name used in this report merely compounds the names of workings at the two ends of the vein zone, and to our knowledge has not been used before.

The leached vuggy quartz rock within the large silicified mass is so erratically distributed that few generalizations can be made. Judging from Mr. Garrey's geologic maps, and from a hurried inspection of the Copper Hill level, the large silicified mass capping the Copper Hill knob apparently gives way at depth to a series of more distinct silicified zones separated by septa of less altered rock. In cross section the knob thus somewhat resembles a tooth, with a solid compact mass on top and a series of roots projecting downward (pl. 2). At the surface the masses of vuggy quartz rock range from elongate branching bodies that reflect a former joint pattern, to more pipelike masses which display irregular but generally equidimensional horizontal cross sections. Local irregular tongues project at random from bodies of all types. The largest masses of vuggy quartz seem to be in the northwestern part of the silicified mass, but lack of exposures here prevent interpreting the shapes or relations of the bodies.

No stope maps were seen to indicate the shape of the ore bodies in vertical section, but the close superposition of the areas of more concentrated mine workings (pl. 4) suggests that most of the ore bodies in the Copper Hill-Esmond vein zone are pipelike. Almost no development work is indicated below the Narrow Gauge level, and the company maps did not indicate the grade or character of the mineralized rock on this level.

LITTLE ANNIE VEIN ZONE

The Little Annie vein zone is the northernmost of the more extensively developed vein zones in the Summitville district, and was the largest producer of gold during the early boom days of the camp. Surface mapping shows that this zone comprises an irregular tabular mass of highly silicified rock and has many local projections where the silicification followed out on eastward and northeastward-trending cross fractures. The silicified material is almost entirely vuggy quartz rock, except for local selvages or irregular inclusions of quartz-alunite rock. The vuggy quartz rock still remaining on the walls of the opencuts and near-surface mine workings is highly stained with limonite, and according to previous accounts, this oxidized material was the chief ore mined from the vein. All workings on the Little Annie vein (pl. 4) are nearly above one another, indicating that the vein is almost vertical.

Exposures near the southeast end of the Little Annie vein zone are too poor for the termination to be mapped accurately, but the zone appears to end abruptly near the portal of the Winchester workings. The northwest end of the zone is covered by the apron of surficial debris that blankets the lower slopes of South Mountain, and apparently is nowhere exposed by underground workings.

The projection of silicified rock extending southwestward from the Annie opencut, and the elongate pipes on trend with it (pl. 3), have been called the Annie Belle vein on several company maps. Poor exposures prevented accurate mapping of this vein, and the vein may be more continuous than is shown. Underground workings have followed out on the Annie Belle trend for short distances on the Winchester, Montroy, and French levels, and marginal notes on some of the company maps indicate fair concentrations of gold and copper in these workings.

The eastward projection from the Little Annie vein north of the Ida shaft and opencut (pl. 3) has been correlated on many of the company maps with the Dexter (Odin) vein, which will be discussed in the next section. No evidence was seen on the surface for connecting this projection with the highly silicified exposures farther east that belong to the Dexter vein, although they certainly seem to have formed along the same structural trend.

The Little Annie vein zone has been developed by the Winchester, Montroy, French, Ida, Chandler, and Reynolds levels (fig. 15). Most of the stoping has been in highly oxidized ores above the Ida level, although some ore has been removed between the Chandler and Ida levels as well. Notations on company maps indicate that gold and copper in commercial concentrations occur on the Reynolds level, but the maps did not show the continuity of ore.

