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THE CLIMAX MOLYBDENUM DEPOSIT OF COLORADO[1]

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WITH SECTION ON HISTORY, PRODUCTION, METALLURGY AND DEVELOPMENT[3a]

by

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SUMMARY

The largest metal-mining operation in the history of Colorado mining 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 important for a short period during the World War; it ceased from April, 1919 to August, 1924, but to 1930 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 broken ore reserve sufficient to furnish 2,000 tons daily for 3 years and is being developed to continue to furnish this and still further increased output as the use of the metal may permit.

The rocks in the eastern part of the district are of pre-Cambrian age and consist mainly of schist intruded by granite. To the west of the pre-Cambrian rocks and separated from them by the Mosquito fault are the Paleozoic sedimentary rocks. Both pre-Cambrian and Paleozoic rocks have

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[3a] TO JAN. 29, 1931. Progress of Phillipson Tunnel is also shown on map (Plate I) to Jan. 29, 1931.

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 strongly 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 envelope 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 small amounts occur near the middle in a few places. Fluorite, a minor constituent, occurs along the middle of the veinlets. Outward from this envelope 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 pyrite veins with a little chalcopyrite, dark-brown sphalerite, hübnerite, topaz, quartz, and fluorite cut the highly altered central core, the moderately altered ore envelope, and the surrounding zone of slightly altered rock. Sericite veins apparently later than the pyrite veins occur throughout the mineralized area. These sericite veins 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 envelope of moderately altered or silicified rock which surrounds the central core of highly silicified rock. Present development indicates that the silicified core and the surrounding ore-bearing envelope expand downward and have the general forms of concentric cones, which have been truncated by erosion. On the upper or Leal Tunnel level the maximum diameter of the central core is about 700 feet, but since much has been eroded only approximations of the dimensions of the deposit 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 envelope surrounding the core so far developed appears to be fairly continuous and varies in thickness, but in places is probably as much as 300 feet thick.

Location and Topography

The Climax district is in northeastern Lake County, where the Continental Divide extends eastward across Fremont Pass and turns northward along the Mosquito Range. It embraces the Tenmile Amphitheater and the peaks and spurs to the north, east, and south, as shown in Plate I. It ranges from about 11,000 to 13,600 feet in altitude. In early reports it 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 (altitude 11,320 feet) on the Platte Canyon-South Park-Leadville narrow-gage line of the Colorado & Southern Railroad, which operates the entire year and gives connection daily with Leadville and Denver. The station is 13 miles north of Leadville and is 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 mine buildings are a mile east of Climax at an altitude of from 11,700 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 from Climax to the mine. The Climax Molybdenum Co. has plans for concentrating all its operations and quarters for employees at Climax when the Phillipson Tunnel, now (October 1930) 2800 feet long, is completed. The portal of this tunnel is about a quarter of a mile northeast of Climax and only a little higher. At present (October, 1930), ore is transported from the White Tunnel level to the mill by aerial cable tram. Early in 1931 the tram will be abandoned, and ore from above the White Tunnel level will be passed down the 465-foot 65° shaft [starting in the moderately silicified granite near the mouth of the White Tunnel and dipping into the highly silicified core] to ore pockets above the Phillipson Tunnel level, and trammed to the mill in trains of ten to twenty 10-ton cars. Beginning early in 1931, ore between the Phillipson Tunnel level and the White Tunnel level will be blocked out. Ore above the White Tunnel level will be blocked out both from the Phillipson Tunnel and from the White Tunnel. Ore below the Phillipson Tunnel level will not be touched for many years.

GEOLOGY

PHYSIOGRAPHY AND GLACIATION

For the broader physiographic and glacial features of the district and the surrounding region the reader is referred to a report by Capps[4] and to the United States Geological Survey's report on the Leadville district[5], which quotes extensively from Capps. The only features that deserve mention here are the drainage relations of Tenmile

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

[5]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.

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 of north-northwestward trend 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 has a north-northwestward trend 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.

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 both the Tenmile and East Eagle valleys, which are separated by another low divide southwest of Robinson. The presence of float, high on the slopes of Chalk Mountain, 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.

