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THE CLIMAX MOLYBDENUM DEPOSIT COLORADO

BY

B. S. BUTLER and J. W. VANDERWILT

WITH A SECTION ON HISTORY, PRODUCTION, METALLURGY, AND DEVELOPMENT

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THE CLIMAX MOLYBDENUM DEPOSIT, COLORADO

By B. S. Butler and John W. Vanderwilt

ABSTRACT

The largest single metal-mining operation in the history of mining in Colorado has been developed at Climax, as a result of the increased use of molybdenum in the steel and other industries. Production of molybdenum at Climax was notable for a short period during the World War; it ceased from April 1919 to August 1924 but since then has shown a steady increase. In 1930 from 1,000 to 1,200 tons of ore was milled daily, using only one unit of the 2,000-ton mill. The mine has a reserve of broken ore sufficient to furnish 2,000 tons daily for 3 years and is being developed to continue to furnish this and a still further increased output as the use of the metal may warrant.

The rocks in the eastern part of the district are of pre-Cambrian age and consist mainly of schist intruded by granite. West of the pre-Cambrian rocks and separated from them by the Mosquito fault are Paleozoic sedimentary rocks. Both pre-Cambrian and Paleozoic rocks have been intruded by Tertiary(?) quartz monzonite and related rocks, which in the pre-Cambrian rocks occur chiefly as dikes and in the sedimentary formation chiefly as sills.

The Mosquito fault, the most pronounced structural feature in the region, is a normal fault with a steep westerly dip and northerly strike. Its age relative to that of mineral deposition as a whole is uncertain, but there has been strong movement on it since the formation of the molybdenum deposit.

The Climax molybdenum deposit is in the pre-Cambrian granite, in which schist inclusions and Tertiary(?) dikes are common. The mineralized area is conspicuous because of the limonite-stained outcrops of altered granite and schist. It includes a central core in which the rocks have been largely replaced by quartz. Around the central core is an envelop made up of moderately altered rock cut in all directions by closely spaced intersecting veinlets. Most of the veinlets are less than a quarter of an inch wide and are composed largely of quartz but in places contain considerable orthoclase. Molybdenite where present is mostly concentrated at the margins of the veinlets, though in a few places small amounts occur near the middle. Fluorite, a minor constituent, occurs along the middle of the veinlets. Outward from this envelop of moderately altered rock the veinlets become less numerous and contain less molybdenite, and the rock grades into the unaltered rocks of the region.

Small veins of pyrite, with a little chalcopyrite, dark-brown sphalerite, hübnerite, topaz, quartz, and fluorite, cut the highly altered central core, the moderately altered ore envelop, and the surrounding zone of slightly altered rock. Sericite veins, apparently later than the pyrite veins, occur throughout the mineralized area. They commonly contain much fluorite and in many places much quartz; in a few places they contain a little molybdenite, dark-brown sphalerite, and topaz, but nowhere do they contain pyrite.

Along strong fissures the molybdenite has been oxidized to considerable depth, but elsewhere oxidation has progressed only a few feet below the present surface. Considerable oxidized material has doubtless been removed by glaciation. No indication of sulphide enrichment of molybdenum has been recognized.

The molybdenite ore occurs in a zone in the envelop of moderately altered or silicified rock that surrounds the central core of highly silicified rock. Present development indicates that the silicified core and the surrounding ore-bearing envelop expand downward and have the general forms of concentric cones that have been truncated by erosion. On the upper or Leal tunnel level the maximum diameter of the central core is about 700 feet, but as much of the deposit has been eroded only approximations of its dimensions above the White tunnel level are possible. The central core on the White tunnel level has a maximum diameter of about 900 feet. The ore zone in the envelop surrounding the core so far developed appears to be fairly continuous and varies in thickness but in places is probably as much as 400 feet thick.

LOCATION AND TOPOGRAPHY

The Climax district is in northeastern Lake County, Colo., in the heart of the Rocky Mountains, where the Continental Divide extends eastward across Fremont Pass and turns northward along the Mosquito Range. (See pl. 24, *B*.) It embraces the Tenmile Amphitheater and the peaks and spurs to the north, east, and south, as shown in plate 23. Its altitude ranges from about 11,000 to 13,600 feet. In early reports the district was said to be in Summit County, but the county line as now determined is three quarters of a mile north of the railroad station at Climax and half a mile north of the present mine workings. Climax station is at Fremont Pass (altitudes 11,320 feet) on the Platte Canyon, South Park, and Leadville narrow-gage line of the Colorado & Southern Railway, which operates the entire year and gives connection with Leadville and Denver. The camp is 13 miles north of Leadville and about 1,000 feet higher, on the highway from Leadville to Dillon, but this highway is generally closed by snow from December to April.

The general offices and mill of the Climax Molybdenum Co. are at Climax, and the men employed in these units live at Climax. The old mine buildings are a mile east of Climax, at an altitude of 11,500 to 11,936 feet, and the employees working in the mine are quartered there. The mine is accessible from Climax only by a road that rises 600 feet in the mile. The Climax Molybdenum Co. has plans for concentrating all its operations and quarters for employees at Climax. The portal of the Phillipson tunnel is about a quarter of a mile northeast of Climax and only a little higher. Prior to 1931 ore was transported from the White tunnel level to the mill by aerial tram, which was abandoned early in that year. Since April 1931 ore from above the White tunnel level has been carried down an ore pass to ore pockets above the Phillipson tunnel level and trammed to the mill in trains of ten to twenty 10-ton cars. The ore pass is 465 feet long and has a slope of 65°. It starts in moderately silicified granite near the mouth of the White tunnel and dips into the highly silicified core of the ore deposit. The blocking out of ore between the Phillipson tunnel and White tunnel levels was begun early in 1931.

CLIMATE

The district has the short, cool summers and long, cold winters characteristic of the high Rockies. Plate 24, *A*, shows the Climax district as it looks for about 6 months in the year.

The following table, from the records of the United States Weather Bureau, gives the average monthly temperature and precipitation for a period of years at Leadville, the nearest station for which records are available.

Monthly, annual, and average precipitation, in inches, at Leadville, Lake County, Colo., 1888–1922 [a]

[Altitude, 10,248 feet]

Year	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Annual
1888	------	------	------	------	------	0.35	1.77	1.06	0.27	1.30	0.68	0.31	------
1889	0.52	0.48	0.68	1.31	2.20	.66	.84	1.58	.53	.69	1.64	1.67	12.80
1890	.42	.68	1.24	.24	------	------	.81	.68	1.20	.77	.11	.38	------
1891	.50	4.75	4.65	1.92	------	------	------	------	------	------	------	------	------
1895	------	------	------	------	------	------	------	------	.78	.58	.65	.85	------
1896	1.26	1.00	3.90	.30	.77	T.	3.00	.85	1.05	.54	.95	.80	14.42
1897	.32	1.54	2.77	1.50	1.34	1.43	1.45	.91	.50	1.74	.62	1.39	15.51
1898	.40	.62	.61	1.88	1.25	.36	1.31	1.49	.20	.93	2.26	.96	12.27
1899	2.98	4.00	4.42	.64	.17	.27	2.21	1.41	.53	2.47	.13	.63	19.86
1900	.60	2.63	.96	4.92	.16	.62	T.	.36	1.00	.75	.62	.88	13.50
1901	1.02	2.13	1.27	1.43	1.28	1.30	.82	1.69	.07	.22	1.13	1.90	14.26
1902	.51	.76	1.77	2.07	.51	.55	.97	2.62	.47	.40	.35	.77	11.75
1903	1.87	1.12	.78	1.77	1.31	1.62	.58	1.06	1.37	.28	.87	.54	13.17
1904	.41	1.19	2.24	.79	2.05	1.35	.51	1.71	1.26	.55	T.	.86	12.92
1907	------	------	------	------	------	------	------	------	------	------	.08	2.13	------
1908	.68	.58	1.14	1.41	2.37	.90	1.65	1.48	.68	.73	.50	1.31	13.43
1909	3.33	1.76	.65	2.82	.94	.29	2.34	4.74	2.84	.81	1.50	1.74	23.76
1910	1.63	1.23	1.04	.64	.95	.64	1.94	1.07	1.23	.98	.55	1.15	13.05
1911	1.86	.82	1.43	2.02	.70	3.03	3.13	2.89	1.52	2.24	.98	.48	21.10
1912	1.14	1.35	1.92	.62	1.01	2.11	2.48	.83	1.42	1.73	.21	.81	15.63
1913	1.28	1.04	.77	1.29	.20	1.32	3.09	1.63	1.45	1.51	.50	1.83	15.91
1914	2.74	.88	.80	2.13	2.37	1.10	2.41	1.46	.86	1.02	.02	.69	16.48
1915	.46	1.17	.76	1.71	.89	1.69	1.17	1.65	1.58	.92	1.75	1.34	15.09
1916	2.17	1.27	1.04	1 62	1.85	T.	1.91	1.68	1.09	1.91	.59	2.25	17.38
1917	.79	1.05	.67	1.42	2.59	.30	2.50	1.26	.65	.86	.72	1.20	14.01
1918	2.29	2.60	2.17	.92	.40	.28	.28	.97	4.10	1.85	1.12	1.00	17.98
1919	.27	1.50	1.35	2 46	.77	1.46	7.72	1.12	3.77	1.09	2.24	.90	24.65
1920	.78	1.84	2.03	4.11	1.35	.57	4.20	3.78	1.02	1.24	1.16	1.40	23.48
1921	1.41	.85	1.19	3.29	1.37	2.66	4.40	5.99	.98	.92	.67	2.03	25.76
1922	1.03	1.88	1.24	1.71	1.05	.47	3.62	5.46	.23	.90	1.75	3.17	22.51
Mean	1.21	1.51	1.61	1.74	1.19	.97	2.20	1.90	1.17	1.11	.84	1.22	16.67

[a] Amounts for 1895 to May 1903, at station 3 miles south of Leadville.

Average snowfall and temperature at Leadville, Colo.

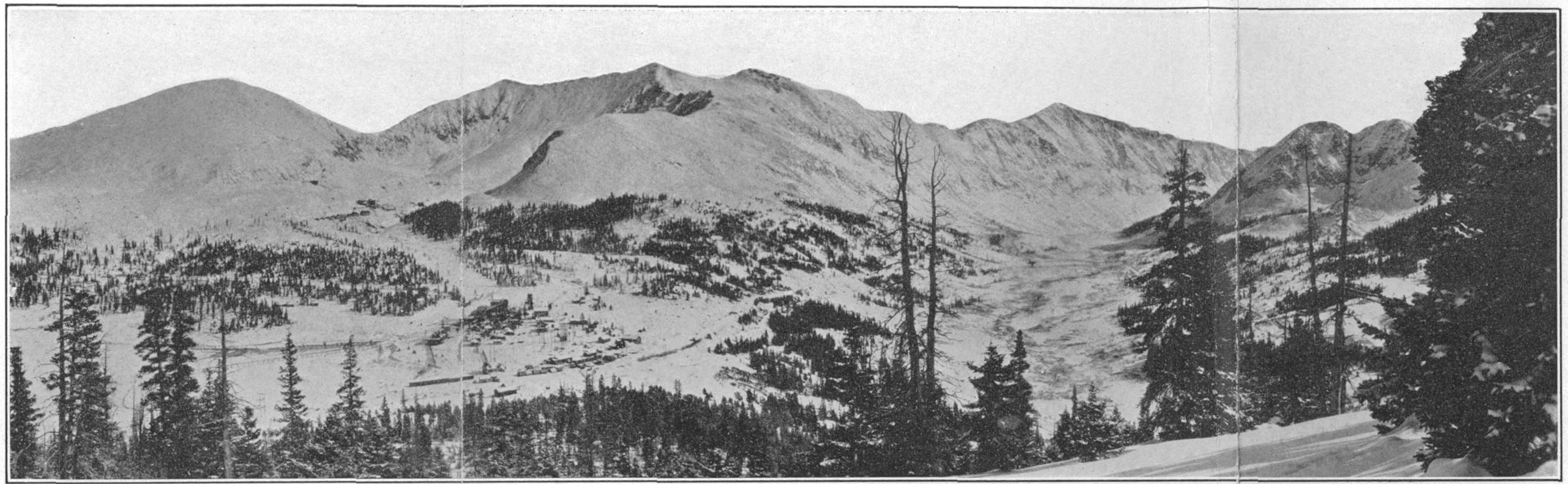
	Snowfall (inches)	Temperature (° F.)				
		Mean	Mean maximum	Mean minimum	Highest	Lowest
Length of record ... years	24	17	17	17	25	25
January	19.0	17.4	29.1	5.6	52	−29
February	20.0	18.6	30.9	6.4	50	−25
March	19.9	24.1	36.4	11.8	57	−15
April	18.0	30.8	42.8	18.8	63	−9
May	8.3	39.9	52.9	26.9	69	6
June	1.7	49.5	64.1	34.9	82	14
July	.2	55.2	69.7	40.6	83	28
August	0	53.8	67.9	39.6	80	25
September	1.8	47.4	61.8	33.1	78	16
October	12.7	36.9	50.0	23.8	74	−5
November	12.4	27.3	39.9	14.7	59	−14
December	16.5	18.2	29.7	6.6	53	−20
Annual	130.5	34.9	47.9	21.9	83	−29

HISTORY AND PRODUCTION

By Charles W. Henderson

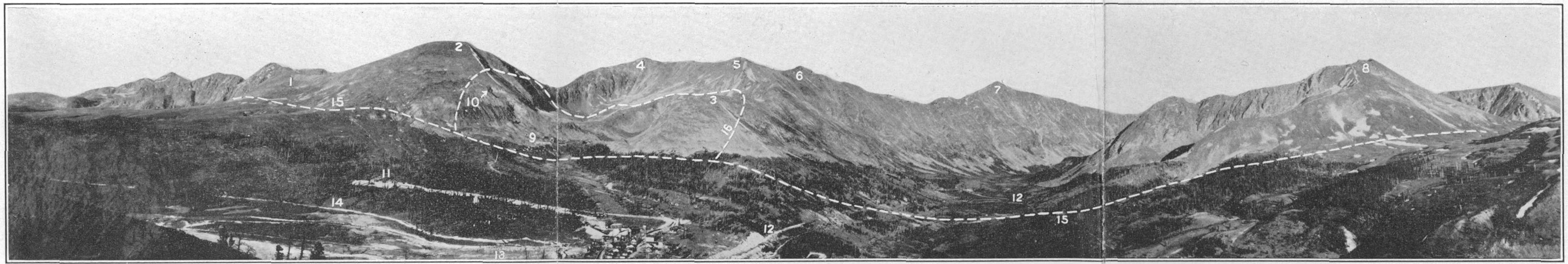
The prominent mineralized outcrop of the Climax deposit, because of its location between the camps of Leadville and Kokomo, must have attracted the attention of prospectors and mining engineers at an early date. The molybdenite, however, was at first mistaken for galena and later for graphite, even as late as 1890. Its yellow oxidation product, molybdite, was also mistaken first for a silver mineral and later for sulphur, as assays showed no silver. Just when these minerals were correctly identified is not known, but they were certainly recognized by one man in 1895 and by the Colorado School of Mines in 1900. The district, like the surrounding region, was prospected for gold, and in 1902 an adit was started by H. Leal to explore a supposed gold-bearing fissure. Molybdenite was recognized during the driving of the last several hundred feet. The adit, still known as the Leal tunnel, passed through several hundred feet of molybdenite ore that carried about 1 percent of MoS_2, which with the talus slopes of ore was so striking and indicated so large a tonnage that it naturally interested miners. Nevertheless, no large amount of capital could be interested to develop the ground. A private report in the files of George E. Collins, mining engineer, of Denver, written in 1905, indicates that he recognized the possibilities of the deposit and recommended the purchase and holding of a large area on Bartlett Mountain, but Mr. Collins' recommendation was not accepted. E. G. Heckendorf, of Denver, spent 3 years, from 1911 to 1913, driving short tunnels through large boulders of brecciated granite that contained molybdenum and lay in the glacial debris at the south and north ends of Chalk Mountain, until he became convinced that the rock was not in place. After 1914 he and others did development work on Bartlett Mountain, including the extension of the Leal tunnel to 690 feet by October 1916. About October 20, 1930, Mr. Heckendorf gave the following interesting history of his part in the opening of the Climax molybdenum deposit:

In 1890 Sam and John Webber and Heckendorf staked claims on Bartlett Mountain. They thought the molybdenite was galena, and when the Colorado School of Mines said it was a poor grade of graphite they dropped the claims. In 1895 a Professor Linderman identified the mineral as molybdenite. In 1900 the Colorado School of Mines identified the molybdenite. As a result of Heckendorf's continued interest, during the summers of 1911 and 1913 he located claims on the glacial boulders of brecciated rock containing molybdenum at Birdseye, near the old town of Tabor, and on the south side of Chalk Mountain. Finding no great quantity here, he moved his operations to the north end of Chalk Mountain, near Robinson. In every place the tunnels would run through the blocks into glacial wash. In 1914 he followed up the glacial debris across Fremont Pass to



A. CLIMAX DISTRICT IN WINTER.

View looking east from Chalk Mountain, which is just west of Climax. Tenmile Amphitheater on the north (left) is separated from the East Fork of the Arkansas River by the Continental Divide, Ceresco Ridge, and Fremont Pass. Bartlett Mountain is on the north side of Tenmile Amphitheater, and the molybdenum-mine workings are on its lower slopes above timber line. Ceresco Ridge forms the south wall of the amphitheater. Climax in the foreground. Mount Democrat (altitude 14,200 feet), in line with the East Fork of the Arkansas, is a short distance south of the area described in this report.