DEXTER (ODIN) VEIN ZONE

The Dexter (Odin) vein zone is the only eastward-trending zone in the Summitville district that has been developed to any significant extent by mine workings. The vein crops out on the lower flank of South Mountain, and is so obscured by surficial debris that the near-surface shape shown on plate 3 is largely conjecture. At one time or another most of the masses of silicified rock on trend with this vein zone have been referred to the Dexter vein, the Odin vein, or the Oding vein. Of these names, Dexter and Odin have been used almost interchangeably and most commonly have been applied to those bodies of silicified rock lying east of the Little Annie vein; the name Oding, on the other hand, has been applied more commonly to those bodies of similar rock west of the Little Annie vein zone. It is not known whether all the silicified bodies along this eastward-trending zone connect at depth, but at the surface the bodies appear to be discontinuous. The different bodies form a distinct zone, however, and geologic maps of the Dexter and French levels prepared by Mr. Garrey indicate that the trend is well defined on these levels as well. As no stope maps were seen, the extent of mine development is not known.

In the past, the more northwestward-trending projections from the Dexter vein have all been given individual names, or have been correlated with other more prominent vein zones in the district. In the early days the large mass projecting southeast and south from the Dexter was believed to be the northwestern extension of the Tewksbury vein. More recently it has been called the Queen vein, or the Highland Mary vein. The northwesterly projections have been called the Pittsburg and the Queen veins.

MINOR SILICIFIED PIPES AND VEIN ZONES

In addition to the highly silicified masses that occur along the well-defined vein zones, many smaller bodies of similar rock occur sporadically throughout the main mineralized area of the Summitville district.

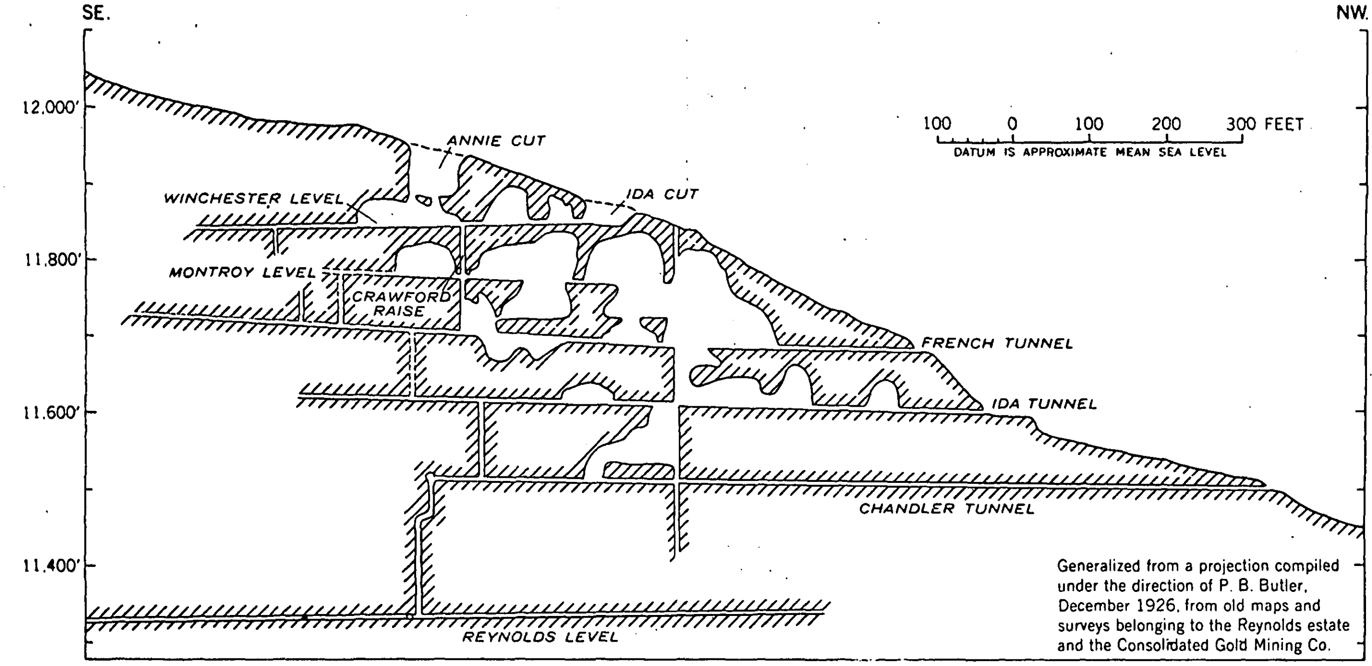


FIGURE 15.—Sketch vertical projection of the mine workings and stopes on the Little Annie vein.