History and Production

By Chas. 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 certainly 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 about 1 per cent MoS_2 molybdenite ore, 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 aroused to develop the ground. A private report in the files of George E. Collins, mining engineer, of Denver, Colo., written in 1905 indicates he recognized the possibilities of the deposit and recommended the purchase and holding of a large acreage on Bartlett Mountain, but Mr. Collins' recommendation was not accepted. E. G. Heckendorf[6], of Denver,

[6]About October 20, 1930, Mr. E. G. Heckendorf, of Denver, Colo., 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 for Heckendorf the mineral as molybdenite. In 1900, the Colorado School of Mines identified the molybdenite. Heckendorf seems to have continued to take an interest in this mineral. As a result of his 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, 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 case the tunnels would run through the

spent 3 years from 1911 to 1913, driving short tunnels through blocks of the brecciated granite containing molybdenum lying in the glacial debris both at the south and north ends of Chalk Mountain until he became convinced the rock was not in place. After 1914 he and others did development on Bartlett Mountain, including the extension of the Leal Tunnel to 690 feet by October, 1916. 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 $2.00 per pound of contained MoS_2, or $3.33 per 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 then knowledge of the flotation method.

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

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blocks into glacial wash. In 1914, he followed up the glacial debris across Fremont Pass to his old locations on Bartlett Mountain. Here he found that A. M. Gillaspey had staked, about 1904 or 1905, 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 in all but the Denver. He was in touch with many chemical works in the United States and Europe. He experienced much difficulty in trying to get assays. Very few assayers 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 per cent saving in the laboratory experiments. In October, 1916, he laid his data before Mr. 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 Ceresco Ridge. As finally executed, the agreement of the operating company was for 80 per cent of the stock of the company, with the remaining 20 per cent divided as follows: John Webber ¼; S. H. Webber ¼; Heckendorf ¼; and a Dr. Harris ¼." 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.—Chas. W. Henderson, Denver, Colo.

of molybdenum lagged, therefore, 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 publicly reported in Mineral Resources of the United States. In 1915, 3,498 tons of raw ore, with its molybdenum content valued at $114,866, an average of $32.84 per ton was reported. In this same year (1915) Climax was first mentioned in a Government publication as a possible producer of molybdenum in the following note in Mineral Resources: "The Pingrey Mines & Ore Reduc[tion] 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."[7] 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 Minerals Separation Co.'s flotation machines.[8]

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, now part of the Climax Molybdenum Co.'s ownership), but only the former made any material production. The Molybdenum Products Co.'s mill produced 65,000 pounds of 65 per cent MoS_2 concentrate in 1918. From February 1918 the Climax Molybde-

[7] Hess, Frank L., Mineral Resources of the United States for 1915, Pt. 1, p. 807, 1917.
[8] Henderson, Chas. W., Mineral Resources of the United States for 1914, Pt. 1, p. 288, 1916; Idem for 1915, Pt. 1, p. 455, 1917; Idem for 1916, Pt. 1, p. 363, 1919; Idem for 1917, Pt. 1, p. 828, 1921.

num Co. produced ore at the rate of 250 tons daily of about 1 per cent 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, molybdenum stocks on hand at the end of the war were slowly reduced, especially by the steel industry. A large quantity is reported as imported in 1922. The Climax Molybdenum Co. kept its plant in shape and spent much money in metallurgical research and widespread advertising of the value of molybdenum steel. With contracts for a limited 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 per cent and grade of concentrates averaging 85 per cent MoS_2. Wills' patents for chrome-molybdenum steels and Alan Kissock's patent on the reduction of MoS_2 to $CaMoO_4$ and the direct use of $CaMoO_4$ instead of ferromolybdenum 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 all of the mineralized area. 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 1929, 5,191 tons of metallic molybdenum, or about 75 per cent of the world's output, was produced from the Climax deposit. The production by years is shown in the following table:

Content of metallic molybdenum in concentrates produced and sold from the Climax deposit 1915-1930, and content of metallic molybdenum in ore and concentrates produced in the United States and sold, world's production, and imports 1913-1929, in pounds.

	CLIMAX[1]	U. S.[2 3]	WORLD[3]	IMPORTS[2]
1913	....	....	(?)	([4])
1914	....	1,297	(?)	([4])
1915	Small	181,769	(?)	([4])
1916	Small	206,740	(?)	(?)
1917	....	350,200	(?)	(?)
1918	342,200	861,637	(?)	[5]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	[6]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	[7]3,716,000	....
1929	3,529,295	3,904,648	4,385,000	....
1930	[8]3,100,000	(?)	(?)	(?)

