Colorado Geological Survey

FIRST REPORT, 1908

With Accompanying Papers

R. D. GEORGE, State Geologist

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GEOLOGICAL BOARD.

LETTER OF TRANSMITTAL.

State Geological Survey, University of Colorado.

May 1, 1909.

Governor John F. Shafroth, Chairman, and Members of the Advisory Board of the State Geological Survey:

GENTLEMEN: I have the honor to transmit herewith the First Report of the Colorado Geological Survey.

Very respectfully,

R. D. GEORGE,
State Geologist.

GEOLOGICAL STAFF.

R. D. George	State Geologist
H. B. Patton	Geologist
Jas. Underhill	Geologist
G. M. Butler	Geologist
R. D. Crawford	Geologist
C. E. Smith	Geologist
Junius Henderson	Paleontologist
J. B. Ekeley	Chemist
C. C. Williams	Draughtsman
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G. D. Kendall	Assistant
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F. H. Millard	Assistant

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ADMINISTRATIVE REPORT

The office of State Geologist was created by act of the Territorial Legislature in 1872, and the Governor of the state was authorized "to appoint, by and with the advice of the Senate, a State Geologist * * * to hold office for a period of two years." This seems to show an early appreciation of the needs of the state, but another clause of the same act reads as follows: "No compensation for services, nor for any expense whatever, shall be paid by the state to or for said State Geologist."

So far as the available records show, the first State Geologist was J. Alden Smith, who was appointed in 1874. The law provided that the Geologist should hold office until his successor was appointed. This may account for certain irregularities in the dates of appointments. In 1881 Mr. Smith was again chosen. From that date until the organization of the State Geological Survey, in 1907, the appointments were as follows: 1883, Ernest LeNeve Foster, of Georgetown; 1885, J. Alden Smith, Denver; 1887, Fred G. Bulkley, Leadville; 1889, 1891, 1893, George E. Kedzie, Ouray; 1895, 1897, 1899, Thomas A. Rickard, Denver; 1901, 1903, John W. Finch, Victor; 1906, B. A. Langridge, Boulder.

As will be seen by the above list, some very able men have filled the office of State Geologist, but the failure of the state to provide funds for the work prevented them from doing much work. Three or four brief reports were published, but these are long since out of print.

The Sixteenth General Assembly of Colorado enacted a law creating a State Geological Survey, and appropriating $5,000 per annum for carrying on the work outlined in the act. The Advisory Board of the Survey met in May, 1907, and instructed the State Geologist to begin work. Unfortunately the Survey appropriation was placed in the fifth class, and, as a result, the funds were not available until April, 1908. However, a field party was formed, an outfit secured, and work was begun early in June, 1907. The State Geologist paid bills and expense accounts to the amount of $1,200.00, and became personally responsible for $1,300.00 more. These adverse conditions, and the necessary reduction of the field force, made it impossible to complete any of the field work undertaken, and consequently impossible to prepare the reports and maps. After the field season closed, the members of the Department of Geology at the University undertook other work, such as the preparation of the bibliography of the geological literature of the state, and the collection and arrangement of data for the revision of the geological map. But as there was no money available it was impossible to push the work as desired. During the season of 1908 the field work outlined below was completed, and the reports are contained in the present volume.

FIELD WORK.

1. An area of 110 square miles about Hahns Peak, Routt county, has been mapped on a scale of one inch to the mile. 2. The Boulder County Tungsten Field, 90 square miles, has been mapped on a scale of one inch to the mile. 3. The sedimentary formations flanking the foothills have been studied and mapped from the Wyoming line southward for 75 miles, to connect up with detailed work done by the U. S. Geological Survey further south, and complete the strip across the state. This work was done to determine the age of the formations preparatory to publishing the geological map, and as a basis for a study of the economic deposits, such as clays, cement materials and building stones. 4. The Montezuma area in Summit county, 22 miles, has been mapped in detail, both topographically and geologically.

ROCK AND MINERAL ANALYSES, ASSAYS AND DETERMINATIONS.

In connection with the field work of the Survey about 50 complete chemical analyses and assays and upwards of 100 other determinations have been made. The State Survey will not do work which should go to private chemists and assayers, but only that demanded by its own reports.

TOPOGRAPHIC MAP OF COLORADO.

The Hayden Survey of the Territories, completed in 1878, made a topographic map of about two-thirds of the state. The King Survey of the Fortieth Parallel included a narrow strip about two-thirds of the way across the northern border of the state. Of the area not covered by these two surveys, over one-half has been mapped in detail by the present U. S. Geological Survey. The other half has been mapped in less detail. The present U. S. Geological Survey has also mapped, in greater detail, a considerable portion of the area covered by the earlier surveys. The maps of the earlier surveys are available to but a very small number of people, and those of the present survey are contained in about 60 separate sheets.

The State Geological Survey has compiled a topographic map of the state on a scale of one inch to eight miles, combining, so far as the scale would permit, the results of these various surveys, and including all the geographical details usually found in a complete state map. This map will be used as a base for the revised geological map, and for maps showing the various mineral deposits, water resources and other economic features of the state. The map is almost ready for the engraver.

GEOLOGICAL MAP OF THE STATE.

The only geological map covering the state is a small one, on a scale of twelve miles to the inch, published by the Hayden Survey in 1879 and 1881. This is very general and very incomplete. The larger Hayden Atlas covers only two-thirds of the state. A vast amount of detailed geological work has been done in Colorado during the last thirty years, and has modified, in many important ways, the conclusions reached by the Hayden geologists in their hurried survey. The results of the later work are published in perhaps forty separate maps, many of which are not easily available.

The State Geological Survey is compiling a map, on the same scale as the topographic map, which shall bring together, so far as the scale will permit, the results of all geological work done in this state up to the present time. The drafting is probably three-fourths done, and the explanatory sketch of the geology, to accompany the map, is also well under way.

SPECIAL MAPS.

A map showing the various metalliferous deposits of the state is approaching completion. Another showing the location of the coal fields is ready for the draftsman.

BIBLIOGRAPHY OF THE GEOLOGICAL LITERATURE OF COLORADO.

This work is well under way, and already contains over 5,000 classified entries, together with reference letters indicating the important libraries of the state, in which the book, article or report may be found.

SURVEY LIBRARY.

A library of over 600 volumes of recent geological literature has been assembled at a total cost not exceeding $10.00 (ten dollars), all of which was spent for freight and expense.

COLLECTIONS.

In connection with the field work of the State Survey complete collections of rock and mineral specimens have been made to illustrate the geology of the areas mapped.

CORRESPONDENCE.

In the two years since the organization of the Survey the State Geologist has received and answered over 1,200 letters bearing on the geology and mineral resources of the state. Over half of these came from outside Colorado. Inquiries for rare metals and other rare geological products came from England, France, Germany, Belgium, Italy and Canada.

A rough classification of the correspondence is as follows:

1. Requests for geological maps, reports and other literature bearing on the mineral resources of the state, 235. 2. Inquiries about metallic mineral deposits, mines, etc., 273. 3. Requests for determination of minerals and rocks, 159. 4. Inquiries about non-metallic products, and other geological facts, 540. This last group covered a very wide range of subjects, such as coal, oil, natural gas, asphalt and bitumen; fireclay, pottery and china clay, kaolin, brick and tile clay, shale and clay for cement, fullers' earth; factory and manufacturing sites near to coal, water, raw materials and transportation; limestone (for flux, sugar refining, cement, lime); building stones of various kinds, marble and onyx; road materials, gypsum, glass sand, building sand; placer deposits and black sands; mineral waters, medicinal clays and muds; artesian waters, artesian possibilities, well possibilities, rendering alkaline and saline waters usable; stream flow, water rights, reservoir sites; soda and potash salts, brine springs and rock salt; mica, abrasives, and numerous other geological products.

OTHER WORK COMMENCED.

A report on the distribution, qualities and value of the clays of the state. (Prof. G. M. Butler, School of Mines). The building stones and marbles of Colorado. (R. D. George and Mr. A. P. Poorman). Cement materials, limestone and gypsum. (Direction of R. D. George). Descriptive geology of the state in two bulletins: 1. General geology; 2. Economic geology. (R. D. George and Professor Crawford.)

THE COST OF THE WORK.

The State Survey has had the services of the professors of geology and other professors in the State University and the

School of Mines, at an average cost of $5.00 per day and expenses. Very valuable services have been rendered by advanced and graduate students of both institutions at no cost to the state except field expenses.

The University has gratuitously provided office room, field and laboratory instruments, the use of library, laboratories, collections and other facilities for carrying on the work. By thus employing her equipment in the service of the state, she is recognizing her right and duty to enter a broader field of usefulness than that usually assigned to educational institutions.

PLANS FOR THE FUTURE.

CO-OPERATION WITH THE U. S. GEOLOGICAL SURVEY.

The Federal Survey is willing to co-operate with the State Survey in topographic mapping. The terms are: The state pays one-half, and the Federal Government pays one-half. The choice of the areas to be mapped is left to the state. These terms are very liberal, and there is no state in the Union to which a complete and detailed topographic map would be of greater service than to Colorado. It is a prime necessity in the development of the water resources of the state, both for power and irrigation purpose; it is needed in railway instruction, the development of the mineral resources, and in many other ways.

SPECIAL BULLETINS

On the various mineral resources of the state, such as: Gold and silver, clays, cement materials, coal, lead and zinc, etc.

FIELD WORK.

The mapping of promising mineral regions not yet studied in detail.

SCHOOL BULLETINS.

The Survey can render the state no greater service than the preparation of bulletins which shall give the youth of the state an accurate and complete knowledge of her vast mineral resources. The bulletins should cover such studies as: the physical geography, the geology, the mining industries and the natural resources of the state.

EDUCATIONAL COLLECTIONS OF MINERALS AND ROCKS.

The Survey hopes to collect and present to each of the High Schools a set of minerals and rocks which shall represent the mineral wealth of the state, and illustrate the bulletins mentioned above.

Colorado State Geological Survey,
University of Colorado,
Boulder, Colorado, May 1, 1909.

R. D. GEORGE,
State Geologist.

THE MAIN TUNGSTEN AREA

OF

BOULDER COUNTY COLORADO

By

R. D. GEORGE

With Notes on the Intrusive Rocks by

R. D. CRAWFORD

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CHAPTER I.—GENERAL GEOLOGY.—Continued.

CHAPTER III.—TECHNOLOGY AND USES OF TUNGSTEN.

INTRODUCTORY.