Some of these bodies have yielded good ore, and the one developed by the Pickens cut was fabulously rich. The shapes of many of these scattered bodies shown on plate 3 are highly conjectural and have been interpreted from inadequate data supplied by small, scattered outcrops. Were exposures better, it is probable that other vein zones would be apparent, and any such zones would be worthy of careful investigation of their economic possibilities. Three small but highly mineralized bodies will be described in this section; although perhaps not typical, they are examples of what may be expected at least locally among the scattered minor bodies of silicified rock.

Of the many minor pipes or replacement veins, the one developed by the Pickens cut (pl. 3, coordinates N. 9270, E. 6930) is by far the most famous. At the surface, this small pipe of highly silicified rock measures not more than 30 feet in its maximum diameter, and it is completely surrounded by soft highly argillized quartz latite. Two joint systems, one striking N. 25° W. and dipping 85° E., and the other striking N. 60° E. and dipping 75° SE., are prominent along the margins of the cut and apparently the ore shoot was controlled by the intersection of these fracture systems. In spite of its limited lateral extent, stopes on the pipe extend to the depth of the Winchester level. The rock removed from these workings was hand sorted to about 800 tons of high-grade ore, which brought a gross smelter return of about half a million dollars.[4]

[4] Gold was valued at $20 an ounce.

The Science vein is a good example of a well-mineralized but hidden vein. The surface above it is completely covered by talus, and it was opened up by a crosscut tunnel that intersects the vein about 200 feet in from the portal. Drifts extend along the vein for about 50 feet each way from the tunnel, and a small stope of ore was extracted near the northwest end of the workings. The vein is a narrow body of vuggy quartz and quartz-alunite rock that locally contains abundant enargite and pyrite. The maximum width is probably not more than 10 feet, and in the workings both walls are composed of soft argillized rock. The vein pinches out into highly argillized rock at the northwest end of the workings, but silicified rock is still present at the southeast end.

The Missionary vein occurs along the margin of the Fisher quartz latite at the north base of South Mountain (pl. 2). In contrast with the steeply dipping or vertical pipes and replacement veins in the main mineralized area, the Missionary vein is flat lying and seems to follow the underlying contact between the Fisher and the Conejos. At the surface the Missionary vein stands out as a highly silicified knob flanked by lower ground of highly argillized and pyritized lava of the Conejos on all but the southwest side. A test hole drilled by Newmont Mining Corp. extended beneath this silicified knob and cut through similar argillized Conejos for its full length. The dump of a test pit dug on the Missionary vein shows abundant pyrite and enargite in the holes of strongly leached, vuggy quartz rock.

DISTRIBUTION OF METALS IN THE ORE

Most of the near-surface mine workings examined by us are closely localized in vuggy quartz rock, and all the primary ore specimens collected from the dumps of deeper levels have a similar gangue. Although greatly predominant, this close association of ore with the more strongly leached rock in the quartz-alunite zone may not be universal; marginal notations on company maps of the deeper levels suggest that gold concentration of commercial grade also may occur in fairly compact rock containing alunite as well as quartz. Evidence is not conclusive, however, and certainly most of the ore mined to date has come from vuggy quartz.