[1]Climax Molybdenum Company's production only. The deposit in 1918 should be credited with small additional production from the Denver claim.
[2]Hess, F. L., U. S. Bureau of Mines Mineral Resources of the United States, 1928, Pt. 1, p. 110, 1929, and prior volumes of Mineral Resources.
[3]Kissock, Alan, Mineral Industry, 1929, p. 448. Hess, op. cit., p. 111, gives nearly 2,500,000 for 1927.
[4]Value $15,939 in 1913; $59 in 1914; and $203 in 1915.
[5]July to December only.
[6]Last 5 months. No production first 7 months.
[7]Hess, op. cit., p. 111, gives nearly 3,430,000.
[8]Yearly production based on 9 months actual, 3 months estimated on fulfillment of contracted sales. [Actual 3,083,000 pounds for 1930. C. W. H. Jan. 1, 1931.]

On October 1, 1930, the company estimates that development of about one-third of the structure has proven 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 broken ore reserves above the White Tunnel level. When the Phillipson Tunnel (465 feet below the White Tunnel level) reaches the ore bodies determined by diamond drilling, and raises and other development are completed, this and still larger tonnages of ore can be supplied. By October, 1930, the new crushing plant at the mill was in readiness for whatever capacity desired up to 300 tons per hour. It was set in motion November 19, 1930. By January 29, 1931, the Phillipson Tunnel had cut and traversed 500 feet of 0.80 per cent $Mo S_2$, confirmed the structure to the west and north of the center core and added a possible 35,000,000 tons of ore.

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[9] and the revision of this report by Emmons, Irving and Loughlin[10], but the molybdenum deposit is not described in either report. It was first publicly described in 1918 by Brown and Hayward[11] and by Holland[12], and in 1919 by Haley[13] and Worcester[14].

Except the reports by Holland and by Worcester these descriptions were written from the viewpoint of those interested in mining operations, and consequently the geologic discussion is confined to a few short paragraphs. The report by Worcester is a survey of all 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 wide extent of the mineralization.

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

[10]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.

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

[12]Holland, L. F. S., Recent developments in molybdenum: Min. and Sci. Press, vol. 117, pp. 529-531, 1918.

[13]Haley, D. F., Molybdenite operations at Climax, Colo.: Am. Inst. Min. and Met. Eng. Trans., vol. 61, pp. 71-76, 1919.

[14]Worcester, P. G., Molybdenum deposits of Colorado: Colorado Geol. Survey Bull. 14, pp. 87-94, 1919.

The views of the reports mentioned above were summarized in 1924 by Hess[15], who, however, did not add to the meager information on the district.

The latest published reports on the district are those in 1929 by Coulter[16], general superintendent of the Climax Molybdenum Co., who briefly summarized the geologic conditions and described in detail the mining and milling practice.

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. Calkin's 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 examination have not been published,[16a] 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 four days in company with Chas. W. Henderson, and on their recommendation a topographic map on a scale of 1,000 feet