HISTORICAL.

Hübnerite, and probably wolframite have been known in the San Juan for over twenty years, and scheelite was long ago reported from Chaffee and Summit counties. A number of mines of the San Juan have produced a few tons of tungsten concentrates, mainly as a by-product, but no vigorous development of the hübnerite deposits has been attempted. In 1870 Sam P. Conger, the veteran prospector, discovered the Cariboo Mine and a few months later the Boulder County Mine. The Cariboo camp became very active, and both miners and prospectors soon became familiar with the heavy dark mineral which occurred as float in the district. It was called by various names, such as: "heavy iron," "hematite," "black iron," "barren silver," and others. Many assays were made, but its true character was not discovered until Conger's partner, W. H. Wanamaker, returned from Arizona, where he had seen the tungsten ore from the Dragoon Mountains. They kept the identity of the ferberite a secret, and started negotiations to secure possession by lease or otherwise of a part of the Boulder County ranch for the purpose of mining the placer tungsten ore and developing the veins. Conger secured the lease in August, 1900, and by the end of the year had taken out about 40 tons of high-grade ore. This was handled by the State Ore Sampling Company, Denver, and half of it netted about \$1.60 per unit. The other half was sold to Mr. Morris Jones, representing the Great Western Exploration and Reduction Company, at \$60.00 per ton, or \$1.00 per unit. Mr. T. S. Waltemeyer was associated with Conger and Wanamaker, and concentrated their ore.

For 1901 a production of 65 tons, running 65 per cent. tungstic oxide, is reported. This was sold at about \$2.25 per unit. In 1902 the market was extremely dull and much difficulty was experienced in selling the concentrates. But considerable prospecting was in progress and some development was done. The year 1903 was very favorable for the tungsten producer, and rapid development marked the history of the Boulder County area. From that time until nearly the end of 1907 development was reasonably steady. But the financial depression put a check upon progress, from which the recovery is not even yet complete. Much exploratory and development work has been going on during the last few months, and the year 1909 promises considerable activity.

The field work was begun in the summer of 1907 and completed in the summer of 1908.

ACKNOWLEDGMENTS.

The writers take this opportunity of thanking all the owners, operators and managers of mines and mills for their assistance, which has contributed much to the value of this report. They would like to mention a few who were called upon more freely than were the others, and who were always ready to assist: Mr. C. F. Lake, Mr. Morris Jones, Mr. H. F. Watts, Mr. Wm. Loach, Mr. Henry E. Wood, Mr. V. G. Hills.

The greater part of the chemical work was done at the University of Colorado under the direction of Dr. J. B. Ekeley.

It would be impossible to acknowledge in the text of this report all the sources from which facts have been drawn. The literature of tungsten is extremely fragmentary and unsatisfactory, and many, perhaps the majority, of the references in the bibliography at the end of this report are to articles ranging in length from four or five lines to a page. Many more references could have been added, but the greater number would have been to matter outside the purpose of this report.

LOCATION.

The principal part of the tungsten district lies in the southeastern quarter of Boulder County, but some promising discoveries have been made in the northern part of Gilpin county. It is covered by the northern six miles of the Black Hawk, the southern two miles of the Boulder, and the northeastern corner of the Central City topographic maps of the U. S. Geological Survey. Another small area, not yet producing, lies chiefly east of Ward in the Boulder quadrangle. The principal places in the district are Nederland, Cardinal, Phoenixville, Rollinsville, Sugarloaf and Magnolia. The Denver, Boulder and Western, formerly The Colorado and Northwestern railway (operated by the Colorado and Southern) runs from Boulder into the tungsten field, and has stations at Sugarloaf, Tungsten and Cardinal. The Denver, Northwestern & Pacific, (The Moffat Road), has a station at Rollinsville. A daily stage runs from Boulder to Nederland, eighteen miles.

TOPOGRAPHY.

The area is a part of a broad eastward-sloping upland belt extending from the ridges of upturned sedimentary rocks at the western border of the Great Plains, westward to the steeper slopes of the Front Range. This belt is an old erosion plain, now deeply dissected by a series of eastward flowing streams and their tributaries occupying cañon-like valleys from which many gulches cut back well toward the divides. The principal streams of the area are North Boulder, Middle Boulder, South Boulder and Beaver Creeks. A few outstanding points such as Sugarloaf and Bald mountain, and those near Rollinsville, are erosion remnants of the earlier period of downcutting, which was approaching base level before the post-Laramie uplift, which increased the vigor of the streams and caused them to cut their deep narrow valleys in the resistant metamorphic rocks.

The transition from the western border of the plains to the eastern border of the upland belt is abrupt. Within a mile the difference of elevation may be as great as 2,000 feet, while the average elevation of the upland above the western border of the plains is about 2,500 feet. This greater elevation is due to two causes: *a*. differential uplift at the close of the Cretaceous, by which the foothills and mountain area was raised more than the plains region, and *b*. differential erosion—the more rapid lowering of the surface of the plains by the erosion of the less resistant sedimentary rocks of the plains.

CLIMATE AND VEGETATION.

The climate is that characteristic of the foothills. On the eastern border the annual rainfall (including snow) is about 16 inches, while that of the western border is somewhat greater. Vegetation is nowhere very abundant, though dense growths of evergreens cover many of the favorably situated slopes. The timber is seldom large.

CHAPTER I.—GENERAL GEOLOGY.

INTRODUCTION.

The area is wholly within the pre-Cambrian belt, called, in a broad way, the Front Range. The nearest sedimentary rocks, except recent stream and lake deposits, are three miles to the east. The most important rock is granite, generally more or less gneissoid. Next in importance is a granitic gneiss frequently grading into quartz-mica-schist and mica schist. While the areas occupied by these two units are, in a large way, well defined, there are numerous bodies of gneiss within the granite, and numerous bodies of granite within the gneiss. In a number of places there is no well-defined contact line between the two, but a band or zone in which the two rocks are mingled, and in which there is frequently a gradual transition from one type to the other.

Cutting the gneissoid granite and the gneiss are granite intrusions in the form of dikes and irregular bodies. In the western and northern parts are many dikes ranging in composition from acidic porphyries to latites, andesites, diabase and basalt.

The two main types of country rock mentioned above are themselves complex bodies, consisting, in each case, of a primary formation and many intruded rock masses. The ratio of the intruded rocks to the primary rocks varies from place to place, but for the whole region it is large. The intrusions vary in age, and consequently in the degree of change which they have undergone. The oldest, having passed through many of the metamorphic processes to which the containing formation has been subjected, bear a very close resemblance to it, and, in places, are with the greatest difficulty distinguished from it. The latest intrusions, on the other hand, probably date from the last great mountain-making disturbance, and consequently show comparatively slight metamorphism. Apart from the dike rocks, however, there is but little strictly nonmetamorphic rock within the area. The beginnings of metamorphism are shown in the development of an indistinct directional structure, and in the partial assembling of the mica into bunches and ill-defined planes. These alterations of the intruded rock are, as a rule, much more pronounced in the gneiss than in the granite.

THE GRANITE AND THE GNEISSOID GRANITE.

So far as the tungsten district is concerned, this is by far the most important rock, both in area occupied and in its relation to the ores.

Lithological character: Within the area mapped as granite there are very wide lithological variations. From the prevailing type—a slightly gneissoid granite—there are transitions, on the one hand, to a perfectly massive granite showing no evidence of directional structure or segregation of the minerals, and, on the other hand, to a rock in which the segregation of the mica, in particular, is very pronounced, and in which a directional structure is very noticeable. In certain parts of the area there seems to have been a poorly defined blocking of the rock in immense masses bounded by pronounced jointing zones or minor faultings. In the various mountain-making disturbances these masses acted as units somewhat as would the blocks of a pavement if it were thrown into undulations. As a result of these movements of adjustment along the zones of weakness, the rocks on both sides of the zone, on the outer borders of the masses, have been rendered gneissoid, or, in places, almost schistose. In other places the rock has been sheeted and sheared. The degree of change and the distance from the zone of movement to which the rock is affected would be roughly proportional to the magnitude of the force.

The mineral composition: The rock is an ordinary biotite granite, with occasional hornblende crystals. The feldspar is mainly orthoclase, and in the distinctly granitic part of the rock is the most important constituent. As the gneissoid character becomes prominent, the relative importance of the minerals changes, and quartz becomes increasingly important. A few granite masses, probably intrusions, show a porphyritic texture in which the feldspars reach from one-half inch to an inch in length. The quartz is in irregular grains and varies in amount, but in the massive granite makes up probably about twenty per cent. of the rock. The biotite of the fresh rock is in tabular crystals twice or three times as broad as thick, and forms perhaps eight per cent. of the rock.

Weathering: The rate of weathering depends quite largely upon the structure and texture of the rock. The more distinctly gneissoid forms weather most rapidly, and the massive granite least rapidly. This fact expresses itself in the topography. In many places the more massive granite forms rather prominent knobs and bosses, and a large percentage of the boulders of decay are granite. Occasionally, where the metamorphism has rendered the rock unusually rich in quartz, the gneiss is quite as resistant as the granite. In the weathering of the gneissoid forms, the mica segregated in bunches and minute lenses and irregular, discontinuous planes is the first mineral to yield. It forms a rusty green chloritic mineral which is very soft, inelastic and brittle. The weakening along these planes causes very rapid granular disintegration of the rock. This is still more marked in the sheeted and closely jointed rocks. The massive form shows a tendency to weather into rounded boulders, knobs and prominences by the slow and uniform penetration of the agencies of weathering. The coarse grained rock weathers more rapidly than the fine grained.

Origin: The intrusive character of a large part, possibly all of the granite and gneissoid granite, is evident from the field relations. Small bodies of hornblende-mica-schist and hornblende-schist of a dark-gray to almost black color, and rather low quartz content are quite numerous, and were evidently torn from an older formation through which the granite found its way to the surface. The contact with the gneiss is, in places, characteristically an eruptive contact. Blocks of gneiss were caught up and surrounded by the granite, and arms and dike-like bodies of granite penetrate the gneiss, following and filling fissures formed at the time of the intrusion. In a few places traces of contact metamorphism are noticeable in the development of garnets and other minerals. In other places there are veinlets and stringers of very fine grained rock resulting from the rapid cooling of the molten granite in contact with the cold rock into which it was intruded.

GNEISS.