B. PANORAMA OF A PART OF MOSQUITO RANGE INCLUDING CLIMAX DISTRICT.

Climax, on Fremont Pass, in foreground. 1, Little Bartlett Mountain; 2, Bartlett Mountain; 3, Ceresco Ridge; 4, Clinton Peak; 5, McNamee Peak; 6, Travers Peak; 7, Democrat Mountain; 8, Arkansas Mountain; 9, Climax Molybdenum Co.'s mine workings, White level; 10, mine caving on surface; 11, Portal of Phillipson tunnel; 12, Colorado & Southern R.R. (narrow gage); 13, tailings pond; 14, Clinton Gulch diversion ditch; 15, Mosquito fault; 16, approximate boundary of limonite-stained surface characteristic of the mineralized area in Tenmile Amphitheater.

his old locations on Bartlett Mountain. Here he found that A. M. Gillaspey, about 1904 or 1905, had staked the Denver claim. He also found that H. Leal had claims on the mountain. About 1914 John Buffehr and C. J. Senter staked claims next to the Denver. Senter had also had the sad experience of driving holes through blocks at Chalk Mountain. Mr. Heckendorf proceeded to get options on all the property and succeeded on all but the Denver. He was in touch with many chemical works in the United States and Europe but experienced much difficulty in getting assays. Very few assays checked with others. Heckendorf and the Webber Brothers staked out many claims. In 1914 he went to Pittsburgh and laid his options, assays, and maps before Sargent, of the Crucible Steel Co., but the answer was, "Time not ripe." Heckendorf experimented with flotation, and J. M. McClave got a 76 percent saving in the laboratory experiments. In October 1916 he laid his data before Max Schott, Denver manager of the American Metal Co. In October or November 1916 H. L. Brown and M. W. Hayward, engineer and geologist for the American Metal Co., examined the property. These engineers saw the open cuts of Heckendorf and Buffehr, and at that time Leal and Heckendorf had the Leal tunnel in 690 feet. Leal had 5, Buffehr 2, Senter 2, and Heckendorf had many claims in the Tenmile Amphitheater. Eric Baer and Leal's son had also located claims to the west of Leal, and O. A. King, of Leadville, had adversed Baer and Leal and also located on Cresco Ridge. As finally executed, the agreement of the operating company was for 80 percent of the stock of the company, with the remaining 20 percent divided equally among John Webber, S. H. Webber, Heckendorf, and a Dr. Harris.

Mr. Heckendorf says that the ore experimented with by the Pingrey Mines & Ore Reduction Co. came from the Leal tunnel and from Buffehr's claims.

Development of the deposit by hand drilling was slow. Prior to 1914 there was only a small market for molybdenum, and the grade of ore here was low. The price in 1914 of $2 a pound of contained MoS_2, or $3.33 a pound of contained Mo, increased the prospectors' hopes, but the very fine, flaky molybdenite was not well adapted to gravity concentration nor effectively concentrated by the flotation method then in use.

Prior to 1913 there was little production of molybdenum in the United States—in fact, from 3 to 10 tons of molybdenum and ferromolybdenum was imported annually. Molybdenum in small percentages was known to give hardness and especially toughness to steel, but the steel industry did not become interested in molybdenum steel for many reasons, one of which was its lack of knowledge that an adequate supply of molybdenum was available. Scientific study of the uses of molybdenum therefore lagged, as compared with studies of other elements used in steels.

In 1913, possibly as a forerunner of the World War, the demand for molybdenum suddenly increased in Europe, and in 1914 a small production was reported in Mineral Resources of the United States. In 1915 the molybdenum content of the 3,498 tons of raw ore reported was valued at $114,866, an average of $32.84 a ton. In the same year

Climax was first mentioned in Mineral Resources as a possible producer of molybdenum as follows:[1]

The Pingrey Mines & Ore Reduction Co., of Leadville, shipped a considerable quantity of low-grade molybdenite ore from the C. J. Senter claims, near Climax, Summit County, and treated it by a flotation process.

The recovery from this shipment of ore is not given. The Pingrey Mines & Ore Reduction Co. that year also treated zinc-lead dump ores from Leadville and Red Cliff in the same mill, the remodeled Leadville district mill, equipped with gravity concentrating tables and the Mineral Separations Co.'s flotation machines.[2]

During 1916 Climax was not credited with any production, although the Pingrey Mines & Ore Reduction Co. continued milling some of the ore experimentally. In the meantime the demand for molybdenum in war materials, especially armor plate for small "tanks", continued. Production in this country increased but was supplied mostly from the lead molybdate, wulfenite, from Arizona.

In 1917 active exploration was begun at Climax by the Climax Molybdenum Co. and the Molybdenum Products Corporation (then owner of the Denver claim), but only the former made any material production. The Molybdenum Products Corporation's mill produced 65,000 pounds of 65 percent MoS_2 concentrate in 1918. From February 1918 the Climax Molybdenum Co. produced ore at the rate of 250 tons daily of about 1 percent MoS_2, with rather poor metallurgical recoveries by flotation. The war had emphasized the value of molybdenum steel, and the development of the deposit at Climax had assured a supply of molybdenum for several years, but although the steel industry used more molybdenum after the war than before, the postwar demand was still too small and erratic to justify operations on the large scale necessary to insure profits at Climax, for the price paid had also dropped to about 72 cents per pound of contained MoS_2. Production was therefore suspended in April 1919.

During the next few years, however, stocks of molybdenum on hand at the end of the war were slowly reduced, especially by the steel industry. A large quantity was imported in 1922. The Climax Molybdenum Co. kept its plant in condition and spent much money in metallurgical research and widespread advertising of the value of molybdenum steel. With contracts for a moderate yearly output the Climax Molybdenum Co. resumed operations in August 1924 at Climax, treating by a remodeled flotation flow sheet 150 tons of raw ore daily, with recoveries averaging 85 percent and the grade of concentrates averaging 85 percent MoS_2. Willis' patents for chrome-molybdenum steels, Alan Kissock's patent on the reduction of MoS_2 to $CaMoO_4$, and the direct use of $CaMoO_4$ instead of ferromolybdenum

[1] Hess, F. L., U.S. Geol. Survey Mineral Resources, 1915, pt. 1, p. 807, 1917.

[2] Henderson, C. W., idem, p. 455.

in the steel furnaces had a strong bearing on the reopening of this deposit. Since 1919 the Climax Molybdenum Co. has been the only producer in the district and has acquired a large part of the mineralized area, including the Denver claim. Gradual increases in sales and gradual improvements in mill recovery and lowering of mining costs induced the company in January 1928 to reduce the price to 95 cents per pound of contained Mo; and on October 1, 1930, despite a decreased output as compared with that in 1929, to 85 cents. From 1924 to 1928 the Climax deposit yielded 3,426 tons of metallic molybdenum, or about 73 percent of the world's output. The production by years is shown in the accompanying table. On October 1, 1930, the company estimated that development of about one third of the deposit had proved 50,000,000 tons of ore. In 1929 the company's mill was enlarged to a capacity of over 2,000 tons of ore a day and was operated at that capacity for several weeks. Coarse crushing at this rate was easily handled by the mine crushing plant and the tram. This supply of ore can be furnished for several years from reserves of broken ore above the White tunnel level. A new crushing plant at the mill, completed in October 1930, is capable of treating 300 tons an hour. It was set in motion November 19, 1930. Early in 1931 the Phillipson tunnel (465 feet below the White tunnel level) had traversed 500 feet of ore carrying 0.80 percent of MoS_2, confirmed the presence of ore to the north and west of the central core, and added a possible 35,000,000 tons to the known ore.

Metallic molybdenum in concentrates produced and sold in 1915–30 from the Climax deposit and in ore and concentrates produced in 1913–29 from the United States, together with world production and imports, 1913–29 (pounds)

	Climax [a]	United States [b, c]	World [c]	Imports [b]
1913			(?)	([d])
1914		1,297	(?)	([d])
1915	Small	181,769	(?)	([d])
1916	Small	206,740	(?)	(?)
1917		350,200	(?)	(?)
1918	342,200	861,637	(?)	[e] 140,222
1919	152,648	297,926	678,000	106,743
1920		34,900	205,000	15,639
1921			19,000	29,783
1922			28,000	412,221(?)
1923		22,667	110,000	16,671
1924	[f] 156,935	297,174	465,000	10,379
1925	821,757	1,154,050	1,380,000	1,954
1926	1,057,367	1,371,000	1,570,000	13,397
1927	1,858,228	2,286,075	2,345,000	12,541
1928	2,957,845	3,329,214	[g] 3,716,000	
1929	3,529,295	3,904,648	4,385,000	
1930	3,083,000	(?)	(?)	(?)

[a] Climax Molybdenum Co.'s production only. The deposit in 1918 should be credited with a small additional production from the Denver claim.
[b] Hess, F. L., U.S. Bur. Mines Mineral Resources, 1928, pt. 1, p. 110, 1929, and prior volumes of Mineral Resources.
[c] Kissock, Alan, Mineral Industry, 1929, p. 448. Hess (op. cit., p. 111) gives "nearly 2,500,000 pounds" for 1927.
[d] Value $15,939 in 1913, $59 in 1914, and $203 in 1915.
[e] July to December only.
[f] Last 5 months. No production first 7 months.
[g] Hess (op. cit., p. 111) gives "nearly 3,430,000 pounds."

PREVIOUS GEOLOGIC WORK IN THE DISTRICT

PUBLISHED REPORTS

Little has been published concerning the geology of the Climax molybdenum district. The area is included on the geologic map of the Mosquito Range that accompanies the report on the Leadville district by Emmons[3] and in the revision of this report by Emmons, Irving, and Loughlin,[4] but the molybdenum deposit is not described in either report. In 1916 Horton,[5] of the United States Bureau of Mines, mentioned the occurrence of a large low-grade deposit of molybdenite at Climax, but he did not describe the deposit. It was first described by Brown and Hayward[6] and by Holland[7] in 1918, and separately by Haley[8] and Worcester[9] in 1919.

Except the reports by Holland and Worcester, these reports are written from the viewpoint of those interested in mining operations, and consequently the description of the geology is confined to a few short paragraphs. The report by Worcester is a survey of all the molybdenum deposits of Colorado without attempting a detailed or comprehensive report on any individual district; nevertheless he recognized the broader relations of the pre-Cambrian granite cut by Tertiary (?) dikes and the age of the mineralization as later than the dikes. He also recognized the replacement character of the deposit and the large extent of the mineralization.

The views of the authors cited above are summarized by Hess,[10] who, however, does not add materially to the meager information of the district.

Two reports by Coulter,[11] general superintendent of the Climax Molybdenum Co. in 1929, briefly summarize the geologic conditions and describe in detail the mining and milling practice.

A report by Staples and Cook[12] in 1931 describes the mineralogy of the deposit and discusses the general occurrence of the ores.

A preliminary report by Butler and Vanderwilt[13] in 1931 describes the general geology and occurrence of the ores.

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[3] Emmons, S. F., Geology and mining industry of Leadville, Colo.: U.S. Geol. Survey Mon. 12, 1886.

[4] Emmons, S. F., Irving, J. D., and Loughlin, G. F., Geology and ore deposits of the Leadville district, Colo.: U.S. Geol. Survey Prof. Paper 148, 1927.

[5] Horton, F. W., Molybdenum; its ores and their concentration: U.S. Bur. Mines Bull. 111, p. 68, 1916.

[6] Brown, H. L., and Hayward, M. W., Molybdenum mining at Climax, Colo.: Eng. and Min. Jour., vol. 105, pp. 905–907, 1918.

[7] Holland, L. F. S., Recent development in molybdenum: Min. and Sci. Press, vol. 117, p. 529, 1918.

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[10] Hess, F. L., Molybdenum deposits; a short review: U.S. Geol. Survey Bull. 761, pp. 4, 9–12, pl. 2, 1924.

[11] Coulter, W. J., Mining molybdenum ore at Climax, Colo.: Eng. and Min. Jour., vol. 127, pp. 394–400, 1929; Crushing and concentrating molybdenum ore at Climax, Colo.: Eng. and Min. Jour., vol. 127, pp. 476–480, 1929.

[12] Staples, L. W., and Cook, C. W., Microscopic investigation of molybdenite ores of Climax, Colo.: Am. Mineralogist, vol. 16, pp. 1–17, 1931.

[13] Butler, B. S., and Vanderwilt, J. W., The Climax molybdenum deposit of Colorado, with section on history, production, metallurgy, and development by C. W. Henderson: Colorado Sci. Soc. Proc., vol. 12, pp. 311–353, 1931.

PRIVATE REPORTS

Paul Billingsley and Tom Lyon, geologists of the International Smelting Co., made a report for the Climax Molybdenum Co. in 1922. At that time only the area above the Leal tunnel level and part of the area above the White tunnel level were developed. The report included a geologic map and sections of the mine. This report was available to the writers, and free use has been made of it. In the fall of 1926 F. C. Calkins, of the United States Geological Survey, examined the deposit. No report on this examination was published, but Mr. Calkins' notes were available to the writers. The deposit has been examined several times by Prof. C. W. Cook, geologist of the University of Michigan, once during a part of the time that the writers were working at Climax in 1929. The results of Cook's examinations have not all been published, but the geologic problems involved were discussed with him by the writers.

FIELD WORK AND ACKNOWLEDGMENTS

The senior author first visited the district in 1926. In September 1927 he made a preliminary examination of 4 days in company with C. W. Henderson, and on their recommendation a topographic map on a scale of 1,000 feet to the inch was surveyed that year by R. R. Monbeck, of the United States Geological Survey, which issued the map in 1928. The present report is based on field work by the writers from August 9 to September 15, 1929. The excellence of the topographic map materially speeded the geologic field work. The areal geology within a radius of about a mile from the deposit was studied in detail and mapped on the topographic base. The geology of the underground workings was mapped, and more than 18,000 feet of diamond-drill cores were examined. The senior author gave 2 months and the junior author 4 months in 1930 to the study and correlation of these field data. The area was again visited by them for a few days in 1930 and 1931.

The authors are greatly indebted to the cordial cooperation of the company officials, H. L. Brown, general manager; W. J. Coulter, general superintendent; and Jack Abrams, assistant general superintendent. The large amount of data collected by the company was placed at the disposal of the writers, and the problems were freely discussed. Such cooperation in an active mine where a large part of the development is still accessible gives a great advantage in geologic study. The personal courtesies extended by the company added to the comforts of the work.

In the preparation of the report the writers have discussed the problems with their colleagues in the Colorado cooperative work, to whom thanks are due for numerous suggestions.

GEOLOGY

GEOMORPHOLOGY

For the broader geomorphic features of the district and the surrounding region the reader is referred to a report by Capps [14] and to the recent report on the Leadville district,[15] which quotes extensively from Capps. The only features that deserve mention here are the drainage relations of Tenmile Creek and the East Fork of the Arkansas River and the local effects of glaciation. Just below the Tenmile Amphitheater Tenmile Creek follows a broad valley which trends north-northwestward and which is sharply cut off at its head from the valley of the East Fork of the Arkansas River at Fremont Pass, on the Continental Divide, by a steep drop of about 300 feet. The upper part of the valley of the East Fork also trends north-northwestward as far as Fremont Pass but there turns sharply to the southwest. These relations suggest that in the early stages of valley development the upper part of the present valley of the East Fork formed the head of Tenmile Valley. At a later stage, but probably still in preglacial time, the headwaters of the East Fork of the Arkansas cut back and captured the head of the Tenmile drainage system.

During glacial time a strong glacier came down from the head of the valley of the East Fork and turned southward, following the present valley, but in the higher stages the ice spilled over the low divide at Fremont Pass and extended down the Tenmile and East Fork of Eagle River Valleys, which are separated by another low divide southwest of Robinson. The presence, high on the slopes of Chalk Mountain, of float similar to the molybdenum ore of the Climax deposit suggests that at some time, perhaps in an early period of glaciation, the glacier from Tenmile Amphitheater pushed across Tenmile Valley against Chalk Mountain. No clear understanding of the conditions can be had until the distribution of float from Tenmile Amphitheater has been more carefully studied.