First-hand information on the distribution of metals and the grade of the ore could not be obtained during the period of fieldwork. Garrey (1950, p. 129), however, has given these data in a general way in a short review of the district from which the following section is quoted:

> Native gold is the chief, and practically the only metal of value in the oxidized zone ores, although traces to several ounces of silver are also present in the veins in certain parts of the district.
>
> The free gold ores in the upper levels gradually change in depth to sulphide ores that consist of quartz and altered wall rocks impregnated with varying amounts of copper bearing sulphide minerals carrying gold values with a slightly greater content of silver, but with lesser amounts of free gold associated with cupriferous pyrite, enargite and covellite as the chief copper bearing minerals, although chalcopyrite and chalcocite are sometimes present. Worthwhile amounts of free gold are still recovered in the concentrates from jigs or tables when sulphide ores extracted from the lowest levels of the mines are treated in the mill.
>
> The copper content in the sulphide ores varies from 0.5 percent to 10 percent, or higher, while the gold content varies from a few dollars to $35 per ton, and locally increases to several ounces of gold with small tonnages carrying high-grade gold values and in some areas, worthwhile silver values.

Some of the gold in the oxidized zone is coarse enough to be recognized easily in hand specimen, but more commonly it is highly dispersed and can be detected most easily by assay. Copper has been leached from most parts of the oxidized zone, but locally, particularly near the base of the zone, secondary covellite fills holes in the vuggy quartz rock. Our investigation of the ore deposits has been too limited to determine the distribution or association of silver or lead in the oxidized zone.

The association of gold in the primary ores is incompletely known. As noted by Garrey (1950, p. 129), some free gold occurs in all of the sulfide ores, and a small grain of gold adjacent to sulfide minerals was seen in one of the polished sections studied by us. The details of distribution of gold in the sulfide minerals is not well understood. Hills (1885, p. 23) stated that the pyrite was "more or less auriferous," whereas according to Garrey the copper-bearing sulfides contain both gold and silver. In the present investigations, two samples of sulfide-bearing vuggy quartz, one (from the dump of the Chandler mine) containing about 50 percent enargite and 1 percent or less of pyrite, and the other (from the dump of the Copper Hill tunnel) containing at least 50 percent pyrite and no visible enargite, were assayed for gold and silver. The enargite-bearing sample contained 0.20 ounce per ton of gold and 4.50 ounces per ton of silver, but the pyrite-bearing sample contained none of either. Although these definitely show that gold and silver are associated with some enargite at least, we consider our data too sparse to generalize concerning the possible lack of gold in pyrite.

Enargite is the chief copper mineral in the primary ores, although chalcopyrite was seen locally. The pyrite also appears to contain copper, as already noted by Garrey (1950, p. 129). A semiquantitative spectrographic analysis of a pyrite concentrate containing some quartz gave the following result:

Semiquantitative spectrographic analysis of a pyrite concentrate containing some quartz[1]

[Analyst, Paul R. Barnett. Laboratory No. C502, field No. Sc-3]

Si	M	Co	0.0003
Al	0.03	Cr	<.001
Fe	M	Cu	1.5
Ti	.03	Ga	<.0005
Mn	.0007	Nb	Tr.
Ca	.015	Ni	.0015
Mg	.0015	Pb	.007
Ag	.015	Zn	.015
Ba	.0015	Zr	.0015
Bi	.015		

[1] Figures are reported to the nearest number in the series 7, 3, 1.5, 0.7, 0.3, and 0.15 in percent. 60 percent of the reported results may be expected to agree with results of quantitative methods. M=major constituent (greater than 10 percent). <=less than number shown; here standard sensitivities do not apply.

Looked for but not detected: P, Na, K, As, Au, B, Be, Cd, Ce, Dy, Er, Gd, Ge, Hf, Hg, In, Ir, La, Li, Mo, Nd, Os, Pd, Pt, Re, Rh, Ru, Sb, Sc, Sn, Sm, Ta, Th, Tl, Te, U, V.

According to this analysis, copper is the main minor constituent in the pyrite, although silver is indicated. The threshold of detection for gold (about 0.003) is so high that gold content of commercial grade could be present but not be detected.

The sparse grains of galena and sphalerite in the ores undoubtedly account for the sporadic distribution of lead and zinc in the ores.