This rock is older than the granite, and, judging by the great degree of metamorphism it has undergone as compared with the granite, it is very much older. It lies mainly in the western and northwestern parts of the tungsten field. Within the gneiss area, rocks of all structures may be found, from massive granite to a perfectly laminated schist, but the prevailing type is the gneiss.

The typical rock has the general composition of a biotite granite, but the proportion of the different minerals varies widely, particularly across the strike of the structure. In places the rock can scarcely be distinguished from the granite, either in composition or structure, while in others the proportion of feldspar has greatly decreased, and that of the quartz has correspondingly increased. Other areas will show quartz and biotite, almost to the exclusion of feldspar. This rock frequently shows an advanced gneissoid, or even a schistose structure. While such transitions to the schist are by no means rare, the schist is usually in narrow bands which soon give way to the gneiss. Small areas of hornblende-gneiss-schist also occur. Attempts were made to map the schists, but it was found impossible to represent them satisfactorily on a map of the scale here used.

Structural features: In many places, as, for example, on the south side of Boulder Creek at Nederland, and on the north side of Beaver Creek, the dip and strike of the gneissoid structure are regular and well defined over considerable areas. But there is no general uniformity or agreement of dip and strike for the region as a whole. Areas which are apparently continuous show wide diversity of dip and strike. This discordance may be due to movements of rotation and tilting during mountain-making disturbances or at the time of the great granite intrusions of the eastern side of the field. West of the tungsten area toward the range there seems to be a greater regularity of dip and strike.

Origin: No absolute proof of the origin of the gneiss can be offered, but the following facts are in keeping with the view that it is derived from sediments. The broader bands of the gneiss differ widely in composition. One may be almost entirely mica and quartz while its contact neighbor may be a granite except for structure. Again, a granitic band may lie against one in which quartz may equal all other minerals together. Another band may show a considerable development of fibrolite while its contact neighbor may show none. These differences of mineral composition suggest such differences of original composition as may be found in successive strata of a sedimentary series. The regularity of the dip and strike of the gneissoid lamination suggests stratification. The fact that a few miles west on the slopes of Arapahoe Peaks there is a strong band of fine quartzite conforming in dip and strike to the structure of the gneiss in which it occurs, suggests a sedimentary origin for the containing rock which is lithologically and structurally similar to the gneiss of the tungsten field. Again, about two miles to the east of the field on South Boulder and Coal Creeks, there is a great quartzite and schist series below the Paleozoic sediments, and in contact with the granite-gneiss series. The schists associated with the quartzite are so related to it that it is hardly possible to doubt their sedimentary origin. On both sides of the area we have metamorphic rocks derived from sediments. Between these lies the great granite and gneissoid-granite series which is in eruptive contact with the quartzite on the east and the gneiss containing the quartzite to the west. The general relations are consistent with the thought of a great metamorphic-sedimentary group intruded by a vast wedge of granite which has widely separated the two parts of the series. A great series of quartzites, quartz-mica schists and mica schists similar to that of Coal Creek is cut by the canyon of the Big Thompson River in Larimer County.

FINE-GRAINED GRANITE.

Within the granite area, a fine-grained biotite granite occurs in numerous masses, of which the largest exposure is shown on the map, about a mile northeast of Nederland. The same rock occurs near by in masses often but a few feet across, and in considerable amount between Magnolia and South Boulder Creek.

The rock is distinctly gneissoid, and where it occurs on the border of the ancient gneiss there is generally no well-defined contact between the two, owing to the fact that they have undergone a high degree of metamorphism which has developed pronounced directional structure in both. Specimens taken from mines usually show the mica to be leached out and the feldspar more or less kaolinized. In this state the rock might at first glance be taken for aplite. The fine-grained variety is cut by pegmatite dikes usually narrower than those cutting the coarser granite. This rock will be further described in connection with the ore bodies.

PEGMATITE.

Pegmatite, both coarse and fine, is very abundant throughout the tungsten field. The relations of the dikes (and veins) to the country rock indicate two modes of origin. There are some dikes which have been formed in much the same manner as dikes are generally formed—by the filling of fissures with molten or, at least, highly plastic rock. Whether the mass was in a state of aqueo-igneous fusion (or in mineral solution), water playing an important role, is not easily determined. Certain it is that in places the mass had sufficient density to pluck off and hold suspended large blocks of the country rock, and that the country rock itself was solid enough to break with sharp angular outlines and retain its form even when surrounded by the pegmatite mass. That some of these dikes are contemporaneous with the solidification of the containing rocks seems very improbable. Erosion has removed a very considerable thickness from the surface of the country, and the parts of the dikes now exposed must have been formed at no small depth. But these plucked-off masses of country rock are found in the deeper workings of the mines. At the same time there is rarely any evidence of contact metamorphism between the blocks and the containing pegmatite or the country rock and the pegmatite. Occasionally the pegmatite dikes are bordered by a few inches of country rock containing little or no dark mineral, and consequently of lighter color than that a little further from the contact. This difference in composition is probably due to subsequent solution and replacement rather than to contact metamorphism. Textural variation from the wall toward the center of the dikes is noticeable. The dikes have well-defined walls and generally regular courses.

There are other veins, or irregular bodies, of pegmatite, mostly of finer texture, but still noticeably coarser than the containing rock, which have had an entirely different origin. They are the result of a process of solution and recrystallization of the country rock along seams and fracture lines. These bodies never have well-defined boundaries, but show a gradual transition to the texture and mineral composition of the country rock. The pegmatization frequently follows branching and rebranching fractures and penetrates the country rock irregularly on the two sides of the fractures, not infrequently resulting in the alteration of two-thirds of the rock volume. This type of pegmatite is particularly common in association with the ore bodies, and does not appear to be abundant elsewhere, although it may be found in parts of the field away from known ore bodies.

The coarse and fine pegmatites occurring in dike form are younger than the containing rocks, and though they do not belong to the latest period of movement and igneous activity, have suffered but little crushing. Three distinct periods of faulting have left their records in many of the dikes with which the ores are associated. The movements do not appear to have been great. In some instances the faulting and its accompanying phenomena follow one wall of the dike, while in others movement has occurred on both sides, and in a few the crushing and movement have involved the whole dike. Rarely do the crushing and brecciation extend far into the country rock. Occasionally, however, the fault breccia contains much country rock. Both tension and compression movements have occurred, and the brecciation is probably more largely due to the latter than to the former.

The topographic effect of the pegmatite bodies is readily observable in both gneiss and granite, where it frequently forms ridges or knobs on account of its greater resistance to weathering. Occasionally, however, the course of a pegmatite body may be known only by the debris on the surface. While the greater part of this type of pegmatite occurs in dikes, irregular, lenticular, and plug-like bodies are quite common. These forms do not show such definite boundaries as do the dikes.

Mineral composition: In the order of their importance, the minerals of the regular pegmatite bodies are: Microcline, orthoclase, (possibly albite), quartz, biotite and muscovite. In some dikes and parts of dikes the feldspar may form almost the entire mass, while in other places quartz is the dominant mineral. Black mica is rarely important—seldom reaching one per cent. of the volume of the rock. Muscovite is remarkably irregular in its general distribution. In certain small sections of a few dikes it may form from five to ten per cent. of the rock and be uniformly distributed. In other cases it is more or less segregated near the walls of the dikes. In two pegmatite dikes to the north of the tungsten area muscovite is locally developed and segregated to such an extent that two or more mica prospects have been located on them. In many dikes quartz is much more abundant in the middle one-third than in the outer parts. A few show distinct banding, though it is rarely so well defined as that often found in vein structure.

The central band is generally quartz, and masses ranging from two or three to twenty-five feet in diameter are found. In these cases the dike locally resembles a strong quartz vein. Graphic granite occurs sparingly.

Small acid granite veins, ranging in width from a fraction of an inch to a few inches, are common in both the gneissoid granite and the gneiss. They are composed of feldspar and quartz with occasionally a meager sprinkling of biotite, and less commonly muscovite. Their composition and their relation to the containing rocks indicate an origin similar to that of the pegmatites.

Rare minerals and minerals in whose formation heated vapors and gases play an important part are characteristic of many pegmatite occurrences. But they are notably absent from the Boulder pegmatites. Ores of tin, antimony, molybdenum and tungsten are also looked for in pegmatites. But in this region, with the possible exception of a very occasional tourmaline crystal, and the doubtful occurrence of fluorite, the tungsten ores occur alone.

INTRUSIVE ROCKS.

By R. D. Crawford.

The intrusive rocks are almost entirely confined to intermediate and basic types. Excepting the pegmatite and aplite, rock of high acidity is found in only one dike, probably in small quantity, and as a differentiation product. Andesites predominate, but their near relatives, the latites and dacites, on the one hand, and basic rocks on the other, are well represented. The dikes are generally narrow; perhaps the majority are less than 20 feet wide, and a few less than 3 feet. They can usually be followed by their outcrops without difficulty, but are often greatly weathered.

The general trend of the dikes in the productive tungsten area is east and west. In the vicinity of the old Boulder County Mine and southward they are most numerous, but many of these are narrow and pinch out a short distance west of the boundary of the map. From Bald Mountain northward the dikes widen greatly, and trend nearly north and south.

Field relations furnish but little evidence of the relative age of the different dikes. Since the diabase is cut by a latite dike, perhaps an offset of the Sugarloaf dike, it is older than the latter rock. The limburgite appears to cut the diabase, but the exposure at the intersection of the two dikes is not very distinct. All the intrusive dikes are younger than the pegmatite. No other field observations made help to determine the succession. A light gray kaolinized dike rock, probably the felsite described below, occurs in the Beddick Mine, but does not reach the surface. The dike cuts the granite, but was intruded prior to the deposition of the ore.

In addition to the dike rocks described below, boulders of monzonite occur on the steep slopes of Eldora Mountain near the west border of the area. These blocks may not be far from their original position, but it is possible that they have fallen from the moraines above.

Andesites.

Hornblende andesite: In the dikes with a general east-west trend in the vicinity of Nederland, and as far east as Bald Mountain, the andesite is fairly uniform in texture and mineral composition. It is commonly medium to light gray, usually with a greenish tinge. It is seldom found quite fresh or dark in color. Although the phenocrysts are generally small, the rock is invariably porphyritic, with the larger crystals not infrequently about equal in amount to the ground-mass. Feldspar phenocrysts are greatly in excess of hornblende phenocrysts, and are commonly 1 to 3 mm. in diameter, though an occasional crystal may reach 5 or 6 mm. Ordinarily the hornblendes are less than 1 mm. in thickness, with a length of 2 to 4 mm.