In the final stages of glaciation the bottom of the Tenmile Amphitheater was probably filled with nearly stagnant ice, and along the margins of the ice terraces of debris accumulated from the steep sides. The prominent terrace bordering the base of Ceresco Ridge along the south side of the amphitheater was formed in this way. Since glacial time there has been only moderate erosion, though in the weaker rocks, especially in fractured areas, much material has broken away and accumulated as talus or slide rock near the bases of the slopes.

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[14] Capps, S. R., Pleistocene geology of the Leadville district, Colo.: U.S. Geol. Survey Bull. 386, 1909.

[15] Emmons, S. F., Irving, J. D., and Loughlin, G. F., Geology and ore deposits of the Leadville district Colo.: U.S. Geol. Survey Prof. Paper 148, 1927.

BEDROCK

The consolidated rocks in the Climax district consist of the pre-Cambrian basement rocks, which occupy most of the area east of the Mosquito fault, and the Paleozoic sedimentary beds, Cambrian to Permian, which lie mainly west of the Mosquito fault. Cambrian quartzite occupies two small areas east of the fault—one on Little Bartlett Mountain and the other near the Mosquito fault at the "Mountain Chief no. 6" adit, which is driven from the west through the fault into Cambrian quartzite on the east side of the fault.

All the pre-Tertiary rocks of the area have been intruded by Tertiary (?) dikes and sills of somewhat varying composition. Near Climax the quartz monzonite porphyry and rocks of similar composition are most abundant.

PRE-CAMBRIAN ROCKS

The pre-Cambrian rocks of the Climax district are a part of a much larger area of similar rocks exposed to the north, east, and south along the Mosquito Range. The earliest rocks of this series are schists that are probably to be correlated with the Idaho Springs formation farther east. These schists have been intruded by pre-Cambrian granitic rocks of medium-grained texture and varying composition ranging from granite to quartz monzonite. These granitic rocks are probably to be correlated with the Silver Plume granite of the areas farther east. Their local distribution is shown on plate 23.

Schist.—In the Climax district schistose rocks form the ridge between McNamee and Clinton Peaks, at the head of the Tenmile Amphitheater and the saddle between Tenmile Creek and Clinton Gulch. These rocks extend northward from the saddle to form part of the southeast slope of Bartlett Mountain and northeastward from the saddle below the Continental Divide to join the mass east of Little Bartlett Mountain. Schist also occupies both sides of the Arkansas River southeast of Wortman. West of the area in which the schist predominates it is present as abundant inclusions in the pre-Cambrian intrusive granite. Such inclusions have been noted on the surface, in underground workings in the Climax mine, in diamond-drill explorations to the north and west of the main developed area of the Climax mine, and in the northern part of Ceresco Ridge.

The schist is uniform in appearance and mineral composition throughout the area, except in those portions that have been altered by the granite intrusion. It is medium-grained and composed largely of biotite, quartz, and plagioclase. Near contacts with the granite it commonly contains sillimanite accompanied by a fibrous mineral (hydromica?). The rock is not notably weathered, except for a thin red-brown iron stain, which is characteristic where biotite is especially abundant. Certain areas of the schist in Clinton Gulch, as well as in the extreme southeastern part of the district, have been recrystallized and partly assimilated by the granite.

The pre-Cambrian schist and intrusive granite are continuous with and similar to those studied by Patton [16] in the Alma district, southeast of Climax, on the eastern slopes of the Mosquito Range.

The unaltered schist as a whole has a uniform composition and consists largely of biotite, quartz, andesine, and small amounts of muscovite. Near the granite contact and in some schist inclusions there is local development of sillimanite, hornblende, augite, titanite, and apatite.

A schistose quartzite occurs in small lenticular masses and layers only a few feet thick. Thin sections of three specimens selected at random from different outcrops showed a rock of medium fine grain composed of a plagioclase-quartz mosaic, with some biotite, in which all the minerals are unaltered.

Sillimanite schist is confined to the vicinity of the granite, both near the contact and as schist inclusions in the granite. The sillimanite replaces quartz, biotite, and plagioclase. Commonly there is intergrown with and replacing the biotite a fibrous mineral, which in the thin section resembles sillimanite, except that the fibers do not show the characteristic transverse fractures. The mineral was too fine-grained to yield many diagnostic optical data, but the index, obtained by the immersion method, is too low for sillimanite. The mineral is probably a hydromica. The sillimanite schist is probably not quantitatively significant, although the sillimanite is not easily recognized in the hand specimen, and it may be more widespread than is known.

Green hornblende occurs about as commonly and in much the same manner as the sillimanite, and in places the two minerals occur together. Where hornblende is abundant augite is a common associate, and in many places apatite and titanite are conspicuous. Quartz, orthoclase, and plagioclase, usually andesine, are invariably present with the hornblende.

Green hornblende is also concentrated in thin layers in the biotite schist. These layers of hornblende-biotite schist consist of a gray-green groundmass set with segregation spots of biotite, giving the appearance of a porphyry. As seen under the microscope, the groundmass consists of biotite with quartz, plagioclase, hornblende, and smaller amounts of apatite, titanite, and magnetite. The spots are mostly composed of biotite and hornblende, although some contain only apatite and titanite with the hornblende. The layers of horn-

[16] Patton, H. B., Geology and ore deposits of the Alma district: Colorado Geol. Survey Bull. 3, 1912.

RECRYSTALLIZED SCHIST.

blende-biotite schist are less than 6 feet thick and parallel to the regional schistosity with one observed exception, where the band cuts across the schist like a dike. The rock is schistose, and the schistosity even in the dikelike band is everywhere parallel to the regional schistosity. The occurrence suggests original sills and dikes.

Altered schist.—The schist near its contact with granite has been changed to a gneissoid granite that is porphyritic in places. Three varieties of altered schist have been recognized and are attributed to (1) recrystallization alone, (2) recrystallization with partial assimilation by the granite, and (3) thorough assimilation of the schist by the granite. There is complete gradation between these varieties, and the separation is made only for convenience of discussion. Not all the schist near the granite is so altered, and very few of the schist inclusions, either large or small, show the alteration.

In a strict sense there has probably been no recrystallization without other changes, but in many places for several hundred feet from the granite the schist has a granitoid texture, with little or no apparent changes in mineral composition. The typical schist is composed of light and dark layers in which the biotite is segregated. On recrystallization it becomes coarser and loses the banding but retains the schistose structure. The average grain of the recrystallized rock is that of the adjacent granite, which it resembles especially on surfaces parallel to the schistosity. The rock occurs either as irregular masses or in zones from a few inches to 50 feet thick and of undetermined length and grades into the schist.

The minerals present in the simply recrystallized rock are the same as those in the schist, and specimens can be selected that contain approximately the same proportions of the different minerals; but usually orthoclase and microcline are more abundant in the altered rock. The similarity in mineral composition and the gradation between the two rocks make it evident that the pseudogranite has been formed chiefly by recrystallization of the schist.

Schist altered to porphyritic gneissoid granite is illustrated in plate 25, which shows microcline and orthoclase phenocrysts, one or both, averaging an inch in length and abundantly developed parallel to the schistosity. Some very inconspicuously oriented biotite foils are concentric to the phenocrysts. Microcline and orthoclase are also developed in the groundmass, making the mineral composition like that of the neighboring granite except for more biotite and in places more titanite and apatite.

In places the phenocrysts are few and the gneissic structure obscure, so that the rock closely resembles the intruding granite—in fact, it grades locally into the normal granite—but more commonly it grades and fingers into the schist, indicating that it was originally schist.

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This kind of alteration involves the addition to the schist of sufficient potassium oxide to form the abundant microcline and orthoclase, but whether it necessitates the addition of silica is not clear.

Granite which has a gneissic structure but which in thin sections shows the same mineral composition as the intruding granite occurs in places, especially in the southeastern part of the area southwest of the Zephyr mine, on Travers Peak, and east of Travers Peak outside the boundaries of the mapped area. In thin section there is no evidence of shearing, and in one place this gneissic granite grades into a hornblende-sillimanite schist. From these relations it is thought that the gneissoid granite of the area is assimilated or replaced schist.

Granite.—Granite is the principal rock that makes up Ceresco Ridge, the head of the Tenmile Amphitheater, and the ridge that includes Bartlett and Little Bartlett Mountains. The area occupied by granite is bounded on the west by the Mosquito fault and extends eastward for more than a mile beyond the area mapped. To the north it extends to the schist areas, less than half a mile beyond the area mapped. To the south its limits have not been determined. Near the contacts of the granite and schist there are numerous inclusions of schist in the granite, and small apophyses of granite, not shown on the map, commonly intrude the schist for short distances. Along the divide south and northeast of Clinton Peak inclusions of schist are numerous but only the largest ones are shown on the map.

The granite is chiefly gray to pinkish gray, medium to coarse grained, and massive. Feldspar, quartz, biotite, and muscovite are invariably recognizable in the field. Medium and coarse textures grade into each other, but the coarser granite is more abundant in the vicinity of Bartlett and Little Bartlett Mountains, and the medium-grained granite prevails on Ceresco Ridge and in Clinton Gulch. The coarse-grained granite is characterized by "flow structure", or a parallel arrangement of numerous tabular feldspars that average about 3 by 8 by 12 millimeters in size. This parallel or flow structure is best seen on weathered surfaces; on fresh surfaces and in thin sections it is inconspicuous. The medium-grained granite is entirely massive, with the grain ranging from a little less than 1 millimeter up to that of the coarse-grained granite, into which it grades.

Thin sections under the microscope show, in the approximate order of abundance, microcline, quartz, orthoclase, oligoclase, biotite, muscovite, apatite, magnetite, titanite, and garnet. A few grains of apatite are found in every thin section examined. Magnetite, usually in well-formed crystals, may or may not be present, and titanite and garnet have only seldom been observed.

Microcline is not only the predominant feldspar but in some of the rock the predominant mineral. Orthoclase is usually present and commonly in appreciable amounts. Microcline and orthoclase in different portions of the same grain, or carlsbad twins with one twin microcline and the other orthoclase, are of common occurrence. The tabular feldspars in the coarser granite mentioned above are almost entirely microcline, and most of them have carlsbad twinning. The microcline and orthoclase are clear and unaltered in thin sections, though they may contain fine needles of rutile (further mentioned under quartz) and also some perthitically intergrown plagioclase as well as some irregular plagioclase inclusions.

The quartz content varies but on the average equals that of microcline. Quartz occurs both as interstitial grains and as small spherical inclusions in all the feldspars. In some of the thin sections examined these quartz inclusions are very numerous, but their total volume is usually less than that of the interstitial quartz, although in some thin sections it appears to be greater. There is no marked parallel orientation of these inclusions, even where several of them occur in a single feldspar grain. The interstitial quartz shows slight undulatory extinction, and almost all of it contains numerous gas and liquid inclusions as well as many fine needlelike crystals of rutile.

The plagioclase is mainly oligoclase, as determined by indices of refraction and by extinction angles on sections normal to albite-twin planes; but some grains are albite, and a few approach andesine in composition. All the plagioclase shows some alteration to sericitic mica, which clouds the grains and makes identification of some of them difficult. The plagioclase content does not vary much and does not average more than 15 percent.

Biotite and muscovite are present everywhere, usually with the interstitial quartz, but flakes may be included in the feldspars. Both micas may occur either separately or intergrown, and their combined volume is estimated as usually less than 15 percent of the thin section, though the composition calculated from the chemical analyses gives a higher percentage. The muscovite is fresh and less abundant than the biotite. Most of the biotite is the common brown variety, though some is green, and nearly all of it is partly or completely altered to an aggregate of chlorite and magnetite.

The chemical analysis and calculated mineral composition of a typical specimen of the most common variety of the granite, from the slope above the Zephyr mine, southwest of Travers Peak, with two analyses of altered rock, is presented on page 225.

The granite at Climax is correlated with the Silver Plume granite in the Georgetown quadrangle, as described by Ball,[17] and in the Montezuma district, as described by Lovering,[18] on the basis of similar mineral composition. It is continuous with the granite in the

[17] Ball, S. H., Economic geology of the Georgetown quadrangle, Colo.: U.S. Geol. Survey Prof. Paper 63, pp. 57–59, 1908.

[18] Lovering, T. S., Geology of the Montezuma quadrangle, Colo.: U.S. Geol. Survey Prof. Paper 178 (in preparation).

Alma district described by Patton.[19] Mineralogically similar granites were found by Crawford [20] in the Red Cliff district and by Howell [21] in the Twin Lakes district.

Pegmatitic rocks.—Dikes and irregular masses of pegmatite are very common in the schist near the granite contact, and stringers and lenses are widespread in the schist far from the contact. Irregular masses are also common in the granite near the contact, but dikes other than small stringers are rare in the granite near the contact, and there is very little pegmatite of any kind in the more central portions of the granite areas.

In mineral composition and texture the pegmatites are typical of those commonly associated with granite, although only a few graphic intergrowths were noted. The essential minerals are quartz, white and locally pink microcline with orthoclase, and muscovite, associated with minor amounts of magnetite, biotite, and red garnet. The irregular masses of pegmatitic rock might be considered a very coarse grained muscovite granite. They differ in mineral composition from the typical Silver Plume granite only in the almost complete absence of biotite.

PALEOZOIC SEDIMENTARY ROCKS

The Paleozoic sedimentary rocks are very largely confined to the area west of the Mosquito fault. The east wall of the fault is the pre-Cambrian granite. At the north end of the area, however, on Little Bartlett Mountain and at the adit of the Mountain Chief No. 6 claim, Cambrian quartzite is present east of the fault in small remnants lying on the pre-Cambrian granite.

The quartzite on Little Bartlett Mountain is a hard, glassy rock typical of the basal portion of the Sawatch quartzite elsewhere in the range. Near the Mosquito fault at the Mountain Chief no. 6 tunnel some of the higher limy beds of the Sawatch quartzite are present. These rocks are much softer than the basal beds, as they have, in part at least, a carbonate cement. They weather to a dirty brown. The uppermost part of the quartzite and the overlying "White" limestone, Parting quartzite, and "Blue" limestone, all of which carry ore at Leadville, are not present east of the fault, and it is not known whether they are present under the Weber (?) formation west of the fault.

The oldest rocks exposed on the west side of the Mosquito fault are a series of predominantly gray sandstones and shales of Pennsylvanian age, called Weber formation by Emmons in the Tenmile folio,

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[19] Patton, H. B., op. cit., pp. 40–45.

[20] Crawford, R. D., and Gibson, Russell, Geology and ore deposits of the Red Cliff district: Colorado Geol. Survey Bull. 30, pp. 24–25, 1925.

[21] Howell, J. V., Twin Lakes district of Colorado (Lake and Pitkin Counties): Colorado Geol. Survey Bull. 17, p. 43, 1919.

above which are the redbeds (chiefly if not wholly of Permian age) which were called Maroon and Wyoming formations in that folio. The Pennsylvanian (Weber ?) beds are found along the Phillipson tunnel line and to the south, the Maroon (red grits and conglomerates) crops out north of the Weber (?) beds, and in the extreme northern part of the area fine-grained red sandstones represent the "Wyoming formation."

Northwest of the Tenmile area and east of Red Cliff, J. H. Johnson measured a section of the Weber (?) beds and the Maroon formation as defined by Emmons. The total thickness of the beds is 5,510 feet, but it was not possible to satisfactorily separate the Pennsylvanian from the Permian. Johnson's section, which is somewhat generalized in figure 27, shows the same general succession as that of the Climax area. The base of the section is just east of Red Cliff, at the top of the Mississippian (Leadville limestone) in Turkey Creek, and the top is about a mile below the head of Turkey Creek, north of the Tenmile area. The Jacque Mountain limestone was traced continuously to its type locality in the Tenmile area. The section as measured shows a porphyry sill near its base which is not included in figure 27. The beds are known to vary greatly in thickness, and the thickness given in figure 27 cannot be used with safety in the Climax area, where owing to poor outcrops of the beds and the complications presented by the drag folds and faults along the Mosquito fault it is difficult to determine the thickness. There are no outcrops south of the vicinity of the line of the Phillipson tunnel. A few prospects have penetrated the glacial covering, and their dumps show neither "Weber grits" or Lincoln porphyry, so that this area west of the Mosquito fault is undoubtedly underlain by sedimentary rocks with sills of Lincoln porphyry.

The Weber (?) formation is made up of red to gray micaceous sandstones and micaceous sandy red to gray and black shales. A limestone bed as much as 40 feet thick in places contains the only fossils found in the district. Among the fossils collected George H. Girty identified *Fusulina* sp., *Bellerophon*, *Squamularia perplexa*, and *Composita subtilita*. Mr. Girty says that this fauna is common and of long range in our Carboniferous rocks and that it is of little significance except as indicating that the age is Pennsylvanian.