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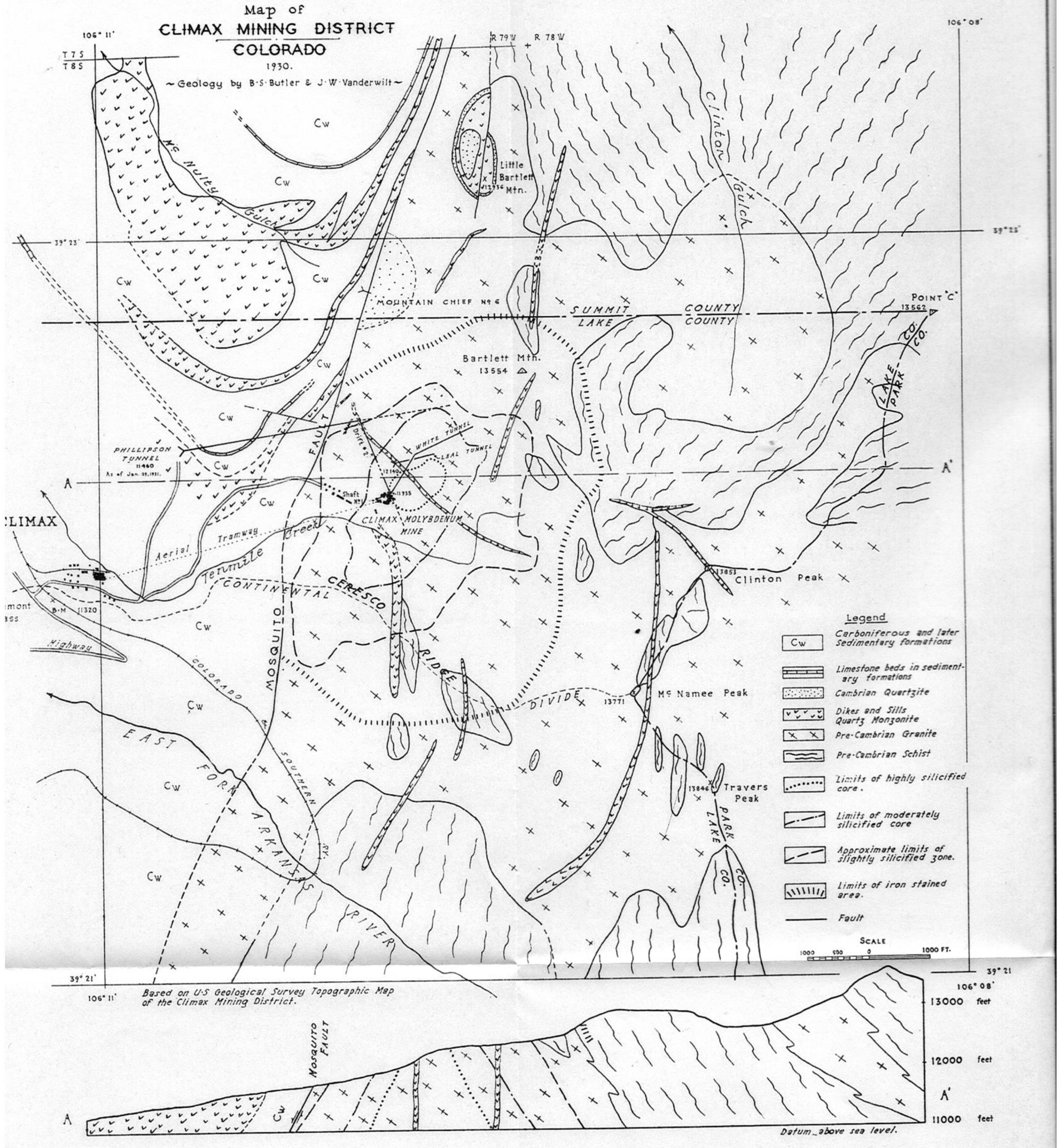
[15]Hess, F. L., Molybdenum deposits—short review: U. S. Geol. Survey Bull. 761, pp. 4, 9-12, pl. 2, 1924.

[16]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.: Idem, pp. 476-480.

[16a]Cook had made no public report when this manuscript was written, but the authors were able to insert in the galley proof Dr. Cook's recent contribution on Climax: Staples, L. W., and Cook, C. W., Microscopic investigation of molybdenite ores from Climax, Colo.: American Mineralogist, vol. 16, pp. 1-17, 1931.


Map of
CLIMAX MINING DISTRICT
COLORADO
1930.
~Geology by B·S·Butler & J·W·Vanderwilt~
106° 11'
106° 08'
T 7 S
T 8 S
R 79 W
R 78 W
39° 23'
39° 21'
Cw
Mc Nulty Gulch
Little Bartlett Mtn.
Clinton Gulch
MOUNTAIN CHIEF Nº 6
SUMMIT COUNTY
LAKE COUNTY
POINT "C"
13562
Bartlett Mtn.
13554
LAKE CO.
PARK CO.
PHILLIPSON TUNNEL
11460
As of Jan. 29, 1931.
WHITE TUNNEL
FAULT
A
A'
Shaft Nº1
11935
CLIMAX
CLIMAX MOLYBDENUM MINE
Aerial Tramway
Tenmile Creek
CONTINENTAL
CERESCO
RIDGE
DIVIDE
13771
Mc Namee Peak
13853
Clinton Peak
B·M 11320
Highway
COLORADO
SOUTHERN
RY.
MOSQUITO
EAST FORK ARKANSAS RIVER
13846
Travers Peak
PARK LAKE CO. CO.
Legend
Cw Carboniferous and later Sedimentary formations
Limestone beds in sedimentary formations
Cambrian Quartzite
Dikes and Sills Quartz Monzonite
Pre-Cambrian Granite
Pre-Cambrian Schist
Limits of highly silicified core.
Limits of moderately silicified core
Approximate limits of slightly silicified zone.
Limits of iron stained area.
Fault
SCALE
1000 500 0 1000 FT.
Based on U.S Geological Survey Topographic Map of the Climax Mining District.
Mosquito Fault
13000 feet
12000 feet
11000 feet
Datum above sea level.

to the inch was surveyed that year by R. R. Monbeck, of the United States Geological Survey, which issued the map in 1928. The basis of the present report is 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 two months and the junior author four months in 1930 to the study and correlation of these field data. The area was again visited by the writers for a few days in 1930.