Thin sections show that the phenocrystic feldspars are mainly andesine, but labradorite may sometimes be present. The hornblende is the common green variety with strong pleochroism. The felty groundmass is composed largely of poorly individualized feldspar laths, with interstitial feldspar and grains of magnetite. A few flakes of biotite are present in occasional specimens. These minerals, together with minute crystals of apatite enclosed in the phenocrysts and groundmass, are the only primary constituents now determinable. Kaolin, calcite, chlorite, epidote, quartz and iron oxides are present in variable amounts as alteration products.

The hornblende andesite dikes with a northward trend, in the vicinity of Bald and Sugarloaf mountains, differ from those described chiefly in color and in the quantity of biotite. These andesites range from very dark to very light grey, but the greenish cast so common in the dikes described above is usually lacking. Hornblende is here, also, the principal ferromagnesian constituent, but biotite very frequently is present in crystals often rounded by re-solution. Phenocrystic orthoclase appears in small amount.

Glassy hornblende andesite: This is a dense black rock, basaltic in appearance, with numerous hornblende phenocrysts and less numerous feldspars. Weathering makes the phenocrysts conspicuous, and brings out the fluxional arrangement of the hornblendes, which are commonly under 6 or 7 mm. in length.

Under the microscope the feldspar phenocrysts prove to be largely labradorite. The hornblende is brownish-green, and resembles the basaltic type. It occurs also in microscopic crystals in the ground mass with a few minute octahedrons of magnetite.

The ground mass varies in different specimens from glassy to microcrystalline. In the latter there are multitudes of lath-shaped feldspar microlites and grains of magnetite in a glassy base. Minute apatite crystals are present in both the glassy and microcrystalline varieties.

Mica andesite: This variety is dark to brownish-gray, with texture very similar to the holocrystalline hornblende andesites, but biotite, instead of an accessory, is the most abundant ferro-magnesian constituent. It occurs in shiny flakes, commonly under 1 mm. in diameter. Prismatic crystals of what appears to have been hornblende are now completely replaced by secondary minerals—calcite, kaolin and iron ores. Under the microscope the felty groundmass does not differ materially from the others described. The feldspar phenocrysts are nearly all plagioclase, but the rock is a close relative of the latite of Sugarloaf Mountain. In the short dike west of Farewell Gulch augite occurs in considerable amount.

Pyroxene andesite: There are two distinct varieties of rock designated on the map as pyroxene andesite: (1) That of the dike crossing the railroad on the south slope of Bald Mountain; (2) that of the dikes in the vicinity of Beaver Creek.

The Bald Mountain type is rather dark grey, and carries a few small pyroxenes and fewer feldspar phenocrysts in a felsitic groundmass. But few phenocrysts of either mineral have a length of 2 mm. Under the microscope multitudes of lath-shaped feldspar with fluxional arrangement are seen. Though not many are 5 mm. long, they are almost all twinned after the albite or the Carlsbad law, or both. Extinction angles (with a maximum of 30°) indicate andesine-labradorite. The few phenocrysts may be somewhat more acid, but all are plagioclase. The pyroxene phenocrysts, and many smaller crystals and formless grains, are colorless augite, but the large proportion of small idiomorphic crystals of pyroxene with parallel extinction suggests the presence of an orthorhombic variety. Many small magnetite crystals and a few apatites are present. Nearly or quite all the interstitial base is anisotropic and apparently largely feldspar.

In the freshest exposures of the dikes in the vicinity of Beaver Creek, provisionally called pyroxene andesite, the surfaces of joint blocks are generally reddish, but the interior is greenish-gray. The most striking feature is the great abundance of feldspar phenocrysts with about one-twentieth as many phenocrysts of augite. Phenocrysts of these two minerals compose approximately half the rock. The feldspars are commonly 2 to 4 mm. in diameter, bluish-gray in color, and usually without megascopic striae. The augite crystals are 1 to 4 mm. in thickness.

In thin section the feldspar phenocrysts are seen to be plagioclase, in large part labradorite, but apparently ranging from andesine to bytownite. The augite is pale green to colorless, and is frequently chloritized. Olivine occurs as an accessory in small but well-formed crystals, usually serpentinized. Serpentine is also scattered throughout the groundmass in considerable amount. Stout apatite crystals are not rare. Magnetite crystals are fairly common. The microcrystalline groundmass is composed almost entirely of feldspar in lath forms and irregular grains. The microlites are often once twinned, and many are doubtless plagioclase. In some specimens they appear to have undergone recrystallization.

Feldspar probably composes 80 per cent. to 90 per cent. of the rock which is apparently the aphanitic equivalent of anorthosite. It may be considered a transition form closely related to the basalts. When material is found sufficiently fresh to warrant minute study, a more detailed description will be given.

Felsite.

The felsite is bluish-gray in the least weathered exposures, but ordinarily it is almost white through kaolinization. Black or greenish prismatic phenocrysts of hornblende or its alteration products can be seen in the less weathered varieties, becoming very noticeable when the surface of the rock is wet. A few phenocrysts of feldspar 1 or 2 mm. in diameter can be seen in the fresher specimens, but are completely replaced by kaolin in the more altered rock.

In thin section some of the feldspars retain traces of polysynthetic twinning, but more frequently a trace of Carlsbad twinning. Whether or not all were plagioclase it is impossible to say. The hornblende has lost almost completely its primary character. The groundmass is composed largely of irregular grains and lath-shaped feldspar microlites, with considerable hornblende and secondary material. The microlites of feldspar are often once twinned. The rock is probably andesite, but since it is distinctly different in textural character from the other andesites in the district, and since there is much uncertainty as to the mineral composition, it seems best to retain the field term "felsite."

Dacite.

The dacite, or quartz andesite, is very similar in color and texture to the hornblende andesites in the vicinity of Nederland. Phenocrysts of feldspar and biotite make up about half the rock. The biotite is abundant in shiny flakes usually about 1 mm. in diameter, or less. The unaided eye can detect an occasional hornblende crystal. A few quartz phenocrysts 1 to 2 mm. in diameter can be seen. They are more evident in the weathered rock, which is otherwise similar to the weathered andesite.

In thin sections quartz phenocrysts are numerous, invariably in rounded forms resulting from re-solution. The biotite often shows the characteristic hexagonal outline. The feldspar phenocrysts are plagioclase. What has been said above in regard to the accessory and secondary minerals and felty groundmass of the holocrystalline hornblende andesite applies to this rock practically without modification.

The very short dike near the road, about a quarter of a mile southeast of the old Boulder County mine, apparently carries much more hornblende than the other dacite dikes. It is badly altered and no microscopic determinations were made.

Latite.

Latite occurs in far greater amount not far north of this region. The strongest dike in the area mapped passes through Sugarloaf Mountain, where it reaches a width of perhaps 60 feet or more, and has been in large measure responsible for the development of the peak. The rock from this dike was once described as andesite,[1] but inasmuch as it contains a large amount of orthoclase and passes into a trachyte toward the northeast, it seems best to consider it latite throughout the entire length of the dike. The chemical analysis[2] indicates its trachytic character, or position intermediate between andesite and trachyte.

The rock contains numerous phenocrysts of feldspar and biotite, less abundant pyroxene and hornblende, and a few crystals of titanite. Feldspar, in white, sometimes glassy crystals usually less than 2 mm. in diameter, is by far the most important phenocrystic mineral. Biotite flakes are commonly less

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[1]Hogarty, Barry, Proceedings of the Colorado Scientific Society, Vol. VI., pp. 173-185.

[2]Ibid., p. 181.

than 1 mm. in diameter. The hornblende and pyroxene prisms are usually not more than 3 mm. long.

The microscope shows the ratio of plagioclase to orthoclase to be about 2 to 1, and the plagioclase to be largely andesine. The biotite is often in perfect crystals, generally with a border suggesting re-solution.

Pyroxene ranks next to biotite in amount. It is pale green, weakly pleochroic, and has the extinction angle of augite. The hornblende is the common green variety with strong pleochroism. Almost invariably the crystals show a re-solution border. Titanite appears as a constant accessory in idiomorphic crystals. The felty groundmass is composed of poorly individualized feldspar microlites with interstitial quartz and possibly feldspar, besides numerous grains of magnetite and much secondary calcite. The quartz is probably chiefly secondary. The feldspar microlites are often once twinned, and have parallel extinction. Practically all of the original constituents show much alteration.

The dike, about a mile east of Rollinsville, is provisionally mapped as latite until fresher material than that at present available for examination may be found. In the freshest exposures observed the rock is greenish or reddish, with feldspar phenocrysts in only moderate numbers, and fewer augite crystals. Under the microscope magnetite, chlorite and calcite appear in the groundmass, which seems to be composed largely of recrystallized or secondary feldspar. The phenocrysts are badly altered, but a few appear to be orthoclase.

Latite Porphyry.

The long east-west dike passing through the high points north of Beaver and South Boulder creeks and Winiger Gulch is of interest chiefly because of the variety that it presents. It can usually be traced only by means of surface boulders. Not one good exposure occurs, and the few shallow prospect holes do not uncover the full width of the dike. Although distinct gradations probably exist, there is no opportunity to observe them in the field, and hence for purposes of description it seems best to consider the characteristic varieties separately. Along the line of the dike, boulders of two or three varieties are usually found, and their disposition gives no clue to the arrangement of the different kinds of rock in place, but it is possible that several intrusions have followed the same line of weakness.

The variety which perhaps occurs in greatest abundance, ranges from a rock composed almost entirely of feldspar phenocrysts 1 to 2 mm. in diameter, with practically no groundmass, to a phase in which part of the phenocrysts reach 8 or 10 mm. in diameter, while the groundmass makes up about two-thirds of the rock. The freshest specimens are bluish-gray in color, and, in addition to the lustrous feldspars, contain many small patches of kaolin and iron oxides replacing hornblende. More weathered specimens are pinkish white and white, containing numerous fresh feldspars, and show many small cavities from which some mineral has been dissolved.

Under the microscope the feldspars are seen to be both orthoclase and acid plagioclase, with the latter in excess in part of the rock, and again almost disappearing from some specimens with much groundmass, when the rock becomes a typical trachyte. In the phase which is nearly devoid of groundmass, the two kinds of feldspar show examples of perthitic intergrowth, and a number of the orthoclases enclose plagioclase in poikilitic manner. In some sections small crystals of biotite are present and the same mineral, in aggregates of minute flakes, occasionally replaces some primary constituent. The groundmass is composed largely of small grains of unstriated feldspar and a little quartz, the latter in large part secondary.