The Maroon formation is indicated by some outcrops of a pink to red arkose which has an average grain of 2 to 3 millimeters and is conglomeratic along some beds. Well-rounded quartz pebbles 2 centimeters or less in diameter and rounded granite pebbles 8 centimeters or less are common in the conglomerate. Even an approximately correct placing of the limits of this formation could not be made, because the outcrops are too few and poor.

The "Wyoming formation" of Emmons is characterized by fine-grained red sandstone and a single limestone bed about 20 feet thick in the largest exposure. The limestone contains no fossils but it is

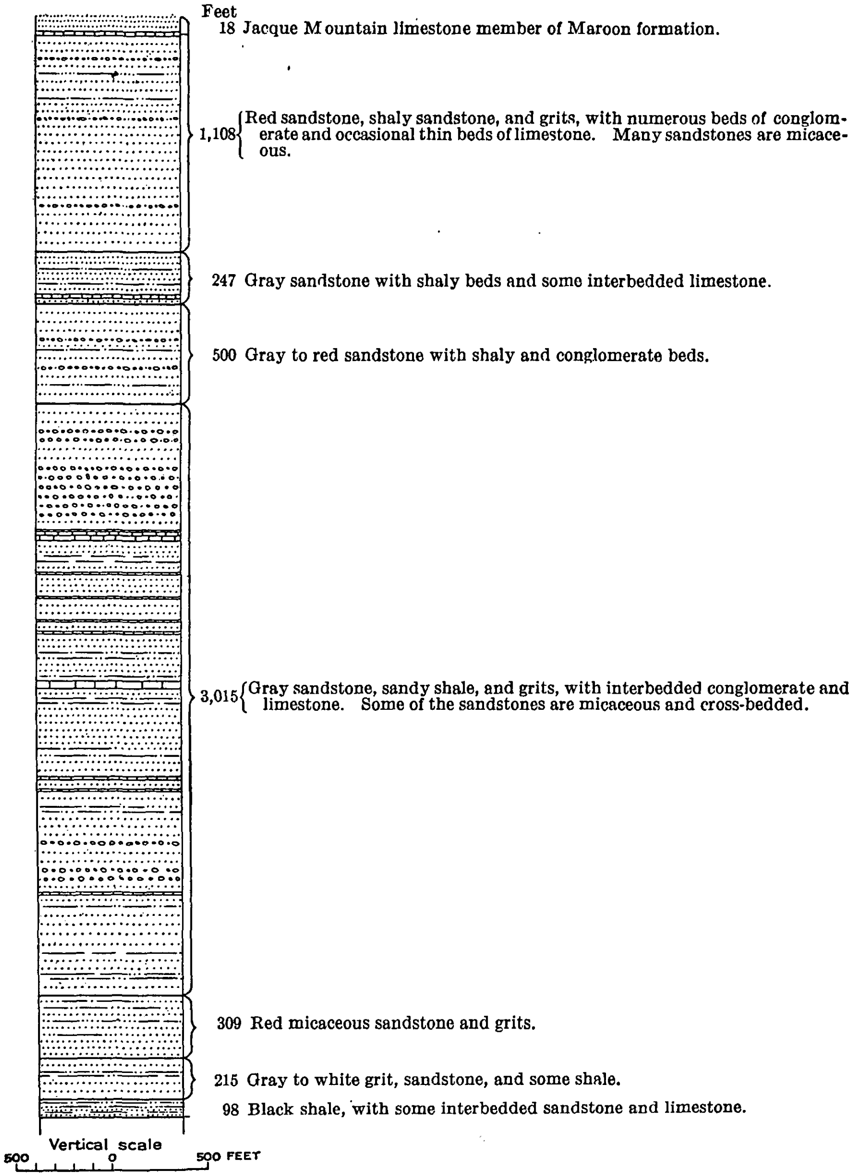

FIGURE 27.—Section of the Weber (?) and Maroon formations in the area northwest of the Tenmile district and east of Red Cliff.

otherwise similar in appearance to the limestone in the Weber (?) formation.

TERTIARY (?) INTRUSIVE ROCKS

Throughout the Mosquito Range all the pre-Cambrian rocks have been intruded by stocks and dikes and the Paleozoic rocks by stocks, dikes, and sills, all of porphyry. There is no direct evidence of the age of the porphyry dikes and sills in the Climax area except that they are later than the Pennsylvanian and Permian sedimentary rocks. On the basis of their petrographic and structural relations they are tentatively correlated with those intrusive rocks that cut Cretaceous rocks in neighboring areas and are regarded as probably of early Tertiary age. In the Climax district, as elsewhere in the Mosquito Range, these intrusive rocks are found most abundantly as sills in the sedimentary rocks and as dikes in the granites. The dikes and sills both have a considerable range in composition and texture, but quartz monzonite porphyry is by far the most abundant kind.

DIKES

The dikes are shown on plate 23 as dioritic and diorite dikes and Lincoln porphyry. The Lincoln porphyry is predominantly quartz monzonite in composition but also includes some granite porphyry. Some dikes of the Lincoln porphyry have middle portions of quartz monzonite and margins of quartz diorite, or middle portions of granite and margins of quartz monzonite. The marginal portions constitute less than 10 percent of a dike, which is therefore identified by the composition of the middle portion. The relative ages of the groups are shown at only one place, where a diorite dike is cut by a dike of quartz monzonite porphyry. This relationship is the same as that recorded at Leadville.

Diorite and quartz diorite dikes.—The margins of some of the monzonite dikes have the composition of quartz diorite, but complete dikes of quartz diorite are not common anywhere, and they are especially uncommon where dikes of Lincoln porphyry are numerous. In the eastern part of the area, on the slopes immediately below the Continental Divide, there are dark-gray to almost black dikes of dense texture that are not over 10 to 15 feet thick and difficult to trace on the surface. Some apparently are not very long. Some show a little free quartz, but it is never conspicuous. In thin sections they are too highly chloritized and sericitized to permit identification of any of the primary minerals except the quartz. On the basis of color, degree of alteration, and scarcity of quartz, these dikes are mapped as diorite.

On Ceresco Ridge, at an altitude of 12,800 feet, there is a fresh, almost black porphyritic dike. In thin section this rock shows abundant green hornblende, zoned oligoclase or oligoclase-andesine, some deep-brown biotite with included grains of apatite, and apatite throughout the groundmass. Quartz is not present. The feldspar of the groundmass has a low index of refraction, which suggests orthoclase, and this dike may therefore be closer to monzonite than to diorite in composition.

Lincoln porphyry.—The dikes mapped as Lincoln porphyry range in composition from quartz monzonite to sodic granite. The correlation with the Lincoln porphyry is made because the group as a whole resembles the Lincoln porphyry in the type area on Mount Lincoln, about 2 miles east of Climax, as described by Emmons.[22] It might be argued that the Lincoln porphyry as described by Emmons is a quartz monzonite and therefore a sodic granite should not be included in it, but the variation in the contents of lime, soda, and potash has been generally recognized, and there is no field evidence which requires a limitation of this variation to exclude from the group a porphyry merely because it contains albite instead of oligoclase. The occurrence of the dikes and the absence of crosscutting suggest a very close genetic relationship.

The dikes are from 15 to 40 feet in width and are traceable on the surface for a few hundred to a few thousand feet. In places, as in Tenmile Creek south of the Climax mine, the outcrops of porphyry indicate an irregular outline rather than the form of a dike. Mine workings and diamond-drill development show that many of the dikes are discontinuous and that small or even sizable masses are to be expected below the surface, even where outcrops are not found. In the mineralized area the porphyry dikes are generally less altered than the granite, and under these conditions they are easily recognized. However, in places the porphyry is sufficiently altered to make it indistinguishable from correspondingly altered granite or schist, and here and there the porphyry is completely replaced by quartz.

The altered porphyry dikes bleach in outcrop to white or light gray and on fresh fractures vary in color from light gray to gray. The group as a whole is characterized by the presence of white or pink orthoclase crystals 10 to 30 millimeters in diameter in a matrix of phenocrysts of plagioclase and quartz 1 to 3 millimeters in diameter and an aphanitic groundmass. The smaller phenocrysts of plagioclase and quartz are everywhere present in the dikes, but the orthoclase crystals vary in number; in a few dikes they are absent. Biotite is present in different amounts. The range in composition from quartz monzonite to sodic granite is gradational. These two varieties, though readily distinguished in thin sections, appear essentially identical in the field.

Quartz monzonite porphyry.—The essential minerals found in the quartz monzonite are orthoclase, plagioclase, quartz, and biotite, all

[22] Emmons, S. F., Geology and mining industry of Leadville, Colo.: U.S. Geol. Survey Mon. 12, pp. 109, 111, 328, 1886.

of which are generally recognizable megascopically and always in thin sections. The groundmass is compact and well crystallized and makes up a large part of the rock. The accessory constituents are allanite, zircon, magnetite, and apatite, most of which are present in every thin section. The orthoclase occurs in phenocrysts 10 to 30 millimeters in diameter and also in notable amounts in the groundmass. The orthoclase shows relatively little alteration. The plagioclase occurs mainly in phenocrysts 1 to 3 millimeters in diameter, and most of it is partly or completely altered to sericite. In some dikes plagioclase is found in the groundmass. The composition of the plagioclase in any one dike ranges within narrow limits, but in the group as a whole it extends from oligoclase to sodic labradorite. Zonal structure is common in the more calcic varieties, and albite twinning is generally but not invariably developed. Quartz is present, both as phenocrysts and in the groundmass. The phenocrysts commonly are bipyramid forms that may or may not show small prism faces. In some dikes the quartz crystals are strongly corroded. Round quartz phenocrysts with the adjacent quartz grains in the groundmass so arranged as to simulate halos when seen between crossed nicols are characteristic. The biotite occurs in both megascopic and microscopic hexagonal crystals, which in many places are changed to green chlorite. The groundmass is homogeneous, composed of quartz, orthoclase, and sericite, which in part at least represents altered plagioclase.

The dikes have felsitic margins that range in width from only a few inches to more than 2 feet. These margins grade, within a distance of less than an inch, into a zone of Lincoln porphyry in which the large orthoclase crystals are absent, and this zone in turn grades into typical Lincoln porphyry. The felsitic margins constitute only 10 percent or less of the total thickness of the larger dikes and a somewhat greater proportion of the smaller dikes. They generally show a few very small and inconspicuous phenocrysts of feldspar or quartz in a microfelsitic groundmass. The quartz and plagioclase phenocrysts may occur together or alone. The quartz crystals are angular and show no corrosion, in contrast with the rounded and corroded forms in the middle portions of the dikes. The plagioclase at the margins shows a higher index of refraction than the plagioclase in the middle of the dike and therefore indicates that the margins are more calcic than the rest of the dike.

Sodic granite porphyry.—The sodic granite is similar to the quartz monzonite in both megascopic and microscopic appearance. The plagioclase, however, is more abundant and is mainly albite or albite-oligoclase. Calcic plagioclase is present only in subordinate amounts. The orthoclase occurs in phenocrysts 10 to 30 millimeters in length and probably also in phenocrysts 1 to 3 millimeters in length. Orthoclase also forms a notable part of the groundmass. Albite occurs in phenocrysts 1 to 3 millimeters long and to some extent in the groundmass. Many of the albite phenocrysts show no albite twinning, so that it is not readily recognized. The relative amounts of orthoclase and albite crystals that may be present can be estimated only with difficulty, but the albite is generally predominant. The albite can be recognized microscopically by its positive optical character and by its low indices of refraction. Quartz appears to be more conspicuous in the groundmass than it is in the quartz monzonite.

The dikes of sodic granite also have marginal felsitic zones that are similar to those bordering the quartz monzonite. The phenocrysts of the marginal zones are oligoclase or oligoclase-andesine and are therefore more calcic than the plagioclase in the main parts of the dikes.

SILLS

The sills in the sedimentary rocks are mostly quartz monzonite. Sills of sodic granite are also present but do not seem to be so numerous as the dikes of sodic granite in the pre-Cambrian area. The sills appear to be identical in range of mineral composition and texture with the dikes in the granite, but sericite, so common in the dikes, is not abundant in the sills. The contacts are too much covered for a satisfactory study of the mineral changes from margin to center, but there appears to be a change similar to that observed in some of the dikes. For this reason the hornblende porphyry, Lincoln porphyry, and rhyolite porphyry west of Little Bartlett Mountain, which Emmons [23] regarded as three distinct sills, have all been included in one sill on plate 23 of this paper. The hornblende porphyry appears to be a basal facies grading upward into Lincoln porphyry, which in turn grades upward into sodic granite porphyry.

The sills in the sedimentary rocks differ from the dikes in the pre-Cambrian rocks in the manner of weathering and in fracturing. The sills weather to gravel and clay as a result of the development of montmorillonite in the groundmass and the plagioclase phenocrysts. The dikes in the granite break up into large massive or slabby fragments and nowhere weather to gravel. In some parts of the weathered sills large unbroken crystals of orthoclase and quartz can be picked from the gravel. In other parts, where the sills have been weakened by crushing, the crystals of orthoclase and to some extent those of quartz crumble when the groundmass disintegrates.

In thin sections only a little sericite is seen. The biotite is relatively fresh, although some chlorite is present. Montmorillonite has replaced nearly all the plagioclase phenocrysts and is also extensively developed in the groundmass, and the orthoclase crystals are also altered to montmorillonite in places. The montmorillonite has a

[23] Emmons, S. F., op. cit. (Mon. 12), p. 198.

grain of 0.005 millimeter where it replaces plagioclase. Its indices of refraction, determined in liquids, are 1.528 and 1.548. In a closed tube it gives off abundant water at a low temperature and when moistened with concentrated HCl gives a distinct potassium flame. The identification of clay minerals is often difficult and inconclusive, but the properties given above agree very well with the description of montmorillonite containing absorbed potassium as described by Ross and Shannon.[24]

The extremely fractured or crushed condition is not accompanied by detectable displacement, even in thin sections. It is evident in the porphyry for several hundred feet in from the portal of the Phillipson tunnel. This porphyry appears firm when first blasted out, but on exposure to the air it crumbles to gravel and clay. It has little supporting strength and requires close timbering. The large feldspars and some of the quartz grains appear intact, but they crumble as soon as the matrix gives way.

STRUCTURE

The structural features of the area may be divided into two broad groups—those that originated in pre-Cambrian time and those that have been formed since, mainly after the intrusion of the porphyries. The pre-Cambrian features, which are only vaguely outlined by the local rocks and can be only imperfectly interpreted from knowledge of surrounding areas, have not been very influential in the localization of the molybdenum deposit and are therefore given no further attention. Any structural features developed between pre-Cambrian time and the Laramide revolution, at the end of Cretaceous time, are also little known and negligible in a practical sense. The outstanding structural features that were formed during and after the Laramide revolution are folds and faults.

FOLDS

The sedimentary rocks west of the Mosquito fault lie in a northward-plunging syncline whose axis, as Emmons [25] has shown, passes through Jacque Mountain, in the Tenmile district. In the vicinity of Climax some minor folds are present, and the steep dip of the east limb of the main syncline indicates drag along the fault. The axes of the main and minor synclines trend nearly due north, whereas the Mosquito fault trends N. 15°–20° E. The structure is shown in cross section in plate 23. Cross sections A–A′ and B–B′ are partly diagrammatic; cross section C–C′ shows the conditions in the Phillipson tunnel, where only one syncline is encountered.

[24] Ross, C. S., and Shannon, E. V., The minerals of bentonite and related clays and their physical properties: Am. Ceramic Soc. Jour., vol. 9, pp. 91, 95, 96, 1926.

[25] Emmons, S. F., U.S. Geol. Survey Geol. Atlas, Tenmile folio (no. 48), 1898.

FAULTS AND FISSURES

Although faulting may have occurred in this area as early as pre-Cambrian time, the most conspicuous faults were formed in Tertiary time. Within much of the area of pre-Cambrian rocks it is not possible to separate the periods of movement. Movement has doubtless taken place along the same break at different times, possibly as widely separated as pre-Cambrian and Tertiary.

Mosquito fault.—The Mosquito fault is one of the major structural features of the region. It extends in a general north-south direction for many miles, and through most of the distance it is a normal fault, with downthrow to the west. In the Mountain Chief no. 6 tunnel, north of Climax, it dips about 80° W.; in the Phillipson tunnel, at Climax, 71° W. At Climax the "Weber grits" form the west wall and pre-Cambrian rocks the east wall. North of Climax, at the Mountain Chief no. 6 tunnel, the "Weber grits" form the west wall and the Cambrian quartzite the east wall. The intervening breccia zone, which is composed almost entirely of dense quartz stained with limonite, is about 125 feet thick. The relation of this silicified zone to the molybdenite deposit has not been determined. In the Phillipson tunnel, at Climax, the rocks on both sides of the fault are much broken for a distance of 100 feet, and the fault itself contains a black shale gouge from 4 to 6 feet thick. This gouge contains polished and abraded fragments of "Weber grits" and of granite. Some of the granite "fragments" in the gouge contain pyrite and fluorite and are identical with similarly mineralized granite adjacent to the fault. Movement on the fault has evidently occurred since the molybdenum deposit was formed, though it may have begun earlier. The amount of movement in this locality cannot be determined until the sedimentary section west of the fault is better known.