VERTICAL CONTINUITY

The highly silicified bodies marking the veins in the Summitville district are characteristically highly irregular, and from what little was seen of the vertical dimension in opencuts and shallow mine workings, the irregularity seems as marked vertically as it is horizontally. This suggestion is borne out by the marked differences in shape of the veins from one level to another as shown by geologic maps prepared by Mr. Garrey. These irregularities, as well as the characteristic lateral discontinuity of many vein zones, make it difficult to predict the presence or position of a silicified mass at any given level, or to correlate an isolated exposure of silicified rock with any vein or vein zone. These difficulties are major factors in planning any exploration program, and add to the risk that must be taken.

The extension of continuous stoping southeast along the Hidden vein beneath surface exposures of soft argillized ground suggests that this vein is blind in part and may never have extended much above present exposures. A similar observation was made at the Aztec glory hole where an envelope of soft argillized rock wraps over the southeast end of the pipe (pl. 7). The compact siliceous cap on the Copper Hill knob, as compared with the more normal vuggy quartz rock and quartz-alunite rock exposed on the Copper Hill level below, also may reflect an approach to the original crest of the silicified mass. If these interpretations are correct, it seems distinctly possible that blind pipes or veins may exist beneath less altered surface rocks, and that such pipes or veins may be strongly mineralized. No criteria are yet known that would permit predicting such hidden veins, and the evidence available is more suggestive than conclusive. Theoretically, they would seem more likely to underlie soft argillized rocks of the illite-kaolinite zone than the less altered rocks of the montmorillonite-chlorite zone, but the argillized envelope around some known bodies of silicified rock is relatively thin and conceivably might be somewhat obscure above such a body.

The vertical continuity of the known vein zones and ore shoots in the Summitville district is of more immediate economic interest. Within the main mineralized area, vein material of ore grade extends from the surface outcrop of the Aztec pipe (altitude 12,320) to the Reynolds level (portal altitude 11,318) and known ore on the Tewksbury vein zone extends for nearly this range. The question of how much deeper the ore-grade material will extend cannot be answered directly, but estimates based on analogies with other districts with similar ore deposits are not optimistic. In the Red Mountain district in the western San Juan Mountains, Colo., similar silicified and mineralized pipes were productive through vertical ranges generally less than a thousand feet (Burbank, 1941, p. 181), and at Goldfield, Nev., Ransome (1909, p. 173) reiterated an earlier statement that "there is considerable evidence in favor of the conclusion that ores of the grade now required for shipment are not likely to extend to as great a depth as 1,000 feet." The ore body of the Flathead mine, Montana (Shenon, 1935) pinches out downward and is nearly absent on the lower levels of the mine, about 150 feet below the outcrop. If the theory of origin of these masses developed by Burbank (1941, 1950) at Red Mountain is correct, the vertical range of the silicified bodies and their contained ores should be limited to that restricted zone where abrupt drops in pressure on the rising hypogene solution permitted fractional vaporization and the development of acid-sulfate condensates.

OTHER FACTORS

Only one minor fault was recognized during surface mapping of the main mineralized area in the Summitville district. This fracture zone extends from near the portal of the Esmond workings north through the portal of the Del Norte workings, and is marked by a zone of brecciated rock 1 to 1½ feet wide. No offset was noted at the margins of the zones of altered rock, and the displacement apparently was minor. In contrast with our surface mapping, Mr. Garrey noted many faults and sheared zones in his studies of the underground workings. Many of the faults shown by Mr. Garrey are in rocks that probably correspond to our illite-kaolinite or montmorillonite-chlorite zones where surface exposures are characteristically sparse. We can only conclude that in the absence of detectable offset at the surface, most of the faults and sheared zones noted in the underground workings must be minor.

Many small bulbous dikes of probable late Fisher age were mapped along the west margin of the main mineralized area. These have been interpreted as occurring after mineralization as they are only slightly altered and cut indiscriminately across zonal margins on the older altered rocks. On the underground geologic maps of Mr. Garrey, on the other hand, many dikes are shown throughout the main mineralized area. We are hesitant to extend our interpretations from the dikes exposed at the surface to those shown by Mr. Garrey, and prefer merely to call attention to the features.