Another phase contains phenocrysts of sanidine up to 15 mm. in diameter, with a multitude of smaller feldspar crystals, the majority of which are plagioclase. Zircon and apatite are present as inclusions. Hornblende and its alteration products occur as in the variety described above.

A quartz-bearing latite porphyry may be considered to represent a transition toward the rhyolite porphyry described below. It contains feldspars of three periods of crystallization. Of the first period there are comparatively few orthoclase phenocrysts with a maximum length of 2 cm. In the second generation both orthoclase and plagioclase occur in rectangular forms 1 or 2 mm. across, with plagioclase in excess. The groundmass contains the feldspars of the third period, which in thin section are seen to be formless grains of orthoclase. The naked eye can also detect many small flakes of biotite which are microscopically seen to be both primary and secondary. Quartz occurs in small phenocrysts corroded by the groundmass, of which it contains numerous inclusions.

Boulders of soda-rhyolite-porphyry can be found almost the entire length of the dike, often in great abundance. Numerous phenocrysts of quartz, feldspar and biotite occur in a granular groundmass. The largest feldspar phenocrysts, which are practically all orthoclase, stand out conspicuously on weathered surfaces. They are from 1 to 2.5 cm. long, and make up one-fourth to one-half the rock. Quartz phenocrysts reach a diameter of 7 or 8 mm., but are usually smaller. They are commonly rounded and very irregularly distributed, varying from almost none to 15 per square inch of surface. This inconstancy in distribution in a rock with both orthoclase and plagioclase is the best evidence we have that the rhyolite and quartz free latite are phases of a single intrusion. Biotite is not seen in all specimens, but may be quite abundant locally in flakes 2 mm. or less in diameter.

The microscope shows orthoclase and plagioclase phenocrysts of medium size. Crystal outlines are generally distinct, but the crystals have suffered grinding and crushing at the margin and are sometimes broken in two. The quartz phenocrysts show no crystal outline, and have been subjected to similar grinding. Zircon and apatite are enclosed by the quartz and feldspars. The groundmass is a holocrystalline aggregate of quartz, orthoclase and plagioclase.

The short dike of latite porphyry in Farewell Gulch contains sanidine phenocrysts up to 2 cm. across, together with many smaller crystals of both orthoclase and plagioclase in a much altered groundmass.

Diabase.

This rock occurs in only two dikes within the area mapped, the longer one of which has been traced approximately ten miles and has a maximum width of about 70 feet. The diabase is dark greenish-gray, very heavy and extremely tough. Greenish-gray lath-shaped feldspars, black pyroxene and magnetite or ilmenite are the essential constituents, with pyrite as an occasional accessory. The feldspar laths are rarely over 3 or 4 mm. long. Pyroxene and the iron ores are almost entirely without crystal boundaries, but are packed in the interstices among the feldspars, producing true diabasic texture. This is best shown on weathered surfaces.

In thin section the feldspar is seen to be almost entirely andesine-labradorite with the usual albite twinning sometimes combined with Carlsbad twinning. The pyroxene is in part augite with a somewhat less amount of hypersthene. The augite is pale brown, and often uralitized and chloritized. The hypersthene is pale yellow, contains the characteristic inclusions, and is frequently serpentinized. Black iron ore, highly titaniferous, is abundant. Apatite is a common accessory enclosed by the other minerals. Very rarely the rock is found in an approximately unweathered state.

Lamprophyre.

The few exposures of lamprophyre that occur might easily be passed over in the field unobserved because of their resemblance in color to the weathered gneiss. Freshest specimens are greenish-gray and show small grains of feldspar less than 1 mm. in diameter and a great amount of epidote.

The microscope shows the rock to be a holocrystalline aggregate of feldspar, epidote, hornblende and magnetite, with apatite crystals enclosed by the essential constituents. Feldspar makes up nearly half of the rock, both orthoclase and plagioclase being present. The extinction angles of the plagioclase indicate albite. Some of the feldspars approach idiomorphic forms, but more are entirely without crystal outline. Many crystals are partly replaced by epidote, the replacement beginning usually at the center of the crystal. Small prismatic, acicular crystals of amphibole seem to have crystallized earlier than the feldspars. A trace of the orthopinacoidal twinning can still be seen, though the mineral is in great degree epidotized. Epidote occurs in an amount equal to that of the feldspar, replacing crystals of amphibole and in irregular masses in and between the feldspars. Other secondary minerals in small quantities are chlorite, serpentine and quartz. The magnetite is perhaps both primary and secondary.

Basalt and Basalt Porphyries.

Basalt: As a rule the basalts are decidely porphyritic, but a few dikes occur which cannot properly be called basalt porphyry. In the less porphyritic form, the rock is very compact, with numerous cavities on weathered surfaces which doubtless mark the former position of ferro-magnesian minerals. On freshly broken surfaces, these do not appear, but many small patches of limonite attest the presence of pyroxene in the original rock.

Idiomorphic augite crystals with a maximum thickness of .5 mm. are seen under the microscope, but these are badly altered. Numerous prismatic forms with the extinction angle of hornblende occur, but they are too badly weathered to permit certain identification. Magnetite is abundant. Serpentine apparently replaces small olivine crystals and occurs throughout the slide in company with chlorite. Minute lath-shaped feldspars compose less than half the rock. Interstitial augite occurs in irregular grains, and minute crystals of apatite are abundant.

In a short dike north of Sherwood Creek a porphyritic basalt occurs, in which the feldspar phenocrysts far outnumber the augites. This rock is more nearly related to the andesites than are the other basalts.

Hornblende basalts: Two varieties of hornblende basalt are present: (1), without olivine and augite; (2), with olivine and augite. The first occurs in a narrow dike a quarter of a mile south of the old Boulder County Mine. It is dark gray with very few phenocrysts of feldspar and numerous phenocrysts of what appears to be hornblende.

The microscope shows that the hornblende has undergone complete recrystallization. The mineral is replaced by aggregates of minute biotite flakes with considerable calcite, magnetite and a small amount of quartz. Inclusions of apatite are present. The biotite is brownish-green with strong pleochroism and high interference colors. The feldspar phenocrysts are too badly altered to be identified. The groundmass is composed of striated and unstriated feldspar, small flakes of biotite, grains of magnetite and crystals of apatite, with secondary quartz and calcite.

The second variety of hornblende basalt is found in a narrow dike south of Nederland, crossing the old Rollinsville road. This rock contains a multitude of hornblende phenocrysts with a few augites which can be determined in the hand specimen. Most of the phenocrysts are not over 6 or 7 mm. long, but a few reach twice that length.

The hornblende is brownish-green in thin section and extinguishes at about 15°. Zonal banding is very marked. The augite is almost colorless and non-pleochroic. The crystals have apparently suffered some re-solution and are bordered, in a few cases, by grains of augite, variously oriented. A few small crystals of olivine are present, but are mostly replaced by serpentine. The groundmass is composed of microlites of feldspar and augite with small grains of magnetite.

Basalt porphyry: This occurs in several dikes, but the freshest rock is exposed at the railway east of Rollinsville, where the dike is 7 or 8 feet wide. The rock contains abundant phenocrysts of augite and feldspar in a dense, microcrystalline, dark gray groundmass. The augites are usually less than 5 mm. long, but a few reach a length of 1 cm. The feldspars are usually less than 2 mm. in diameter and are bluish-gray with a vitreous luster in the least altered rock. They become white and more conspicuous through kaolinization. The groundmass becomes greenish or light gray through weathering, or on sheltered surfaces often has a reddish cast.

Under the microscope the rock is seen to be holocrystalline, with the phenocrysts composing one-fourth to one-third of the rock. The augite is pale green and slightly pleochroic. Olivine occurs in idiomorphic crystals 1 mm. long, or less. These phenocrysts are less numerous than the augites. Alteration to serpentine is common, some crystals being completely replaced. The feldspars are largely basic labradorite or bytownite, and probably exceed the augites in number. The groundmass is composed of minute feldspar laths, and interstitial magnetite, pyroxene and olivine. Apatite needles are abundant as inclusions.

A much coarser textured rock occurs in the dike about a quarter of a mile south of Cardinal Station. In this rock a few feldspars reach a diameter of 1 cm., but are mostly under 3 mm. The pyroxene phenocrysts are more numerous. Small crystals of pyrite are occasionally present. The naked eye can distinguish the feldspar grains and magnetite of the groundmass. In addition to these minerals, the microscope shows an abundance of minute apatite crystals and flakes of chloritized biotite in the groundmass, besides many olivine crystals of small size. The augite is invariably uralitized.

Pyroxenite.

This is a greenish-gray, even-grained rock, composed almost entirely of pyroxene. The texture varies, but is always sufficiently coarse to show the cleavage surfaces, which sometimes have a sub-metallic luster. The microscope shows the presence of both monoclinic and orthorhombic pyroxene, and perhaps an amphibole, but the material collected is too unsatisfactory for further description.

Limburgite.

The several exposures of this rock are probably all in one dike, which is so narrow that it does not reach the surface continuously along its course. The width ranges from less than a foot to about four feet. The rock is almost black, and basaltic in appearance. It contains abundant grains and pseudomorphs of serpentine from less than 1 mm. in diameter to 3 or 4 mm. Brown mica, in occasional small crystals, is the only primary megascopic constituent. Amygdaloids of calcite are common. They are usually less than 1 cm. in diameter. Fragments of the country rock usually rounded by corrosion are very commonly enclosed by the dike. These inclusions are generally less than 2 inches in diameter.

The microscope shows abundant olivine, which, in its phenocrystic form rarely reaches a diameter of 5 or 6 mm. Much of the olivine is serpentinized, and green chloride occasionally accompanies the serpentine. Olivine in smaller crystals and grains, minute prismatic crystals and grains of augite, grains of magnetite and multitudes of apatite microlites make up nearly the entire rock mass. These occur in a colorless, isotropic base which is very subordinate in amount.

SURFACE DEPOSITS.