Other faults.—There are many other faults in the area. Most of them are in the pre-Cambrian rocks, and their displacements are not easily determined. The East or "main" fault in the Climax mine has been given considerable attention, as it has been thought by some to displace the ore body. To do so, this fault, which has a northwesterly strike and northeasterly dip, should cut and offset a prominent Tertiary dike that is clearly earlier than the mineralization; but the dike shows no displacement, and it seems, therefore, that any considerable movement along the fault must have taken place earlier than both the intrusion of the dike and the period of mineralization. There are, however, clear examples of minor faulting of Tertiary dikes, including some on Bartlett Mountain not far from the Climax mine, and there are also strong shear zones in and along the Tertiary dikes. Most of these shear zones are mineralized. Slickensides on quartz and other evidence indicate renewed movement along veins after mineralization.

Age of faulting.—Nothing substantial regarding the age of faulting is here added to the discussion in the latest Leadville report,[26] which recognizes that all the major faulting took place later than the intrusion of porphyry sills and includes the Mosquito fault in a small, poorly understood group of composite reverse and normal faults, along which movements took place both before and after ore deposition. The wide zone of highly silicified rock in the Mosquito fault at the adit on the Mountain Chief no. 6 claim implies premineral movement, whereas the absence of silicification and the presence of mineralized "pebbles" in the fault in the Phillipson tunnel proves some postmineral movement. Emmons [27] realized the possibility of premineral movement in the Tenmile district. Similar evidence has been found by Behre along the Mosquito fault at the head of Evans Gulch,[28] and along the Lyddia fault at Iowa Gulch, in the Leadville region. At both of these places the main fault is barren, but parallel and apparently auxiliary faults are mineralized. The age of many of the other faults cannot be closely placed, but many mineralized fissures show evidence of movement, and much of the faulting clearly preceded mineralization.

FISSURES

There can be no sharp separation of faults and fissures in this area. Some movement, shown by pronounced brecciation and slickensiding, has taken place along many of the mineralized fissures. Such fissures are clearly exposed on the north face of Ceresco Ridge, where they contain prominent quartz veins and locally considerable fluorite. Similar fissures that contain vein quartz and generally some fluorite and have strongly sericitized wall rock are exposed in the Climax mine. The East fault in the Climax mine contains a little sphalerite in addition to pyrite. In many such fissures there is clear evidence of some renewed movement after mineralization.

Many fissures occur in the mine, and the strikes and dips of 24 of the more prominent ones have been recorded. All but three have strikes of N. 10°–80° E. and dips mostly 50°–60° SE., although a few are vertical. On the surface east of the Climax mine and southwest of Mountain Chief no. 3 tunnel most of the prominent fissures have westerly strikes with southerly dips, but many of the smaller fissures are approximately at right angles to them in typical coordinate arrangement.

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[26] Emmons, S. F., Irving, J. D., and Loughlin, G. F., Geology and ore deposits of the Leadville mining district, Colo.: U.S. Geol. Survey Prof. Paper 148, pp. 62–97, 1927.

[27] Emmons, S. F., U.S. Geol. Survey Geol. Atlas, Tenmile district folio (No. 48), 1898.

[28] Behre, C. H., Jr., personal communication, 1929.

THE MOLYBDENUM DEPOSIT

CONCENTRIC ZONES OF MINERALIZATION

One of the striking features of the Tenmile Amphitheater, where the molybdenum deposit crops out, is the yellowish to reddish-brown color of the rocks that border it on both sides, as contrasted with the somber colors of the rocks in the head of the amphitheater and of the main range in general. These highly colored rocks on and between Bartlett Mountain and Ceresco Ridge outline the area in which the rocks have undergone rather intense alteration, although the color alone is not a reliable indication of the degree of alteration. This area is roughly circular, except where it is cut off by the Mosquito

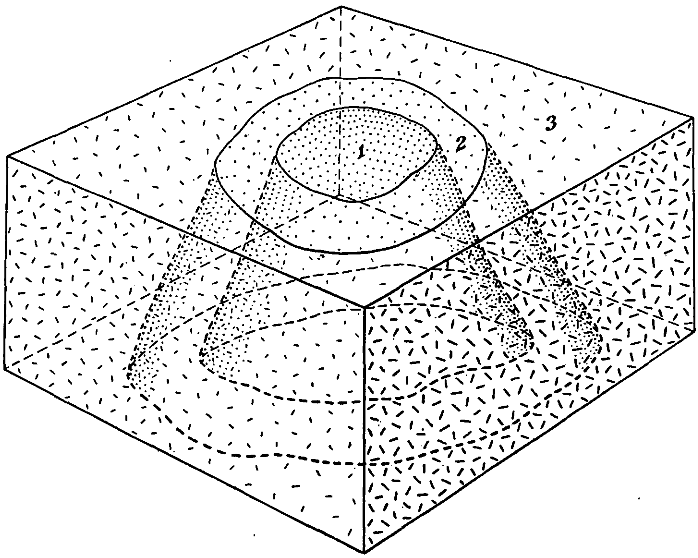


FIGURE 28.—Idealized representation of Climax molybdenum mineralized pipe or stock. 1, Highly silicified core; 2, moderately silicified zone in which the ore occurs; 3, slightly silicified outer zone.

fault, and is approximately 1 mile in diameter. The high color of the altered rock is only superficial and is due to the oxidation of pyrite, but the color effect is the same whether much or little pyrite was originally present. On fresh fracture one of the most conspicuous features of alteration is the bleaching of the ferromagnesian minerals. The different kinds of rock in the mineralized area are similarly altered but to different degrees. Granite, which is the most highly fractured rock, is the most readily altered, whereas the tougher and more flexible schist is generally much less affected. However, where no. 2 drift on the Phillipson level cuts the ore zone the prevailing rock is in altered schist, which throughout the ore zone makes a very good grade of ore. Similar altered schist has been found in some of the diamond-drill holes. The porphyry dikes also are less altered except along shear zones, where they are as strongly altered as the granite.

The form of the molybdenum deposit is still only imperfectly known, even after the last 7 years of intensive development, but in general it is that of a conical stock enlarging downward and separable into an outer zone of weak alteration, an intermediate zone of more intense alteration and ore deposition, and a highly silicified core. Figure 28 represents the idealized form of the deposit as revealed by mine development, and figure 29 is a block diagram of the mineralized area showing its relation to the different geologic features and the portion that is being developed from the Phillipson tunnel.

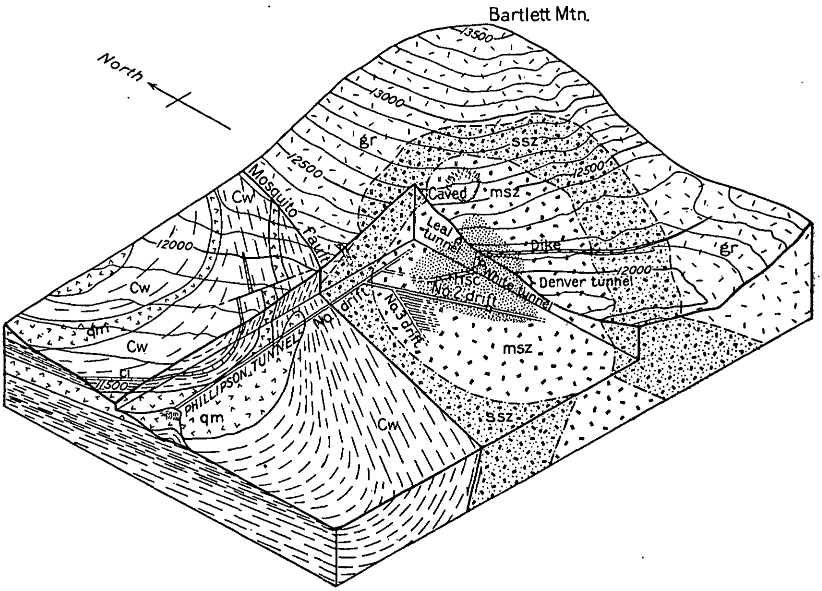


FIGURE 29.—Climax molybdenum deposit in block diagram. Pr, Pre-Cambrian granite country rock with schist inclusions; qm, quartz monzonite (Tertiary); Cw, Carboniferous beds (Weber? formation), including a bed of limestone (cl); hsc, highly silicified core; msz, moderately silicified zone; ssz, slightly silicified zone.

Transition from the surrounding unaltered area to the zone of weak alteration is indicated by a bleaching and softening of the feldspar phenocrysts as well as the groundmass and by the presence of rock impregnated with small grains of pyrite. Biotite is changed to muscovite with fine grains of magnetite along its cleavage, and plagioclase is thoroughly sericitized. Scattered veinlets of fine-grained milky quartz are also present. Toward the transition to the next inner zone small bluish-gray replacement veins of quartz and orthoclase, together with finely divided molybdenite, which gives the bluish color, are characteristic. Molybdenite is confined to the veins, whereas pyrite impregnates the rock. The rock is appreciably silicified, and the original phenocrysts of microcline and orthoclase have been partly replaced by or recrystallized into aggregates of fine-grained secondary orthoclase. (See pl. 26.) Muscovite has also been replaced by orthoclase along cleavage planes and boundaries (pl. 27, A). Where alteration of this kind is only slight there is no noteworthy decrease in the amount of alkalic feldspar, but microcline phenocrysts, originally abundant, are practically absent, and only orthoclase phenocrysts are present. The cause of this change is not known.

Transition from the outer to the intermediate or ore zone is gradual, with respect both to rock alteration and to the increasing content of molybdenite. (See fig. 30.) The rock in the ore zone is composed largely of quartz and secondary orthoclase, but the outlines of rock fragments are still readily recognized. It is impregnated with pyrite

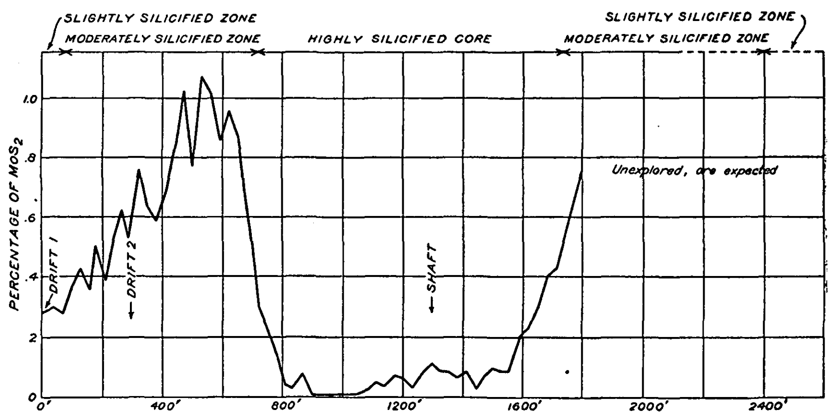
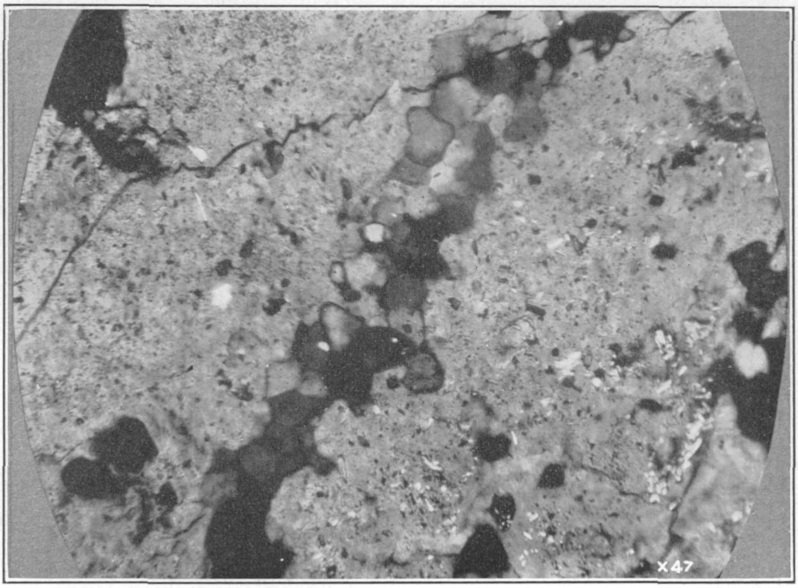


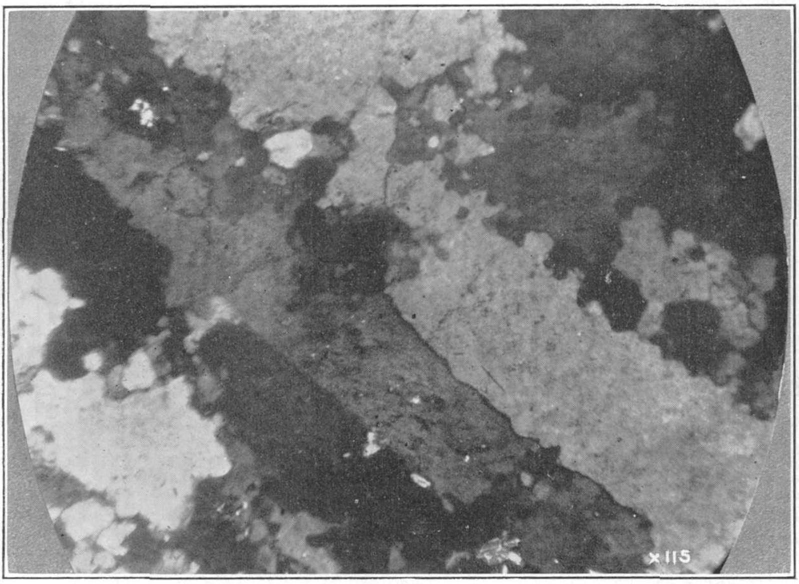
FIGURE 30.—Molybdenite content in drift 2, Phillipson level. Shows gradual increase of molybdenite from outer zone through intermediate zone and abrupt decrease from intermediate zone to highly silicified core. In this drift to the right of 1,800 feet the conditions that have been found to the left of 700 feet are to be expected.

but not notably more so than in the outer zone. Small veinlets, mostly less than a quarter of an inch thick, cut the rock in every direction and are so closely spaced that in many places it is impossible to find a cubic inch of rock free from them. (See pls. 28–31.)

Some veinlets in the outer part of the ore zone consist largely of "blue quartz" (pl. 31) colored by minute crystals of molybdenite and containing considerable orthoclase, which in some places is concentrated along the margins and in others along the middles. Veinlets in the ore zone characteristically contain molybdenite concentrated along their margins (pls. 28, 29), and some of them contain small amounts of fluorite along their middle portions. A few of the molybdenite veinlets contain a little pyrite. Definite veinlets of molybdenite free from quartz can also be detected, especially in the schist.



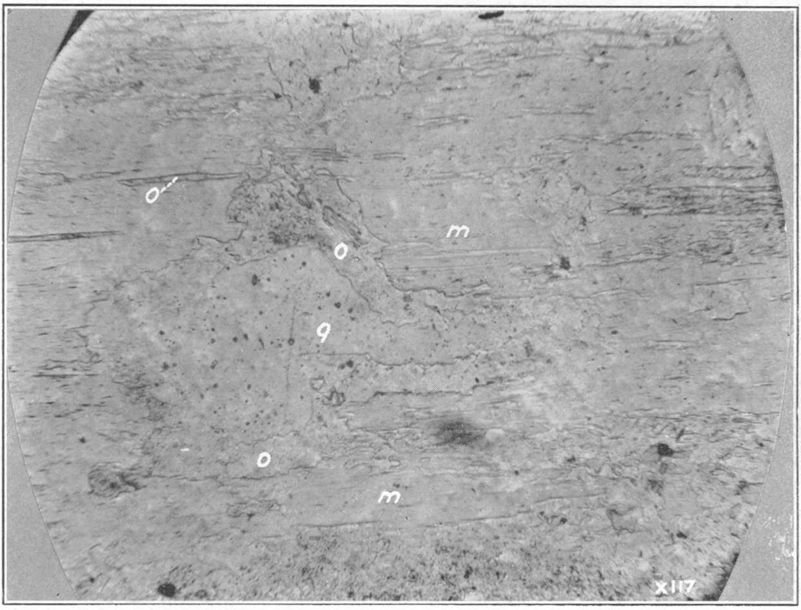
A



B

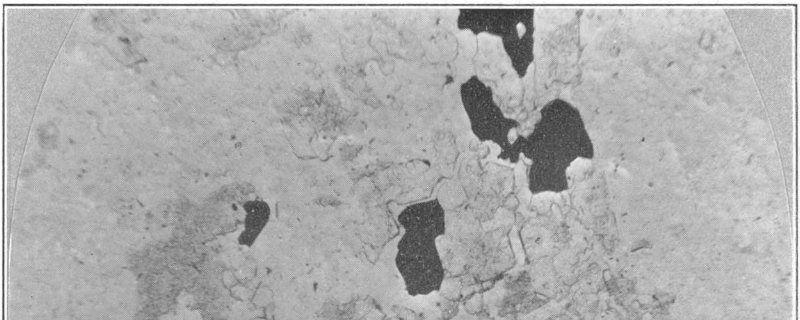
SECONDARY ORTHOCLASE.