SUGGESTIONS FOR PROSPECTING

Within the main mineralized area (pl. 3), the best exploration possibilities seem to be at depth along the known vein zones. These possibilities are more suggestive than conclusive, as our observations have been limited largely to surface exposures, and we are without firsthand knowledge of the character of the altered rock or distribution of ore at depth. Incidental notations on many of the company mine maps indicate that in places at least ore extends to the Reynolds level on every vein zone intersected by this level. Considering that the Tewksbury and Aztec-McDonald-Black Wonder veins are very little explored below the Iowa level (figs. 12, 13), the southeastern part of the main mineralized area would seem more favorable for development work on the lower levels. The large silicified mass extending from the Copper Hill knob to the Esmond vein is virtually unexplored below the Narrow Gauge level. The erratic distribution of vuggy quartz rock and ore within the explored parts of this mass would suggest that it may be difficult to locate targets for exploration work with any precision, but the possibility for local ore bodies seems good. The Little Annie vein zone proper has been developed down to the Reynolds level and although the lower levels have not produced much ore, notations on company maps indicate that ore-grade material is present. The intersecting vein zones, such as the Annie Belle or the Dexter (Odin) zone, have not been explored thoroughly, and may be favorable areas for exploration work. In addition to the known vein zones, many of the smaller pipes or replacement veins may be worthy of careful investigation; if the existence of additional vein zones can be established by such work, they may hold promise of more continuous stoping ground.

Only a part of the main mineralized area of the Summitville district is included in the detailed geologic map (pl. 3) or the composite map of underground workings (pl. 4). Highly silicified pipes and replacement veins occur along the north flank of South Mountain for 1,200 feet or more west of the area shown on plate 3, and in addition, the highly silicified and mineralized Missionary vein at the northern base of South Mountain suggests that other silicified masses may exist beneath the thick apron of surficial debris that covers the lower slopes of the mountain between the area shown on plate 3 and the Missionary vein. None of these marginal pipes has been productive to date, but many are as intensely altered as some of those known to be mineralized, and none can be ignored by any comprehensive exploration program.

A prominent area of altered rocks marked by abundant opal and soft clay occurs along the ridge crest 1,000 to 3,000 feet northwest of Cropsy Peak (pl. 2). These rocks are similar to those generally formed under near-surface acid-sulfate conditions where the sulfuric acid can be ascribed to surficial oxidation of H_2S (White, 1955). Two small masses of porous gray to bluish-gray quartzose rock containing disseminated pyrite, similar to the mineralized vuggy quartz rock in the veins on the northeast face of South Mountain, were noted near the lowest saddle on the ridge, indicating that the opaline and clayey rocks may be underlain by rocks altered under deeper level acid sulfate conditions similar to those that effected the main mineralized area. Our present knowledge is too sketchy, however, to permit predicting the presence or relations of any mineralized bodies. Thus, although the general character of the altered rocks suggests that this local area is possibly worthy of long-range exploration, we cannot outline specific targets.

The lobate enlargement at the southwest end of the larger area of rocks altered during Fisher time (pl. 2) contains many clayey and opaline rocks similar to those along the ridge crest northwest of Cropsy Peak, and in a few places contains bodies of gray quartz rock containing abundant fine pyrite. Exposures are too poor to assess the potential of this area, but the intensity of alteration, and type of decomposition products suggests that this area is worthy of some prospecting. The pyritic gray quartz rock closely resembles the rock in some of the ore-bearing siliceous bodies in the main mineralized area, and thus is of the most immediate economic interest. Bodies of this rock were noted at two places near the southernmost part of the area of altered rocks.

Small elongate masses of pyritic vuggy quartz rock were noted in both of the marginal areas of altered rocks along the western part of the area covered by our reconnaissance survey (pl. 1). Rocks in both of these areas were altered during the Fisher period of volcanism, and the decomposition products show many similarities to those in the vicinity of South Mountain. The ground was covered too rapidly to permit close inspection of the highly silicified bodies, but our brief observations suggested that further prospecting in these areas might be well worthwhile.