Glacial: The town of Nederland is just within the glaciated area. Glaciers coming down from the crest of the range, in their greatest extension down Middle Boulder Creek, passed but a short distance beyond Nederland. The source of all the morainal deposits of the region is to the westward, northwestward, and perhaps a little to the southwestward. It is not unlikely that the main ice streams of South Boulder, Middle Boulder and North Boulder Canyons may have coalesced on the lower portions of the divide, as morainal matter is found at high points adjacent to the canyons. Little is yet known as to distinct periods of extension and retreat of the glaciers of the region, but whatever fluctuations there may have been, the general movement of the ice was probably always from west to east, though varying a few degrees locally. Hence it is safe to say that all the material of the various moraines has in a general way come from a westerly direction. The drift is without doubt chiefly Pleistocene, but inasmuch as moraines are now forming at the foot of Arapahoe Glacier, those in the west part of the area under consideration should perhaps be considered in part Recent.

The drift material is a mixture of glacial clay and boulders, which include gneiss, granite and porphyries, some of which are not represented in the unglaciated area toward the east. The boulders range in size from mere pebbles to masses several feet in diameter. Angular forms are sometimes present, but the boulders are commonly more or less rounded as the result of a rolling, grinding movement. Such faceting as occurs is usually obscure, and the character of the material leads to rapid weathering, so that any polishing and striation that may have been originally present have been destroyed on all material examined.

Alluvial: In the western part of the area where streams have only a moderate gradient, North, Middle and South Boulder Creeks have locally accumulated a considerable depth of alluvium. Gold placers were formerly worked in South Boulder at Pactolus and near the mouth of Winiger Creek. In the meadows in Middle Boulder Creek, about two miles above Nederland, the alluvium is largely of lacustrine origin, doubtless deposited in a glacial lake which has since been drained by a lowering of the outlet. The alluvium of the Barker Meadows just east of Nederland was also deposited in a lake formed by the damming of the channel, probably by stream-carried glacial debris at the dam site of the Eastern Colorado Power Company.

Exposed rock surfaces gradually become covered by a thin layer of mineral grains and rock fragments of various sizes, which have been loosened from the parent mass in the ordinary processes of weathering. By further decay of this detritus a matrix of clay and fine rock grains fills the spaces between the fragments. Heavy showers, forming temporary streams and sheets of water, sweep this material from the steep mountain and hill sides to the gentler slopes of the valley, where the stream loses its force, spreads over the surface or sinks into the ground, and its load of detritus is left stranded. Such deposits of sheet-wash or slope-wash are formed most rapidly where small, steep ravines join the larger valley with its gentler slopes. If these small ravines or notches are numerous, these deposits may spread until their edges unite and the gentler slopes of the larger valley may be deeply buried by a continuous sheet. Such sheets of slope-wash occur locally along all the main streams of the tungsten area. The more prominent examples of this kind are on the north side of Beaver Creek, near Pactolus on South Boulder, and east and west of Nederland on Middle Boulder.

CHAPTER II.—ECONOMIC GEOLOGY.

TUNGSTEN MINERALS.

The tungsten of commerce is obtained almost exclusively from the four minerals: wolframite, ferberite, hübnerite and scheelite.

Hübnerite is theoretically a tungstate of manganese, Mn WO_4, but iron generally replaces a small part of the manganese The average of eleven analyses of hübnerite gives the following percentage composition:

WO_3 (tungstic oxide)	75.23
FeO (ferrous oxide)	2.11
MnO (manganous oxide)	23.07

Well-formed crystals of hübnerite are very rare, but forms with two or three crystal faces are somewhat common. The mineral shows a tendency to form groups of bladed, prismatic, and needle-like crystals in which the individuals are frequently divergent. Thin tabular forms occur alone, and in lamellar masses. Compact, granular ore is common. The cleavage is perfect. The color of the crystal faces is usually dark-brown to black; but the flat, very smooth or splintery cleavage faces are commonly reddish brown to hair-brown, and sometimes black. It is easily scratched with a knife, and the powder formed shows lighter shades of brown than the surface from which it comes. (The water-made concentrates from some of the San Juan ores of Colorado are very dark—almost bluish black.) The luster of crystal surfaces is bright submetallic, while that of cleavage and fracture surfaces is submetallic to resinous. The specific gravity is 7.2 to 7.5, or about three times that of quartz or granite. The fusibility depends upon the purity. Thin splinters of the pure mineral are readily fused before the blowpipe, and small grains will fuse rather readily in the forge. If quartz is intimately mingled with the mineral, as is frequently the case, it becomes difficultly fusible, and sometimes almost infusible before the blowpipe.

Wolframite is an iron-manganese tungstate in which the ratio of iron to manganese may range from 9:1 to 2:3. This variation in the ratio of two of the three metallic elements results in a varying percentage of each of the metallic oxides composing the mineral. With the increase of the iron percentage, it approaches ferberite, and with the increase of manganese it becomes more like hübnerite. The average of about 20 analyses gives the following result:

WO_3 (tungstic oxide)	76.0%
FeO (ferrous oxide)	16.0%
MnO (manganous oxide)	7.7%

With some modifications, the description of hübnerite would apply to wolframite. The color is dark brown to black, and sometimes dark steel gray. The powder and streak are generally dark-brownish black, but may be black or grayish black. The luster of cleavage surfaces is fairly bright submetallic. The cleavage of crystals is good and causes them to break into plates. As an ore it is commonly massive granular, but druses or crusts of ore frequently show enough crystal faces to make out prismatic and chisel-shaped forms. The granular aggregates are likely to part between the crystal grains and show comparatively few cleavage faces, while the broken or bruised surfaces of druses will show many cleavage planes which may be mistaken for crystal faces.

Scheelite is a calcium tungstate, $CaWO_4$, with WO_3 80.6% and CaO 19.4%. Molybdenum may replace part of the tungsten. In color it varies from colorless and transparent to honey-yellow, greenish yellow, to rusty brown, pink and reddish. Crystals are frequently found on the walls of cavities. Four-sided pyramids and octahedral forms are commonest. Tabular forms and forms described under wolframite and ferberite are found—the latter are pseudomorphs after wolframite or ferberite. The luster of crystal faces is vitreous to adamantine, while that of fractures and cleavage faces is less brilliant, and inclines, at times, to resinous and greasy. The mineral is often coarsely granular, with cleavage faces fairly prominent on the broken surface of the mass. It is rather easily scratched with a knife, has a specific gravity of 6, or a little more than double that of quartz. It is readily soluble in nitric and hydrochloric (muriatic) acid, with the formation of a yellow powder, tungsten-trioxide, which is soluble in ammonia. (Pour off excess of acid, leaving yellow powder behind. Add ammonia liberally.) The yellow powder treated with zinc or tin in the acid solution is reduced to a lower oxide form having a beautiful blue color, changing slowly through wine color and purple to brown.

Minerals which resemble scheelite are: quartz, barite (barium sulphate), witherite (barium carbonate), anglesite (lead sulphate), and cerussite (lead carbonate). The following table gives the distinguishing features of these minerals and scheelite:

	Hardness compared with knife blade.	Weight compared with equal volume of granite or quartz.	Cleavage—tendency to split with smooth flat faces.	Fusibility in forge or before blow-pipe.	Solubility in hydro-chloric and nitric acids.	Flame coloration.
Scheelite	Scratched by knife.	Over twice as heavy.	Fair in one direction.	Rather difficult.	Easily soluble in both—forming yellow powder.	None.
Quartz	Scratches steel.	About same.	None.	Infusible.	Insoluble.	None.
Barite	(2.5-3.5) Very easily scratched.	Nearly twice.	Good in two directions.	Easily fusible.	Insoluble.	Yellowish green.
Witherite	(3.-3.75) Easily scratched.	One and one-half times.	Fair in one direction.	Very easily.	Soluble in hydro-chloric.	Yellowish green.
Anglesite	Very easily scratched.	Same as scheelite.	Two fair; very brittle.	Very easily; boils and spurts and yields metallic lead.	Difficulty in nitric acid.	Not distinctive.
Cerussite	Very easily scratched.	Slightly heavier than scheelite.	Two fair.	Very easily, and gives metallic lead.	Soluble in dilute nitric.	Not distinctive.

Ferberite: The name was first applied to an iron-manganese tungstate from the Sierra Almagrera, Spain, which contained 3.0 per cent. of MnO. The view that the name should be reserved for a practically pure ferrous tungstate seems to be somewhat prevalent, but the example above, and the common usage in regard to other minerals, do not justify this restriction. Dana does not mention any crystallographic difference between ferberite and wolframite greater than that recorded between different hübnerite crystals. Reinite (**34**, p. 991) is a pure ferrous tungstate from Japan, but the crystals are probably pseudomorphs after scheelite. A "wolframite" from the Black Hills (**34** "Appendix," p. 73), is said to show no reaction for manganese, and is "inferred to be the pure iron tungstate." The crystal angles correspond closely with those of ordinary wolframite. In speaking of artificial ferrous tungstate, Dana says (**34**, p. 985): "A little manganese is also present." The following analyses of ores from the Nederland-Beaver Creek part of the field show a very small percentage of manganese, and when the parts not essential to the mineral are eliminated, the remainders show an excess of ferrous oxide over that required to make the ferrous tungstate, $FeWO_4$. Magnetite is present in small amount in most of the ores and in some of the gangue material, but the ferric iron was not worked out, and therefore the extent to which this excess of iron would be reduced by eliminating the magnetite cannot be determined. A few inexact tests of Nederland ores show from .5 to 1.2 per cent. of magnetite. Dana suggests that the ferberite molecule may be n $FeWO_4.FeO$. This would take care of the excess of FeO.

The manganous oxide, MnO, of the complete ore analyses averages 0.5 per cent., and that of the same analyses after the non-essentials are removed averages 0.56. (Similar results are shown by the partial analyses of ores and concentrates from the same part of the field.) If, as suggested by Roscoe and Schorlemmer (**98**, p. 1058), the MnO is taken with the FeO the composition would be n $FeWO_4.(FeMn)O$. In the Nederland-Beaver Creek ores the value of n would range from 3 to 21. Comparing these with Dana's analyses of ferberite, it is evident that they are much more nearly pure ferrous tungstates than was the original ferberite. Dana also says (**34**, p. 983), "Hübnerite is nearly pure $MnWO_4$." But the ten analyses given (**34**, p. 984) all contain FeO, and the average percentage is 2.11. These ferberites are therefore more nearly pure ferrous tungstates than are Dana's hübnerites pure manganese tungstates.