A, A veinlet of orthoclase cutting a crystal of orthoclase in granite. *B*, Granulation of primary orthoclase to secondary orthoclase along crystal boundaries.



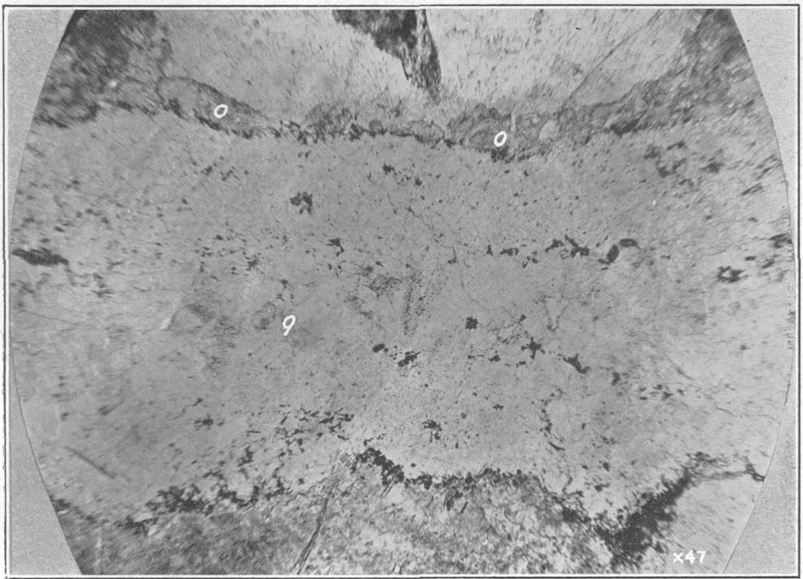
A. ORTHOCLASE (*o*) REPLACING MUSCOVITE (*m*) ALONG CLEAVAGE LINES AND CRYSTAL BOUNDARIES.

q, Quartz.



B. PYRITE VEIN WITH TOPAZ GANGUE.

Black areas, pyrite; gray with high relief, topaz.



A. MOLYBDENITE-QUARTZ-ORTHOCLASE VEIN.

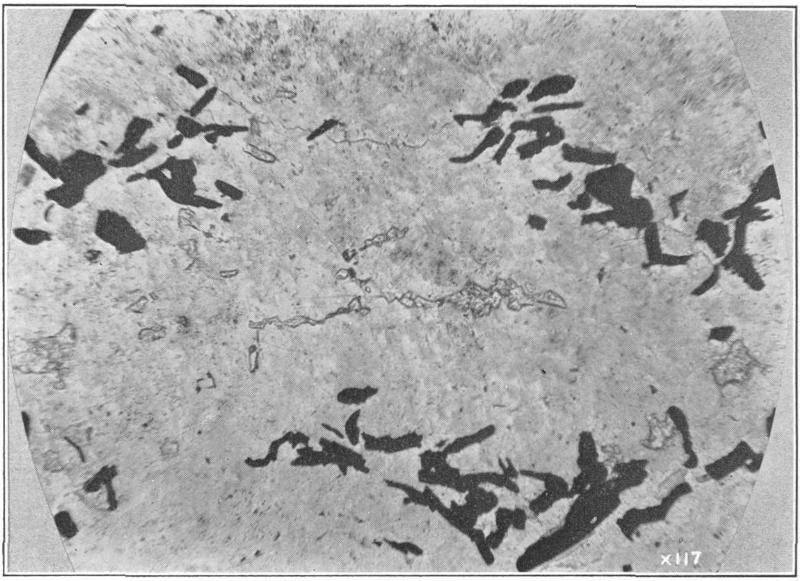
Orthoclase (*o*) along walls of vein and fine-grained molybdenite crystals concentrated at the margins. Black specks are molybdenite; *q*, quartz.

B. MOLYBDENITE-QUARTZ VEIN.

Relatively large molybdenite crystals intergrown with sericite concentrated at margins of vein. Black areas, molybdenite; *s*, sericite; *q*, quartz; *f*, fluorite.

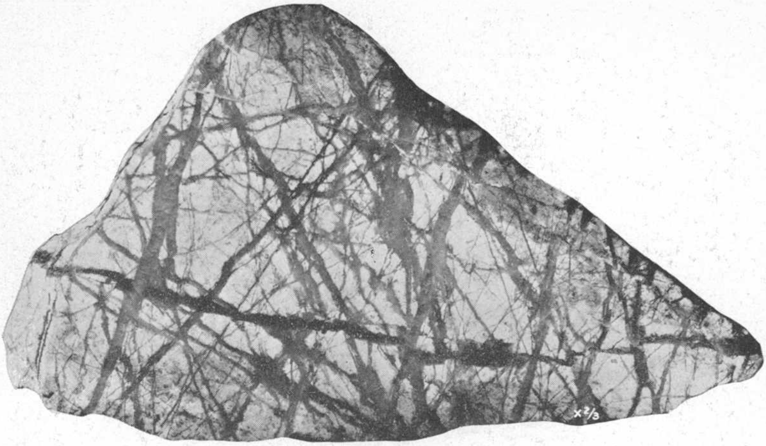
A. MOLYBDENITE-QUARTZ-ORTHOCLASE VEIN.

Showing orthoclase along central portion of vein. Black areas, molybdenite; dark gray, orthoclase; light gray, quartz.

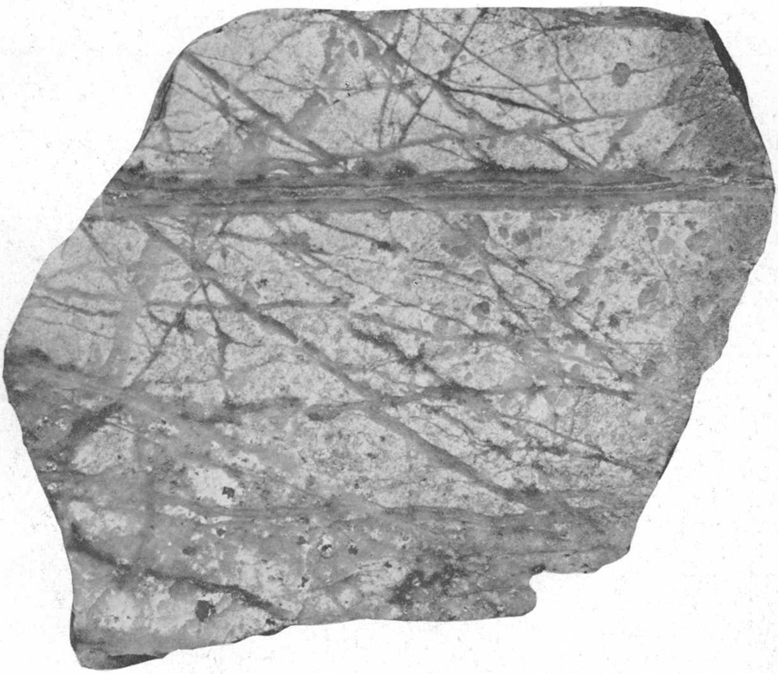


B. MOLYBDENITE-QUARTZ VEIN WITH FLUORITE ALONG CENTRAL PORTION.

Black areas, molybdenite, marking the margin of the vein. The mineral with low relief is fluorite, and the gray is quartz.



A



B

MOLYBDENUM-QUARTZ VEINS IN MODERATELY SILICIFIED ROCK.

A, Good grade of ore in granite. *B*, Veined Lincoln porphyry from Denver workings.

"BLUE QUARTZ" VEINS IN SLIGHTLY SILICIFIED GRANITE.

Locally veins of "blue quartz" are present in the inner part of the ore zone and may be readily mistaken for ore, although their content of molybdenite is low.

Toward the central core the replacement veins become larger and more coarsely crystalline, finally coalescing and leaving only faint "shadows" of the original rock fragments. Both veins and wall rock contain more quartz and less orthoclase. The molybdenite content on the whole decreases to much below that necessary for ore, but small occurrences of ore are present within the core. The core consists essentially of rather fine grained replacement quartz. Original quartz grains, which resisted alteration elsewhere, have disappeared. Here and there irregular bodies of coarse salmon-colored orthoclase occur in the quartz of the core. Pyrite within the inner core is practically confined to the later veins. It is coarser grained and more conspicuous but not appreciably more abundant than in the surrounding zones.

The preceding description is considerably idealized or conventionalized; as a matter of fact areas of moderately silicified rock are found within the highly silicified core, and extensions of the core into the moderately silicified rock are found. The zones are clearly defined, but their boundaries are gradational and would doubtless be mapped somewhat differently by different individuals or even by the same individual at different times.

Later than the main silification and ore deposition there were formed veins, generally less than half an inch wide, that cut all the zones. The most abundant of these are quartz-pyrite veins, which in places contain a little chalcopyrite, dark sphalerite, hübnerite, fluorite, and topaz. Probably still later than the pyrite veins are veins characterized by abundant sericite together with quartz, fluorite, a little molybdenite, and, in some at least, topaz and dark sphalerite. The sericite veins are most abundant in and near the central core, though they are present in all the zones and especially conspicuous along the stronger fractures, where they attain a thickness of 1 to 2 feet. They are not confined to strong fractures, however, but are also present in microscopic fractures throughout the mineralized zone.

CHEMICAL AND MINERAL CHANGES IN ALTERATION OF GRANITE

Chemical changes in the process of alteration are illustrated by the chemical analyses and a calculated analysis given in table 1, below. Table 2 expresses these changes by amounts of the different constituents in a given volume of rock. Table 3 shows the mineral changes that have taken place. Figure 31 shows graphically the changes in amount of oxides and minerals shown in tables 2 and 3. In figure 31, A, the minerals are arranged in order, with the most stable ones below and the least stable ones above.

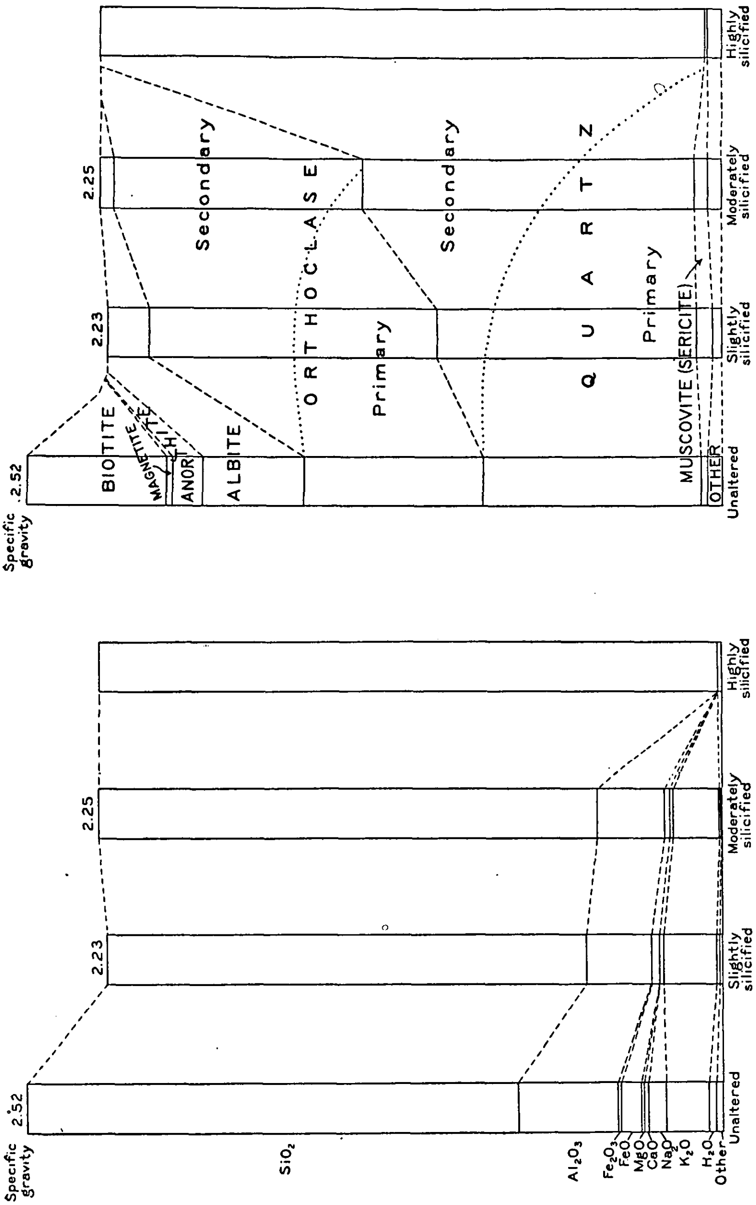


FIGURE 31.—Changes in the alteration of pre-Cambrian Silver Plume granite. A, Change in amount of oxides; B, mineral changes.

TABLE 1.—*Chemical composition of fresh and altered pre-Cambrian Silver Plume granite from the Climax district*

	1	2	3	4
SiO_2	70.83	78.62	80.78	98.23
Al_2O_3	14.41	10.80	9.26	----------
Fe_2O_3	.35	.05	Trace.	----------
FeO	2.94	1.13	1.34	----------
MgO	.56	.05	.10	----------
CaO	.64	.05	.10	----------
Na_2O	2.44	.76	.31	----------
K_2O	6.21	8.11	7.68	.06
H_2O	.04	.10	.01	----------
H_2O	1.34	.43	.46	.02
TiO_2	.24	.04	Trace.	----------
P_2O_5	.15	.10	.08	----------
Cl	.04	.04	.04	Trace.
F	.00	.00	.05	Trace.
S	.01	.06	.03	.01
BaO	.02	.03	.01	----------
Mo	.00	.10	.12	.01
	100.22	100.47	100.37	98.52
Specific gravity:				
Specimen in lump	2.52	2.23	2.25	2.25?
Specimen crushed	2.68	2.60	2.57	(?)
Weight of specimen (grams)	95.00	90.00	85.00	----------

1. Specimen C54 A-4, fresh rock. J. G. Fairchild, analyst.
2. Specimen C35 A, slightly silicified rock. J. G. Fairchild, analyst.
3. Specimen C195, moderately silicified rock. J. G. Fairchild, analyst.
4. Calculation based on studies of thin sections. Corresponds to column 4, table 3.

TABLE 2.—*Oxides, in grams per cubic centimeter, in fresh and altered pre-Cambrian Silver Plume granite from the Climax district, Colo.*

[Calculated from figures given in table 1]

	1	2	3	4
SiO	1.780	1.750	1.820	2.19
Al_2O_3	.363	.241	.208	.0043
Fe_2O_3	.008	.001	----------	----------
FeO	.074	.025	.030	----------
MgO	.014	.001	.0025	----------
CaO	.016	.001	.0025	----------
Na_2O	.061	.016	.008	----------
K_2O	.156	.189	.176	.0014
H_2O	.038	.099	.010	.0005
Others	.013	.010	.006	.054
	2.523	2.243	2.263	2.2502
Specific gravity	2.52	2.23	2.25	2.25

From the tables and figure 30 it is evident that the first stages of alteration resulted in a large removal of NaO_2, CaO, MgO, and Fe_2O_3 and a reduction of FeO. There has also been a reduction, though much smaller, in Al_2O_3. SiO_2 has changed but little, whereas K_2O has been notably increased. The further change to rock that is classed as moderately silicified is not great, consisting notably in a decrease in K_2O and indicating progress toward the stage of highly silicified rock, from which all the constituents except silica have been largely removed. It is evident that the general trend of the chemical alteration is a leaching of all the bases and alumina and a residual concentration and possibly addition of silica. In the early stages of alteration there was an addition of potassium, but in the more advanced stages this also was leached. In the veins there was an addition of molybdenum, sulphur, and fluorine. Pyrite is present throughout the deposit, but the iron in the pyrite, as already suggested, may easily have been derived from the altered country rock. The solutions that accomplished the alteration, then, were of such character as to take into solution nearly all the original rock-forming elements, including aluminum and in the later stage potassium, but not including silicon. The later veins contain abundant sericite with some topaz. The solutions that made these later veins must have been rich in both potassium and aluminum, as well as fluorine.