LITERATURE CITED

Allen, E. T., and Day, A. L., 1935, Hot Springs of the Yellowstone National Park: Carnegie Inst. Washington Pub. 46, 525 p.

Anderson, C. A., 1935, Alteration of the lavas surrounding the hot springs in Lassen Volcanic National Park: Am. Mineralogist, v. 20, no. 4, p. 240–252.

Burbank, W. S., 1941, Structural control of ore deposition in the Red Mountain, Sneffels, and Telluride districts of the San Juan Mountains, Colorado: Colorado Sci. Soc. Proc., v. 14, no. 5, p. 141–261.

——— 1950, Problems of wall-rock alteration in shallow volcanic environments: Colorado School Mines Quart., v. 45, no. 1B, p. 287–319.

Butler, B. S., 1919, Primary (hypogene) sulphate minerals in ore deposits: Econ. Geology, v. 24, no. 8, p. 581–609.

Cross, Whitman, and Larsen, E. S., 1935, A brief review of the geology of the San Juan region of southwestern Colorado: U.S. Geol. Survey Bull. 843, 138 p.

Day, A. L., and Allen, E. T., 1925, The volcanic activity and hot springs of Lassen Peak: Carnegie Inst. Washington Pub. 360, 190 p.

Emmons, W. H., 1912, The agency of manganese in the superficial alteration and secondary enrichment of gold deposits in the United States: Am. Inst. Mining Engineers Trans., v. 42, p. 3–73.

Emmons, W. H., 1913, The enrichment of sulphide ores: U.S. Geol. Survey Bull. 529, 260 p.

Endlich, F. M., 1877, Geologic report on the southeastern district [Colorado]: U.S. Geol. and Geog. Survey Terr., 9th Ann. Rept., p. 103–235.

Fenner, C. N., 1936, Bore-hole investigations in Yellowstone Park: Jour. Geology, v. 44, no. 2, pt. 2, p. 225–315.

Garrey, G. H., 1950, Summitville mines, Rio Grande County, Colorado, *in* The Nineteen Fifty Mining-Year Book: Colorado Mining Assoc. and affiliated organizations, p. 129–130.

George, W. O., 1924, The relation of the physical properties of natural glasses to their chemical composition: Jour. Geology, v. 32, p. 353–372.

Graton, L. C., and Bowditch, S. I., 1936, Alkaline and acid solutions in hypogene zoning at Cerro de Pasco: Econ. Geology, v. 31, no. 7, p. 651–698.

Grim, R. E., 1953, Clay mineralogy: New York, McGraw-Hill Book Co., 384 p.

Hauser, E. A., and Reynolds, H. H., 1939, Alteration of glasses to montmorillonite: Am. Mineralogist, v. 24, no. 9, p. 590–597.

Henderson, C. W., 1926, Mining in Colorado: U.S. Geol. Survey Prof. Paper 138, 263 p.

Hills, R. C., 1885, Ore deposits of Summit district, Rio Grande County, Colorado: Colorado Sci. Soc. Proc., v. 1, p. 20–37.

——— 1917, Notes on rare mineral occurrences: Colorado Sci. Soc. Proc., v. 11, p. 203–208.

Johannsen, A., 1932, A descriptive petrography of the igneous rocks, v. 2, The quartz-bearing rocks: Chicago Univ. Press, 428 p.

——— 1939, A descriptive petrography of the igneous rocks; 2d ed.; Chicago Univ. Press, v. 1, 318 p.

Krauskopf, K. B., 1951, Physical chemistry of quicksilver transportation in vein fluids: Econ. Geology, v. 46, no. 5, p. 498–523.

Larsen, E. S., Jr., and Cross, Whitman, 1956, Geology and petrology of the San Juan region, southwestern Colorado: U.S. Geol. Survey Prof. Paper 258, 303 p.