Analyses of Ferberite from the Nederland-Beaver Creek area:

	WO_3	FeO	MnO	CaO	SiO_2	Al_2O_3	MgO
Clyde Mine	61.15	19.33	0.51	0.38	16.10	2.49	0.39
Barker Ranch	65.88	24.14	0.37	0.35	6.45	2.19	0.50
Conger Mine	60.98	19.13	0.08	0.44	15.94	3.10	0.59
Last Chance	62.30	19.90	0.69	0.79	14.68	1.34	...
Magnolia	73.94	23.85	0.67	0.60	0.49	0.25	0.12
Elsie	73.52	22.65	0.60	0.42	1.81	0.75	...
Manchester Lake	74.13	23.15	0.56	1.28	0.71	0.46	...

As scheelite is present in many of the mines, it is probable that most of the CaO comes from that mineral. A small part may come from the feldspar of the gangue, but as plagioclase is rather rare, in the rock fragments, the quantity of CaO from this source may be neglected. Assuming that the CaO is from the scheelite, and deducting enough tungstic oxide to satisfy it, and eliminating the silica, alumina and magnesia as non-essentials, the analyses in the first group, reduced to a basis of one hundred per cent., would read:

	WO_3	FeO	MnO	Excess of FeO
Clyde Mine	75.28	24.43	0.64	1.06
Barker Ranch	72.36	27.11	0.42	4.65
Conger Mine	75.68	24.47	0.10	0.99
Last Chance	73.92	24.92	0.86	1.99
Magnolia	74.58	24.90	0.70	1.75
Elsie	75.35	23.76	0.60	0.38
Manchester Lake	74.57	25.12	0.61	1.98

*Partial analyses of Nederland ores:

WO_3	MnO
39.82	0.53
35.12	0.38
41.52	0.52
50.20	0.56
20.52	0.30
21.00	0.31
64.90	0.93

*Assays by H. F. Watts, Boulder.

*Partial analyses of Nederland concentrates:

WO_3	MnO
60.42	0.64
52.30	0.38
61.10	0.69
62.49	0.50
63.21	0.64
61.50	0.66

Analyses of ores from the northeastern area: The following three analyses are of ores from the northeastern area. These, and assay returns from both ores and concentrates, show higher percentages of manganous oxide for this part of the field. A large number of assays and analyses made by the Colorado Tungsten Corporation at the Boyd Mill show an average of 3 per cent. manganous oxide, MnO.

	WO_3	FeO	MnO	CaO	SiO_2	Al_2O_3	MgO
Boulder Falls	70.42	19.85	3.36	2.87	2.37	1.26	...
Hal Harlow	55.05	17.69	1.47	3.05	19.23	3.70	...
Gordon Gulch	61.80	16.36	3.12	0.35	15.93	1.06	1.71

After satisfying the CaO with WO_3 (to form scheelite), and eliminating the silica, alumina and magnesia, the following results are obtained by reducing the remainders to the basis of 100 per cent.:

	WO_3	FeO	MnO
Boulder Falls...............	71.70	24.32	4.16
Hal Harlow.................	69.02	28.78	2.39
Gordon Gulch...............	75.85	20.56	3.92

By treating Dana's ferberite analyses (**34**, p. 985), in the same way, it is found that the ratio of MnO to WO_3 is practically the same as in these three. The average percentage of manganous oxide for the ten analyses above is 1.44, while the lowest percentage given in Dana's analyses of wolframite is 2.37 and the average is 7.66 (**34**, p. 984).

The following are analyses of tungsten minerals from other parts of the State:

Wolframite:

	WO_3	FeO	MnO	CaO	SiO_2	Al_2O_3
[1]Sultan Mountain, near Silverton	74.09	11.07	14.35	...	0.43	...
Johnnie Ward Mine, Ward.	71.27	20.01	7.15	1.58	...	...

*Assays by H. F. Watts, Boulder.

1 From Dana's System of Mineralogy, page 984.

Hübnerite:

	WO_3	FeO	MnO	CaO	SiO_2	Al_2O_3
Natalie Mine, Gladstone...	70.21	2.03	21.72	0.37	4.91	0.56
[1]N. Star Mine, Silverton...	74.75	2.91	21.93	0.11	...	...
[1]Cement Creek, Silverton...	76.63	1.61	21.78	0.09	...	...
[1]Ouray County	75.58	0.24	23.40	0.13	...	...

The ferberite is generally almost black, with a slight tendency to brownish black, and on fresh granular surfaces a weak steel gray color. The luster varies with the surface examined. Natural crystal surfaces are usually submetallic to dull submetallic, while cleavage surfaces are brilliant submetallic, often rivaling black mica in brightness. The fresh surfaces of the massive, granular mineral frequently show a rather high submetallic luster. The cleavage is perfect, and the mineral shows a tendency to break into thin crumbling plates. Small crystals are common in cavities. The prevailing forms are thick, chisel-shaped, having two curved, and generally striated, faces, converging to form the cutting edge of the chisel. The other two faces are parallel, and approximately at right angles to the cutting edge. Lance or spear-head crystals are also rather common—the longer diameter of the cross section of the spear-head being double the shorter. Loose bunches of lath-shaped and slender prismatic crystals are found. These crystals commonly lie with their longer dimensions parallel to the surface to which they are attached. The great bulk of the ore is very fine, massive granular. The specific gravity ranges from 7.1 to 7.5 (nearly three times that of quartz). The streak made on a light colored, hard surface, or on rough porcelain, is dark grayish black, with a suggestion of brown. The powder made by scratching the surface with a knife is black to very dark brownish black.

The fusibility varies with the purity. The pure mineral, in thin splinters, is rounded and fused with no great difficulty, but the siliceous granular ore is nearly infusible. The fusibility seems to vary with the percentage of manganese present. Even pure crystal fragments of the ore almost free from manganese are difficultly fusible, and the siliceous ore of the same composition remains practically unchanged before the blowpipe.

Minerals resembling the dark tungsten ores: Minerals which may be mistaken for wolframite, ferberite and hübnerite are: magnetite and hematite (iron oxides); limonite, goethite and turgite (hydrous oxides of iron); ilmenite (iron-titanium oxide);

1 From Dana's System of Mineralogy, page 984.

psilomelane, manganite (hydrous oxides of manganese); pyrolusite (oxide of manganese); rutile (titanium oxide); cassiterite (tinstone, tin oxide); tourmaline (a complex silicate of boron, aluminum, etc.). All of these but manganite, ilmenite and tourmaline are infusible. Manganite and ilmenite are nearly infusible, and black tourmaline is very difficultly fusible. In specific gravity, all except cassiterite are far below the tungsten minerals. The heaviest, hematite and magnetite, are about twice as heavy, volume for volume, as granite, while tourmaline is only slightly heavier than granite. The tungsten minerals are nearly or quite three times as heavy as granite. The three tungsten minerals have very perfect cleavage. Only manganite, turgite (and rutile) resemble them in this respect. Manganite and pyrolusite are quite soft, while rutile, cassiterite and tourmaline are harder than the tungsten ores and can scarcely be scratched with a knife. The others have about the same hardness as the dark tungsten ores. All but rutile and tourmaline are soluble in hydrochloric acid (cassiterite nearly insoluble), but only ilmenite gives a yellow solution. The yellow color of the tungsten solution is due to the formation of yellow tungstic oxide, which soon settles to the bottom after boiling ceases, while that of the ilmenite solution is a true coloration. The tungsten minerals are much more brittle and easily powdered than are the iron ores, ilmenite, and cassiterite and tourmaline.

A number of other minerals bearing tungsten are known, but they have not yet been found in commercial quantities. The names and compositions of a few are as follows:

Reinite—a ferrous tungstate, $FeWO_4$—possibly a pseudomorph after scheelite; stolzite—a lead tungstate, $PbWO_4$; raspite—a lead tungstate; cuprotungstite—a copper tungstate, $CuWO_4$; cuproscheelite—a tungstate of calcium and copper, $(Ca, Cu)WO_4$; tungstite (and meymacite)—hydrous tungstic oxide, $WO_3. H_2O$, (**119**).

TESTS FOR TUNGSTEN.

1. Completely pulverize the mineral, place a small quantity in a test-tube with hydrochloric acid. Boil vigorously for fifteen or twenty minutes if hübnerite, ferberite or wolframite is looked for, or about ten minutes if scheelite is expected. A fine

yellow powder, tungstic oxide, WO_3, is formed. When a small piece of tin or zinc is added, the yellow powder and the powdered tungsten mineral are changed to a fine blue. The tungstic oxide is reduced by the stannous chloride to a lower hydrous oxide, $W_5O_{14}.H_2O$, (1). If concentrated or very strong hydrochloric acid is used the blue solution will soon change through wine color to purple-brown, and finally to brown. If dilute acid is used the blue color will last much longer. Dilute sulphuric acid may be used, but in the case of the dark tungsten ores, requires a longer time to produce the tungstic oxide. The blue color obtained by reducing with zinc or tin is more lasting than that obtained by treating with strong hydrochloric acid. If the finely powdered mineral is fused with ten to fifteen times its volume of sodium carbonate (or baking soda) in an iron spoon, and then dissolved in acid and treated with the zinc or tin, the results will be the same, but the test will be more certain, since the minerals are rather hard to break up with the acids alone.

2. A test which has proved satisfactory with the dark tungsten ores may be made as follows: Reduce the mineral to a very fine powder and fuse with sodium carbonate (baking soda). Dissolve the mass by boiling in water, add a few grains of ammonium sulphocyanate, and heat gently to dissolve the salt. Add dilute hydrochloric acid. A bright wine-red is produced. Add tin and boil. The red disappears and is followed after a short time by a rich-green solution. The depth of the green will depend upon the strength of the solution.

3. Follow the first test until the first boiling has occupied twelve or fifteen minutes, then add a little nitric acid and boil about five minutes. Allow the yellow powder to fall to the bottom, and drain off the liquid. Add ammonia. If the yellow powder is dissolved, it was formed by tungsten. The ammonia solution may be acidified with hydrochloric acid and tin added. The blue color produced by boiling will not disappear when the solution is diluted with water.

4. The salt of phosphorous bead containing a little tungstic oxide is colorless in the oxidizing flame, but blue in the reducing flame.

OCCURRENCE OF TUNGSTEN MINERALS.

The modes of occurrence of the various tungsten minerals can best be understood by reference to typical deposits.

Scheelite: In the Cariboo district near Barkerville, B. C., a white to buff-colored scheelite of rather coarse granular habit accompanies galena, pyrite and siderite in quartz stringers in a zone from twelve to twenty feet wide in a highly altered mica schist. The scheelite is semi-transparent to opaque, shows distinct cleavage faces, and has a dull, almost earthy luster. The scheelite at Nome, Alaska, is in a similar country rock.