TABLE 3.—*Mineral composition of altered and fresh pre-Cambrian Silver Plume granite*

[Figures in columns 1 to 3 calculated from the chemical analyses shown in table 1. Minerals calculated were observed in thin sections of the rock specimens represented. Composition shown in column 4 determined from thin sections]

	1	2	3	4
Quartz	31.63	42.81	49.50	98.00
Orthoclase	21.86	46.11	44.31	
Albite	20.68	6.70	2.32	
Anorthite	2.24			
Muscovite (sericite)	.95	2.79	1.53	.50
Biotite	20.77			
Magnetite	.51			
Apatite	.40	(?)	(?)	
Fluorite			.12	.01
Molybdenite			.15	.02
Others		[a] 1.60	[a] 2.10	[b] 1.00
	99.04	100.01	100.03	

[a] A little over 1 percent is FeO which has not been accounted for. Thin sections show small grains resembling titanite that may contain the FeO, but the mineral has not been identified. A small amount of apatite is probably present, though not shown. Hand specimens show a very little limonite stain.

[b] It was estimated that there is about 1 percent of pyrite, hübernite, and topaz in the late veinlets that cut the rock.

ALTERATION OF OTHER ROCKS

The schist throughout the mineralized area has been bleached. In the ore zone, especially on drift 2 in the Phillipson level, it is ore of as high grade as found in the granite and in the highly silicified core it has been completely replaced by quartz. Mineralogically the schist is more readily replaceable by quartz than the granite, but in reality small schist masses in granite areas show less alteration than the granite and small granite masses in schist areas are more altered than the schist. This greater resistance of schist to alteration is probably due to its relative toughness and resistance to fracturing.

The porphyry dikes alter essentially like the granite. Where the porphyry is moderately altered the feldspar phenocrysts have become very indistinct and the rock can be recognized only by the quartz phenocrysts, which resist replacement longest. When the quartz phenocrysts eventually succumb to replacement by the fine-grained quartz the porphyry is difficult or impossible to recognize because of its similarity to altered granite. The porphyry dikes as a whole are less altered than the other rocks. In places even in the highly silicified core only the margins of dikes show alteration. In the ore zone the dikes or portions of them are ore, but the change from ore to barren, unaltered porphyry is so sharp in places that mineralization contacts were mistaken for intrusive contacts, and during the early development of the deposit the dikes were considered younger than the mineralization. The resistance to alteration of the dike rocks cannot be due to their composition alone, for it is similar to that of the granite, but must be ascribed to differences in the amount of fracturing in the younger and older rocks.

MINERALOGY

The minerals introduced during the epoch of mineralization that brought in the molybdenite are briefly described below in alphabetic order, and the few secondary minerals derived from them are similarly considered. These descriptions are followed by a list of the minerals found in small fissure veins in granite and schist that have no apparent relation to the molybdenum deposit.

PRIMARY MINERALS OF THE MOLYBDENUM DEPOSIT

Chalcopyrite ($CuFeS_2$).—Chalcopyrite is present, though not abundant, in the molybdenite deposit. It occurs with sphalerite and fluorite in the quartz-pyrite veins and probably accounts for the presence of small quantities of copper in the concentrate.

Fluorite (CaF_2).—Small amounts of colorless, green, red, and purple fluorite can be detected by the naked eye in the silicified rock, but it is most abundant in the sericite fissure veins, where it occurs as octahedral crystals and in irregular masses as much as several inches across. On the north slope of Ceresco Ridge a band of white fluorite 14 inches wide was observed in a fissure vein. The green, red, and purple fluorite is readily recognized, but the colorless variety, which blends with other minerals, is easily overlooked. As much of the fluorite is colorless, the mineral is probably more abundant than was formerly suspected.

Thin sections under the microscope show a wide distribution of the fluorite that is not suspected from an examination by the unaided eye. Small irregular grains of fluorite are scattered through the silicified rock and very commonly along the middle portions of quartz or quartz-orthoclase veins. The fluorite is no more characteristic of veins that carry molybdenite than of veins without molybdenite, but on the whole it is most common where molybdenite is most abundant. In molybdenite veins it occurs along the middle portions. It is also very common in the sericite veins, and in both kinds of veins it was deposited later than the molybdenite.

Hübnerite ($MnWO_4$).—Veins half an inch or less thick containing hübnerite are easy to find in the float, and several have been observed in place in the mine. The hübnerite is characterized by a reddish-brown to black color, a high luster, a distinctly red though dark streak, and good cleavage. Lathlike crystals with quartz are fairly typical. Hübnerite occurs with sericite in small quartz veins that cut the silicified rock and the molybdenite veins and is also present in many of the quartz-pyrite veins that cut all zones of alteration, including the molybdenite veins. In these quartz-pyrite veins the hübnerite occurs in scattered laths along the walls. Only a little iron is indicated by qualitative tests. In liquids under the microscope the hübnerite is translucent, showing a deep-red color.

Molybdenite (MoS_2).—Molybdenite (60 percent metallic molybdenum and 40 percent sulphur) is the one commercially valuable metallic mineral in the district. It occurs characteristically as fine specks along the margins of small ramifying veins with quartz or quartz and orthoclase gangue. In most of these veins it is the only metallic mineral present. It is readily recognized by its shiny dark metallic-gray to black color, similar to that of graphite. The crystals are flat and six-sided but are rarely large enough for their forms to be recognized except under the microscope, where the hexagonal outline is commonly evident. Much of the molybdenite, however, even when highly magnified, appears only as tiny black specks. The uniform fine-grained character of the molybdenite at Climax is exceptional, as in most other molybdenite deposits large crystals, many an inch or more across, are common.

Orthoclase ($KAlSi_3O_8$).—The secondary finely granular orthoclase characteristic of the mineralized area can be recognized only under the microscope. In this area there has been a general finely granular recrystallization of the original microcline and orthoclase of the igneous rocks, beginning along the margins and cleavage planes of the grains. Calculations based on chemical analysis of the moderately silicified granite show 44 percent of orthoclase and only 2 percent of the albite molecule. This amount of albite is evidently present in unreplaced remnants of original microcline, orthoclase, and oligoclase. Little or none of it is thought to be present in the secondary orthoclase, although its absence can not be proved. Fine-grained orthoclase, which rarely shows crystal outlines, also occurs along the walls or middle of many quartz veins. It is characteristic of both slightly and moderately silicified zones but is probably a little more abundant in the moderately silicified zone.

In the highly silicified core there are in places small irregular veinlike bodies of coarse salmon-colored orthoclase that have the appearance of pegmatite.

Pyrite (FeS_2).—Pyrite occurs throughout the area as small cubes disseminated in altered rock and as a constituent of veins that contain quartz and topaz. Much of the disseminated pyrite was formed at an early stage of mineralization, whereas the pyritic veins, which cut all the altered zones and the molybdenite veins as well, belong to a distinctly later stage. At the surface and for a few inches to a few feet below the surface the pyrite is mostly oxidized, but its former presence is everywhere indicated by cubical cavities and by the limonite stain on the rocks.

Quartz (SiO_2).—Quartz in crystals, measuring only about 1 by 3 to 2 by 5 millimeters, appears to be confined mostly to the sericite veins. Massive quartz in veins and as a constituent of the country rock is the most abundant mineral in the district. The White tunnel cuts about 900 feet of white, well-crystallized massive fine-grained quartz, which locally resembles quartzite. In places, notably in the slightly silicified zone, the quartz in the veins is blue or bluish gray, owing to the presence of scattered microscopic crystals of molybdenite. The quartz in the larger veins looks well crystallized, but in some of the smaller veins individual crystal faces cannot be detected by the eye, and the quartz looks very dense. In thin section the massive replacement quartz and the quartz in the larger veins form fairly uniform mosaics. In the smaller veins, especially in the outer zone of mineralization, the very dense quartz is also well crystallized but finer-grained.

Sericite (*muscovite*).—Sericite occurs in the slightly silicified zone and outer fringe of the mineralized area, where it replaces plagioclase and to a small extent microcline and orthoclase. It was apparently one of the first alteration minerals to form. In parts of the ore zone a little sericite, which is intergrown with molybdenite plates, was also formed during the later stage of moderate silicification. The most extensive occurrence of sericite is in fissure veins of a still later stage, which are found throughout the mineralized area but are most numerous in the central portions. Sericite collected from one of these fissures was analyzed by J. G. Fairchild, with the result given below. The material as collected contained quartz, jarosite, limonite, molybdenite, and possibly topaz. The mineral separations were made by C. S. Ross.

Analysis of sericite from vein in Climax molybdenite deposit

[J. G. Fairchild, analyst]

SiO_2	49.14	Na_2O	0.23
Al_2O_3	32.27	K_2O	10.88
Fe_2O_3	.70	H_2O	4.42
FeO	.42	TiO_2	.02
MgO	1.81	P_2O_5	.04
CaO	.80		

The analysis approximates the formula $K_2O.4Al_2O_3.8SiO_2.2H_2O$.

Sphalerite (ZnS).—Dark-brown to black sphalerite was observed with fluorite in a sericite vein and in pyrite veins. It occurs only sparingly and is associated with minerals that formed late in the sequence of mineralization.

Topaz ($(AlF)_2SiO_4$).—Topaz is widespread at Climax but everywhere as microscopic crystals. It occurs disseminated through silicified rock, as irregular veinlets that cut molybdenite-bearing quartz veins, and as a characteristic gangue mineral in the late pyrite veins. It mostly forms equidimensional grains and to a small extent lath-shaped grains with cleavage normal to the longer dimension.

Unidentified mineral.—A mineral not identified is common in small amounts in places associated with secondary orthoclase. The mineral may occur in orthoclase veins or be disseminated through the rock. It resembles titanite, but chemical analysis of a specimen containing the mineral showed too little titanium. The analysis showed over 1 percent of ferrous iron, which could not be accounted for and which suggests the possibility that the unidentified mineral is iron-bearing.

SECONDARY MINERALS OF THE MOLYBDENUM DEPOSIT

Chalcocite (Cu_2S).—Chalcocite and bornite occur as films coating pyrite, sphalerite, and chalcopyrite.

Jarosite ($K_2O.3Fe_2O_3.4SO_3.6H_2O$).—Jarosite is common throughout the mineralized area and occurs as ocher-yellow incrustations along fissures and in seams, but it so closely resembles limonite that its abundance is difficult to estimate.

Limonite ($Fe_2O_3.H_2O$).—Limonite stains the surface rock throughout the mineralized area, giving it a distinctive color, which even from a distance contrasts with that of the surrounding area. Where the rock is massive the limonite is confined to a thin surface zone, but along fissures and fractures it extends some distance below the surface. It has been formed by oxidation of pyrite and is mostly yellow, although locally it may be reddish.

Molybdite ($Fe_2O_3.3MoO_3.7\frac{1}{2}H_2O$).—Molybdite, or molybdic ocher, which has been formed by oxidation of the molybdenite (MoS_2), is very conspicuous in places at the surface because of its canary-yellow color. It is so finely crystalline that much of it is earthy, but in places in the mine it forms beautiful clusters of fine silky needles that grow from the walls of fissures. As oxidation on the whole has been shallow, molybdite is mostly found within a few feet of the surface, but along the more open fissures it is prominent at considerable depths. Assays of diamond-drill cores show small amounts of molybdenum oxide of no economic importance several hundred feet below the surface.

MINERALS IN VEINS NOT ASSOCIATED WITH THE MOLYBDENUM DEPOSIT

Numerous veins occur in the pre-Cambrian granite and schist in the Mosquito Range in the Leadville, Alma, and Climax districts. Such veins in the Climax area are small and not continuous, and only a few have yielded any appreciable production. Numerous prospect pits and tunnels testify that these veins have had the close attention of early prospectors. Little or no information can be obtained concerning most of these prospects, and little is revealed by the weathered dumps, which commonly show only quartz and pyrite and in places galena, sphalerite, chalcopyrite, and hübnerite. Some of the veins carry a little gold and silver.

Most of the veins observed are in schist and parallel the schistosity. A few appear to occur along dike walls. Limonite stains make the veins conspicuous in places. Only in the John Reed mine, at Wortman, and, to a lesser extent, in the Zephyr mine, both in the Arkansas Valley, has recent work been done. At the John Reed mine a mill was constructed to treat ore, but not much production is reported. Since the burning of the mill several years ago no mining has been done. The mine dump shows a great deal of Lincoln porphyry. The ore on the dump contains dark-brown sphalerite with a little chalcopyrite and galena. Pyrite and quartz are plentiful. The Zephyr mine dump shows mostly quartz and pyrite with a very little sphalerite, galena, and chalcopyrite.

On the slopes east of Clinton Gulch a limonite-stained vein, roughly parallel to the valley, is conspicuous at an altitude of about 12,700 feet. Where prospected it shows mostly quartz with abundant carbonate in places. At one place there is a small quartz vein with coarse hübnerite crystals and a little galena.

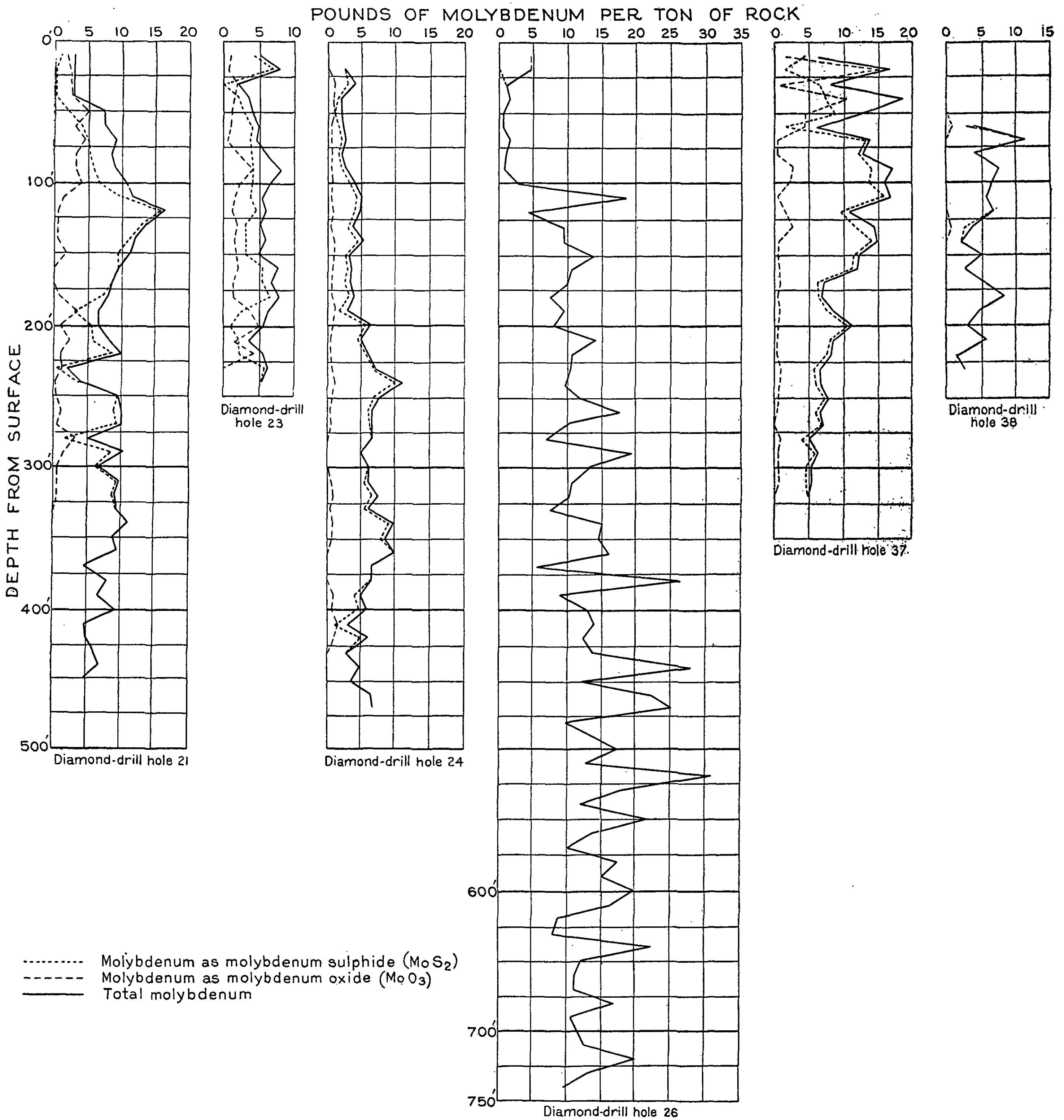
In a tunnel at the south end of Ceresco Ridge a short distance below timber line a small vein about an inch wide cuts the slightly silicified granite and the molybdenite-quartz veins. The vein contains quartz, sphalerite, chalcopyrite, and galena and is evidently later than the molybednite mineralization in this portion of the area.