Any success attained in this study is due in large part to the cordial cooperation of the company officials, General Manager H. L. Brown, General Superintendent W. J. Coulter, and Assistant General Superintendent Jack Abrams. 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 writers wish also to acknowledge the personal courtesies extended by the company that 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. The history, production, mine development, and metallurgical notes were edited by Chas. W. Henderson of the U. S. Bureau of Mines, at Denver; and brought up to Jan. 29, 1931.

Rocks

The consolidated rocks in the Climax district consist of the pre-Cambrian basement rocks, which make up most of the area east of the Mosquito fault, and the Paleozoic sedimentary series, Cambrian to Pennsylvanian, which is 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 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 somewhat varying composition and texture, but mainly ranging from granite porphyry to quartz monzonite porphyry. These granitic rocks are probably to be correlated with the Silver Plume granite of the areas farther east. Their local distribution is shown in Plate I.

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, extending 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 from Wortman. West of the area in which the schists predominate they are 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 granite contacts 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[17] in the Alma district, southeast of Climax, on the eastern slopes of the Mosquito Range.

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 granite area is bounded on the west by the Mosquito fault and exends eastward for more than a mile beyond the limits of 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 granite and schist contacts 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 schist inclusions 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 always recognizable in the field. Medium to 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

[17] Patton, H. B., and others, Geology and ore deposits of the Alma district, Colorado: Colorado Geol. Survey Bull. 3, pp. 33-47, 1912.

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 good 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 section, though they may contain fine rutile needles (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 per cent.

The micas, 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 per cent 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, are presented on pages 339 and 341.

The granite at Climax is correlated with the Silver Plume granite in the Georgetown quadrangle as described by Ball[18], and in the Montezuma district as described by Lovering[19], on the basis of similar mineral composition. It is continuous with the granite in the Alma district described by Patton[20].

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

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

[20] Patton, H. B., op. cit., pp. 40-45.

A mineralogically similar granite was found by Crawford[21] in the Red Cliff district and by Howell[22] in the Twin Lakes district.

Pegmatitic Rocks.—Pegmatite dikes and irregular masses 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 asociated with granites, although but few graphic intergrowths were noted. The essential minerals are quartz, white and locally pink microcline with orthoclase, and muscovite, with minor amounts of magnetite, biotite, and red garnet. The irregular masses of pegmatitic rock are all coarse grained, but a few of the dike-like masses are medium grained and are more aptly termed muscovite granite. They differ from the typical Silver Plume granite only by the almost complete absence of biotite.

Paleozoic Sedimentary Rocks

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

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

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

limy beds of the Sawatch quartzite are present. These are much softer than the basal beds, as they have, in part at least, a carbonate cement, and weather to a dirty brown. The uppermost part of the quartzite and the overlying "White" limestone, "Parting" quartzite, and "Blue" limestone all economic horizons at Leadville, are not in existence east of the fault and it is not known whether they are present or not under the Weber (?) formation west of the fault.

The oldest rocks exposed on the west side of the fault are grits with beds of shale and limestone. In the lower portion the grits are gray, in the upper portion maroon to red. In the Tenmile folio they were classified by Emmons as Weber, Maroon, and Wyoming.

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, 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 or possibly 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 of early Tertiary age. In the Climax district, as elsewhere in the Mosquito Range, these intrusives are found most abundantly as sills in the sedimentary rocks, and as dikes in the granites. Both have a considerable range both in composition and texture; but quartz monzonite porphyry is by far the most abundant kind.

Dikes.—The most abundant variety represented by the dikes in the local pre-Cambrian rocks is quartz monzonite porphyry closely allied to the Lincoln porphyry, whose type locality is on Mount Lincoln, east of the Climax area, and whose characteristic features are light-gray color, abundant, conspicuous phenocrysts of quartz, and rather large well-formed phenocrysts of gray to pink feldspar, which are