Leonard, R. J., 1927, The hydrothermal alteration of certain silicate minerals: Econ. Geology, v. 22, no. 1, p. 18–43.

Lovering, T. S., 1950, The geochemistry of argillic and related types of rock alteration: Colorado School Mines Quart., v. 45, no. 1B, p. 231–260.

MacGinitie, H. D., 1953, Fossil plants of the Florissant beds, Colorado: Carnegie Inst. Washington Pub. 599, Contr. Paleontology, Washington, D.C., 198 p.

Morey, G. W., and Ingerson, Earl, 1937, The pneumatolytic and hydrothermal alteration and synthesis of silicates: Econ. Geology, v. 32, Supp. to no. 5, p. 607–761.

Patton, H. B., 1917, Geology and ore deposits of the Platoro-Summitville mining district, Colorado: Colorado Geol. Survey Bull. 13, 122 p.

Pirsson, L. V., 1894, On the crystallization of enargite: Am. Jour. Sci., 3d ser., v. 47, p. 212–215.

Ransome, F. L., 1909, The geology and ore deposits of Goldfield, Nevada: U.S. Geol. Survey Prof. Paper 66, 258 p.

Raymond, R. W., 1877, Statistics of mines and mining in the States and Territories west of the Rocky Mountains: U.S. Treasury Dept., U.S. Commissioner Mining Statistics, 8th Ann. Rept.

Ross, C. S., and Hendricks, S. B., 1945, Minerals of the montmorillonite group, their origin and relation to soils and clays: U.S. Geol. Survey Prof. Paper 205–B, p. 23–79.

Schmitt, Harrison, 1950, The fumarolic-hot spring and "epithermal" mineral deposit environment: Colorado School Mines Quart., v. 45, no. 1B, p. 209–229.

Schwartz, G. M., 1953, Geology of the San Manuel copper deposit, Arizona: U.S. Geol. Survey Prof. Paper 256, 65 p.

Searls, Fred Jr., 1948, A contribution to the published information on the geology and ore deposits of Goldfield, Nevada: Nevada Univ. Bull., v. 42, no. 5, 24 p.

Shapiro, Leonard, and Brannock, W. W., 1952, Rapid analysis of silicate rocks: U.S. Geol. Survey Circ. 165, 17 p.

Shenon, P. J., 1935, Genesis of the ore at the Flathead mine, northwestern Montana: Econ. Geology, v. 30, no. 6, p. 585–603.

Steven, T. A., and MacLachlan, J. C., 1953, Geology of the Summitville mining district, Colorado: Mines Mag. [Colorado], v. 43, no. 3, p. 18, 139.

Tröger, W. E., 1952, Tabellen zur optischen Bestimmung der gesteinsbildenden Minerale: Stuttgart, E. Schweizerbart'sche Verlagsbuchhandlung.

White, D. E., 1955, Thermal springs and epithermal ore deposits: Econ. Geology (50th Anniversary Volume), pt. 1, p. 99–154.

—— 1957, Thermal waters of volcanic origin : Geol. Soc. America Bull., v. 68, p. 1637–1657.

Willard, M. E., and Proctor, P. D., 1946, White Horse alunite deposit, Marysvale, Utah: Econ. Geology, v. 41, no. 6, p. 619–643.

Williams, Howel, 1932a, The history and character of volcanic domes: California Univ. Pubs. Geol. Sci., v. 21, no. 5, p. 51–146.

——— 1932b, Geology of the Lassen Volcanic National Park, California: California Univ. Pubs. Geol. Sci., v. 21, no. 8, p. 195–385.

Winchell, A. N., 1951, Elements of optical minerology, 4th ed., pt. 2, New York, John Wiley & Sons.

Yoder, H. S., and Eugster, H. P., 1955, Synthetic and natural muscovites: Geochim. et Cosmochim. Acta, v. 8, nos. 5, 6, p. 225–280.

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