In the small veins in the Climax district the following minerals were observed, named in their approximate order of abundance: Quartz, pyrite, dark-brown sphalerite, galena, hübnerite, fluorite, brown carbonate, and magnetite. As most of these veins are only poorly exposed in old prospects a detailed study of them has not been attempted, and the above list of minerals is probably not complete.

SIZE OF THE MINERALIZED AREA

Development as yet is too incomplete to give more than a rough approximation of the size of the mineralized area. Plate 32 shows the topography, together with the mine workings and diamond-drill development, and plates 33–37 show several cross sections of the deposit. The central core of highly silicified rock extends for about 900 feet along the White tunnel level and about 700 feet on the upper or Leal tunnel level. At right angles to this direction its extent is not known but is probably somewhat less. On the Phillipson tunnel level, about 460 feet below the White tunnel level, the maximum horizontal dimension of the highly silicified zone, less definitely determined by drifting and drilling, has increased to about 1,500 feet.

The ore zone or envelop that surrounds the central core is undoubtedly of variable thickness, and portions of it may not contain



CONTENT OF MOLYBDENUM AS SULPHIDE AND OXIDE IN SOME DIAMOND-DRILL HOLES.

sufficient molybdenite to be classed as ore. Moreover, the general dip of the ore zone has not been closely determined and is still unknown in several areas. Any estimate of thickness of the ore envelop is therefore subject to modification and correction. Most of the development work has been done to the northwest and north of the central core. There has also been development to the southeast and south but almost none elsewhere. If an average dip of 60° is inferred for the northwestern and northern parts of the ore zone, its thickness there, at right angles to the dip, is 300 to 350 feet. Development in other areas does not yet indicate the thickness. There is some basis for the inference of a 60° dip at the north, but the dip may vary considerably from that figure, and at other points on the periphery it may not be the same as at the north. To the present depth of development, which is mainly above the Phillipson tunnel level, there is no consistent change in the character of the ore down the dip of the ore shoot. Drill holes 26 and 38C, which extend 368 and 480 feet respectively below the Phillipson tunnel level, are in ore of good grade, and neither indicates any change in character of ore.

The company in October 1930 estimated its developed ore at 50,000,000 tons, and development on the Phillipson tunnel level to 1931 added an estimated reserve of 35,000,000 tons, making a total of 85,000,000 tons. As only part of the area has been developed, and none of it to any great depth, there can be no doubt that much ore in addition to that now known will be found.

GRADE OF ORE

As there is a gradation from one mineralized zone to another, there is no sharp change in the metal content between ore and waste. The metal content necessary for ore is therefore determined by the price of the product and the cost of production. The average molybdenite content of ore milled has been about 0.83 percent. The Climax Molybdenum Co. regards ground that averages 0.7 percent or more of molybdenum sulphide (MoS_2) as ore. Whenever the grade of rock that can be profitably treated is materially lowered, the amount of ore available for treatment will be decidedly increased.

SUPERGENE ALTERATION

Besides the conspicuous red and brown staining of rock in the mineralized area, the vicinity of the ore zone is also characterized by a minor amount of canary-yellow material at the surface. The red and brown colors are the result of the oxidation of pyrite to limonitic minerals. The yellow is the result of the oxidation of molybdenite to molybdite. The oxidation of pyrite and molybdenite has not gone to great depths, nor has it been complete even at the surface. In the more open fissures both sulphides may be altered to considerable depths, but in the more massive veins both pyrite and molybdenite are present within a few inches of the surface. The reasons for the relatively shallow oxidation are probably both chemical and physical.

The outcrop of the deposit is largely at altitudes of 11,500 to 13,000 feet, and at the higher altitudes the temperature a short distance below the surface remains below the freezing point of water for a large part if not for all the year. No exact data on local rock temperature at different depths are available, but in the Climax mine and in numerous others at corresponding altitudes ice crystals form on the walls of workings, evidently collecting moisture from the air. This low temperature has prevented a free downward movement of surface solutions during glacial and postglacial time, but in preglacial and interglacial time [29] conditions were favorable for extensive oxidation. As the deposit lies on and near the axis of the glaciated Tenmile Amphitheater, a considerable quantity of oxidized ore may have been removed from the deposit by glaciation. This removal, together with the unfavorable conditions for oxidation in postglacial time, probably accounts for the shallowness of the present oxidized zone.

The chemical behavior of molybdenite in oxidation has not been much studied and is not well known. Under the conditions that prevail in the Climax deposit, however, the molybdenum seems to have been in large part oxidized to the higher oxide MoO_3, which combined with ferric oxide from the oxidation of pyrite to form molybdite. This compound seems to be only slightly soluble under existing conditions, and there is little evidence of movement or concentration of the molybdenum. So far as has been determined there is no indication of the formation of secondary molybdenite and therefore no indication of sulphide enrichment of molybdenum ore.

Plate 38 shows the molybdenum content both as sulphide and oxide, as determined in six vertical drill holes from the surface to different depths. It is based on assays made by the Climax Molybdenum Co., which show amounts as small as 0.01 percent of molybdenum. When these records are considered together with the character of mineralization they do not indicate a movement of molybdenum during oxidation. The records are summarized below.

Hole 21. Molybdenum oxide attains a maximum amount at a depth of 50 to 75 feet and then decreases, though with some fluctuations. Molybdenum sulphide is abnormally high at a depth of 120 feet and below the average at 180 to 240 feet, but the average above 240 feet is fairly close to that between 240 feet and the bottom at 450 feet.

Hole 23. Molybdenum oxide is at a maximum at a depth of 80 feet and near the bottom of the hole. The molybdenum sulphide content is fairly constant throughout but varies inversely to that of the oxide near the bottom of the hole.

[29] U.S. Geol. Survey Prof. Paper 148, pp. 271-272, 1927.

Hole 24. Molybdenum oxide is at a maximum at about 430 feet, near the bottom of the hole, but ranges only from 0 to 1.55 pounds to the ton. Molybdenum sulphide increases gradually to a depth of 240 feet, maintains a high average between 240 and 370 feet, and then decreases.

Hole 26. Molybdenum oxide is confined to the first 20 feet. Molybdenum sulphide increases slowly to about 100 feet and averages more than 10 pounds to the ton from 100 to 790 feet, or the bottom.

Hole 37. Molybdenum oxide attains a maximum in the first 50 feet and decreases rapidly, but small amounts persist to the bottom, at 320 feet. Molybdenum sulphide increases as the oxide decreases, attaining a maximum at 110 feet, but then gradually decreases.

Hole 38. Molybdenum oxide is confined chiefly to the first 60 feet. The average content of molybdenum is small but after the first 50 feet is fairly constant. The first 50 feet is in talus. Molybdenum oxide in small amounts occurs in the first 10 feet of rock in place and also at the depth of 130 feet. Molybdenum sulphide maintains a fairly constant average from the top of bedrock to the bottom of the hole at 230 feet.

ORIGIN OF THE MOLYBDENITE

Most of the large number of deposits of molybdenite that have been described are closely associated with intrusive rocks and have been generally regarded as genetically related to the igneous rocks. The association ranges from pegmatite dikes, in which molybdenite is regarded as a primary mineral, through high-temperature veins to intermediate-temperature veins. Molybdenum is apparently also present in deposits formed at relatively low temperature, for some of the lead deposits on oxidation yield abundant lead molybdate. The primary mineral from which the molybdenum was derived in the lead deposits has usually not been determined.

The minerals associated with the molybdenite at Climax give no very definite evidence as to the temperature of formation. Pyrite, the most abundant metallic mineral, is formed through a long range, and sphalerite and chalcopyrite are also formed through rather long ranges of temperature. Among the nonmetallic minerals quartz, the most abundant mineral, and orthoclase, sericite, and fluorite are minerals of long range. Topaz is perhaps indicative of moderately high temperature, but taken alone it would hardly give any clear indication of the conditions of temperature under which the deposit was formed.

The general kind of rock alteration associated with the molybdenum deposit is rather closely similar to that of some of the disseminated copper deposits, notably the deposits at Ely, Nev.,[30] and Bingham, Utah.[31] The similarity is especially noteworthy in the presence of abundant secondary orthoclase. The fact that both of these copper deposits contain minor amounts of molybdenite is another indication of similar conditions of formation. Spencer considers that the Ely

[30] Spencer, A. C., Geology and ore deposits of Ely, Nev.: U.S. Geol. Survey Prof. Paper 92, p. 56, 1917.
[31] Butler, B. S., and others, The ore deposits of Utah: U.S. Geol. Survey Prof. Paper 111, p. 166, 1920.

deposits have formed at temperatures between 200° and 350°, or in the general range of the mesothermal deposits as defined by Lindgren. The Bingham disseminated deposits were doubtless formed under similar conditions. Buddington [32] has described deposits at Shakan, Alaska, which are similar to the deposits at Climax in the abundance of secondary orthoclase or adularia but differ in the presence of other sulphides in considerable abundance and in a later stage of zeolitic mineralization. As to the conditions of formation Buddington concludes:

The minerals of the adularia period appear to follow the pegmatite stage and to be best grouped, following Lindgren's classification, as of hypothermal origin. Insofar as the sulphide minerals themselves are concerned, they might belong to either hypothermal or mesothermal veins; but since, with the exception of pyrite, they follow for the most part the adularia period and are succeeded by the zeolites, it would seem that they are best grouped as belonging to the mesothermal period and the minerals of the zeolite period as formed in the epithermal stage.

The similarity of the Climax deposits to these cited would seem to justify the assumption that the deposits were formed under conditions represented by the lower temperature range of hypothermal or upper temperature range of mesothermal zones.

A deposit of molybdenum in the Valley of Ten Thousand Smokes, Alaska,[33] is of particular interest, as the conditions of formation are better known. This deposit of "molybdenum blue" ($Mo_3O_8.xH_2O$) occurs in and around a steam vent that had a temperature of 264° C. and contains calcium sulphate, ammonium and ferric chloride, and sulphate combinations. Fluorine was also present. This combination of molybdenum with oxygen rather than with sulphur, even though hydrogen sulphide was abundant in the area, is striking. Zeis says:

Molybdenum blue is quite easily formed when a solution of an alkaline molybdate is treated with a reducing agent, such as hydrogen sulphide. * * * If it is exposed for a considerable period to hydrogen sulphide, however, an insoluble sulphide of molybdenum will eventually be formed.

This fumarolic occurrence suggests that molybdenum is not carried as the sulphide but in some more highly oxidized form or as a fluoride or chloride, and that when the temperature becomes sufficiently low for the formation of hydrogen sulphide in the solutions the molybdenum is either deposited as the insoluble molybdenum sulphide or eventually reduced to that substance.

Staples and Cook [34] point out that the molybdenite at Climax occurs in small crystals as contrasted with large crystals in most

[32] Buddington, A. F., Molybdenite deposits of Shakan, Alaska: Econ. Geology, vol. 25, pp. 197–200, 1930.

[33] Zeis, E. S., The Valley of Ten Thousand Smokes: Nat. Geog. Soc. Katmai Series, vol. 1, No. 4, 1929.

[34] Staples, L. W., and Cook, C. W., A microscopic investigation of molybdenite ore from Climax, Colo.: Am. Mineralogist, vol. 16, pp. 1–17, 1931.

deposits and suggest that the molybdenum was carried and deposited as colloidal sulphide. There is, however, no colloidal molybdenite in the deposit. Even the finest material is definitely crystalline, and some of it is rather coarsely crystalline. The authors cited offer no suggestion as to how or when it was changed from colloidal to crystalline molybdenite.

The genetic relation of the copper deposits of Ely and Bingham and the molybdenum deposits of Alaska already mentioned to bodies of intrusive rock is much more evident than that of the deposit at Climax, but the mineralogy of the Climax deposit and the associated rock alteration are so similar to those of the other deposits that they strongly suggest such a relation. The mineralized Tertiary dikes in the Climax district were probably intruded shortly before the period of mineralization, but their association with the ore is not sufficiently close to point to them as sources of mineralization. In its general pipelike or stocklike character the deposit is also similar to the numerous other deposits. The O. K. mine, in the Beaver Lake district, Utah,[35] is a good example of such a pipelike body with a siliceous core surrounded by less completely replaced rock containing ore minerals, including molybdenite. The Cactus mine, in the San Francisco district,[36] is a similar pipelike deposit on a larger scale, in which the rock shows strong brecciation and replacement. The disseminated copper deposits of Bingham, Utah, and Ely, Nev. are much larger breccia stocks, in which there has been strong replacement of the rocks.

There are numerous breccia chimney or stock deposits in Colorado that have physical similarities to the Climax deposit but contain different metals. Some such deposits are the Patch, in the Central City district; the Bassick, in the Querida or Rosita Hills district; and numerous pipe or stock deposits of somewhat similar character in the Red Mountain section of the San Juan region.

The origin of deposits of this type is as yet somewhat uncertain. In the earlier descriptions of such deposits it seems to have been generally considered that the brecciation was due to movement of the rock or to volcanic activity, and that the mineralizing solutions found the breccia zone an easy passageway and replaced the breccia in whole or in part. Butler [37] states for the Utah deposits that "the structural relations indicate that the space occupied by the ore and gangue minerals was formed largely by the solution of the rock in the early stages of mineralization and not by dynamic movement."

[35] Butler, B. S., and others, The ore deposits of Utah: U. S. Geol. Survey Prof. Paper 111, p. 517, 1920.
[36] Idem, p. 317.
[37] Idem, p. 517.

Recently Locke [38] has suggested that in the early stages of mineralization there was solution of the rock, with the production of open cavities. The rock around such openings caved much as a mine stope caves, and the caved area enlarged in the fashion of a shrinkage stope until the chimneys or stocks were produced. In the later stages of mineralization deposition exceeded solution, and the rock fragments were partly replaced and cemented by ore and gangue minerals, which filled or partly filled the spaces between fragments.

In the Climax area there has undoubtedly been a good deal of fissuring of the pre-Cambrian rocks, as is evident from their highly fissured character outside the mineralized area. There has also been shearing in some of the Tertiary (?) dikes, and such shear zones are the most highly mineralized. Mineralization occurred in rocks that were much broken, but it is not evident that before mineralization they were more broken than the rocks in some other parts of the pre-Cambrian granite, and it is not clear why one particular area was mineralized and others not. Staples and Cook [39] have suggested that the fracturing was due to torsional stresses set up by the movement on the Mosquito fault and that its localization was due to a change in direction of dip on the fault at this point.

There has been much fracturing of the rocks adjacent to the Mosquito fault, but as seen in the Phillipson tunnel the fracturing obviously associated with the fault seems to be independent of that associated with the mineralization. Moreover, there is no indication of a change in the direction of the dip of the Mosquito fault in the vicinity of Climax, though there is a slight change in the angle of dip from place to place.

ZONAL DISTRIBUTION OF MINERALIZATION

In many mining districts a zonal arrangement of the minerals and metals has been recognized. Certain metals and minerals that are abundant near the center of the mineralized area give place upward or outward to others. There is no clear evidence of such zoning in the Climax district except in the zones in the deposit itself. There are, to to sure, a few veins containing zinc and lead in the surrounding area, but no evidence has been found to indicate that they are directly related to the molybdenum deposit. This absence of other metals associated with the molybdenum, with the exception of iron, a little zinc and copper, and a very little tungsten, is rather surprising, and the reason for it is not clear, though there are numerous molybdenum deposits in which pyrite is the only other mineral.

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38 Locke, Augustus, The formation of certain ore bodies by mineralization stoping: Econ. Geology, vol. 21, pp. 431-453, 1926.

39 Staples, L. W., and Cook, C. W., op. cit., p. 10.

From the similarity to other deposits that are known to be associated with intrusive bodies it may be inferred that the Climax deposit is associated in its origin not with the exposed dikes but with a larger though still concealed intrusive body whose apex had approached sufficiently near to the surface for the gases liberated from it to escape through the fractured rock. For some reason that is not apparent the escape started at the locality of the present deposit and, once started, continued to drain the gases from the crystallizing stock. These escaping gases effected the alteration of the rock and deposited the molybdenite. If there were zoning in a deposit formed in such a "blow hole" the zoning would probably be mainly in a vertical direction, and the erosion surface at any given time would show but one zone. This may be the reason why molybdenite is the only commercial metal found in this deposit. George E. Collins, in a private report dated September 1907, has suggested a similar origin for the Patch in Central City. He states:

Not improbably the whole area may be underlain at great depth by a mass of eruptive [andesite] and its mineralization may have been effected by hot magmatic waters given off by the latter on cooling.

As the molybdenite deposit itself is the strongest evidence of the presence of an unexposed stock, the argument presented above will be differently appraised by different readers, according to their views regarding the association of ore deposits with intrusive stocks.

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