In the Victorio district, near Deming, N. M., scheelite occurs with pyrite, lead minerals and hübnerite in a vein cutting limestone.

Contact deposit at Trumbull, Conn.: Scheelite occurs at the contacts of a limestone and a hornblende gneiss, where it is associated with quartz, zoisite, garnet, epidote and other minerals characteristic of contact metamorphism. The scheelite occurs mainly in the upper part of the hornblende gneiss, just below the lower contact plain, where it is irregularly distributed in grains, crystals, and aggregates as large as the fist, and forms 5 per cent. of the vein. Wolframite derived from the scheelite is also present.

In La Sorpresa mine, Spain, scheelite and wolframite occur in white quartz at the contact of Cambrian slates and granite.

As a gangue mineral: In the eastern part of Missoula Co., Mont., scheelite forms the gangue or vein matter of a gold deposit. Near Jardine, Park Co., Mont., scheelite occurs in bluish white quartz. Near Caliente, Kern Co., Cal., a rich ledge of scheelite occurs in a lead-silver mine.

Scheelite occurs in a number of placer deposits, as at Nome, Alaska, but the mineral is derived from nearby vein deposits.

Near Hill Grove, in New South Wales, scheelite occurs in numerous veins in a gneissic granite. In New Zealand, scheelite occurs in the auriferous quartz reefs of Otago and Marlborough. In Marlow township, Beauce Co., Quebec, scheelite occurs in association with specular iron, pyrrhotite, galena, chalcopyrite, pyrite, in quartz veins cutting Cambrian slates. Tungstite (or meymacite) sometimes accompanies the scheelite.

Scheelite in small quantity has been found associated with pyrrhotite, chalcopyrite, pyrite, pentlandite and various other rare minerals in the Victoria mine (nickel, Sudbury, Ontario). The country rock of the nickel deposits is norite.

Scheelite and other tungsten minerals are associated with tin ores in many tin-mining regions, such as England, Bolivia, Queensland, New South Wales, East Indies, Australia, Spain, Portugal, and Germany. In a number of these the country rock is greisen. Other minerals with which scheelite may be found are topaz, fluorite, apatite, molybdenite and antimony.

Wolframite and hübnerite: The Black Hills wolframite occurs in flat, horizontal, but rather irregular masses, intimately associated with the oxidized, refractory siliceous ores formed by the replacement of a magnesian limestone by uprising solutions along fracture lines passing from the underlying pre-Cambrian rocks up into the limestone. Before oxidation, the ore carried pyrite, fluorite, barite and occasionally gypsum. In the Tungsten Mining District southeast of Ely, Nevada, hübnerite in fine grains, with a little fluorite, pyrite and scheelite, occurs in compact quartz forming a branching system of veins cutting a granite porphyry intruding Cambrian quartzites and argillites. Wolframite occurs as a pseudomorph (replacement retaining the same crystal form) after scheelite in the Trumbull, Conn., deposit mentioned above. At Nigger Hill and Etta tin mines, in the northwestern Black Hills, wolframite is found in the pre-Cambrian rocks as a constituent of pegmatitic granites of the greisen type. In Beira Baixa province, Portugal, wolframite occurs with cassiterite, oxide of iron, pyrite, arsenopyrite and mica in a quartz gangue in schists of Cambrian age.

In northern Queensland wolframite deposits occur in granite, greisen, felsite, quartz-porphyry, chlorite schist, slate and quartzite. The gangue materials are almost as varied—including quartz, chlorite, muscovite, biotite, topaz rock, fluorspar, beryl-rock and greisen with and without quartz. The commonest country rock is granite and the commonest gangue is quartz. With the wolframite are also associated bismuth in several forms, molybdenite and minerals bearing manganese, tin, iron, copper, lead, zinc, uranium and cerium.

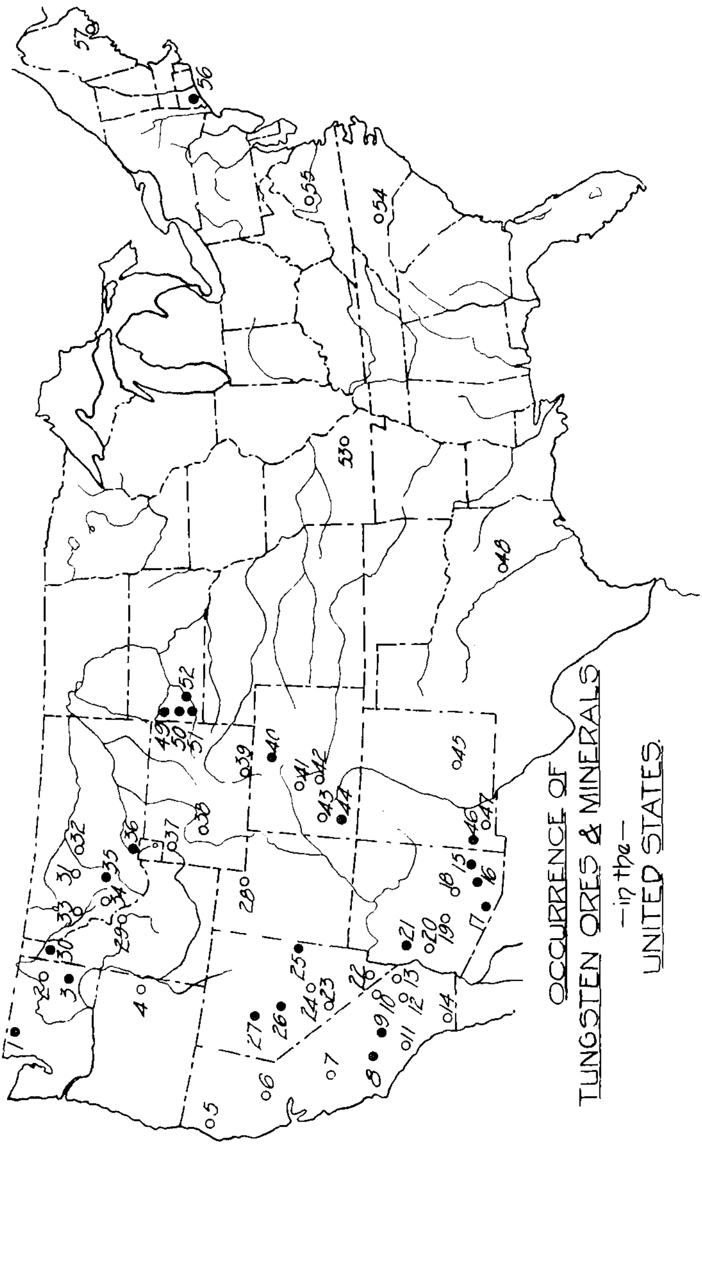
In the North Star mine, Silverton, Colorado, hübnerite, associated with fluorite, occurs in a quartz gangue carrying auriferous pyrite, argentiferous galena, tetrahedrite, chalcopyrite, sphalerite and barite. The fluorite and hübnerite are later than the main vein filling. The country rock is a quartz monzonite.

Ferberite: The Boulder deposits are rather remarkable for the almost complete absence of minerals commonly associated with tungsten ores in other parts of the world. The ore is mainly in the form of a breccia, the fragments of which include chalcedonic quartz or hornstone, dike granite and pegmatite, country rock and ferberite. The dike rock shows various stages of alteration from that in which the original character is readily made out to forms in which the original materials are almost entirely replaced by silica. The matrix is very commonly ferberite, but in that ore in which fragments of ferberite occur a matrix of crushed rock or of hornstone may partly or almost wholly replace the ferberite. Pyrite occurs in very small amount, and a rare crystal of galena is found. Fluorspar has been reported, but the writer has not seen any. There are, however, very minute cubical cavities and a few minute grains of an isotropic mineral in the silicified dike rock gangue and in the hornstone. These cavities may have been occupied by fluorite, and the isotropic grains may be fluorite. A few very small flakes of molybdenite have been found, and at one or two points near Magnolia and near Sunshine gold tellurides are associated with the ferberite.

TUNGSTEN LOCALITIES IN THE UNITED STATES.

Tungsten minerals have been reported from about sixty localities in the United States. In the following list the numbers refer to the accompanying sketch. (Plate I.) The dots mark places which have produced ore; the circles indicate the presence of tungsten minerals—rarely in commercial quantity.

PLATE I.



Washington:

1. Near Loomis, Cascade Mts., Okanogan Co. Wolframite. Shipping. (**68**), (**76**), (**93**).

2. Vicinity of Deer Trail, Stevens Co. Two localities. (**54**), (**76**).

3. Cedar Canyon and Springdale District, Stevens Co. Opened up. (**76**).

Oregon:

4. Virtue district, east of Baker City. Scheelite in placer gravels of Cliff mine. (**87**).

California:

5. Eureka, Humboldt Co. Tungsten mineral not specified. (**4**).

6. Howard Hill, Grass Valley, Nevada Co. (**86**).

7. Twelve miles northeast of Raymond, Madera Co., and in southern Mariposa Co. Scheelite. (**93**).

8. Caliente, Amalie and Paris, Kern Co. Scheelite in a lead-silver mine at Caliente. Producing. (**76**), (**93**).

9. Randsburg and Johannesburg district in Kern and San Bernardino counties. The Atolia Mining Co. Scheelite. Producing. (**76**), (**92**), (**125r**).

10. Ivanpah district. Wolframite occurs. No production reported. (**125k**).

11. Sierra Madre, Los Angeles Co. Tungsten—minerals not specified. (**4**).

12. Near Kelso, on the Salt Lake Road. Scheelite. (**93**).

13. Manvel and Signal. Scheelite. Producing. (**125r**).

14. Julian, San Diego Co. Tungsten—minerals not specified. (**4**).

Arizona:

15. Cochise Co., six miles north of Dragoon, on the A. T. & S. F. Produced. (**91**), (**97**).

16. Whetstone Mts. Euclid Mining Co. Operated wolframite mines in 1906. (**76**).

17. Near Arivaca, in Santa Cruz Co. Hübnerite has been mined. (**13**), (**91**).

18. Santa Catalina Mts., near Southern Bell Gold Mine. Scheelite. (**13**).

19. On Buffalo-Arizona Company's property, near Phoenix. Ore reported. (**76**).

20. Sixty miles south of Hackberry, in Aquarius Mts., Mohave Co. (**91**), (**125**p).

21. Near Owens, 80 miles south of Kingman and 12 miles east of Big Sandy river. Wolframite. Small shipment in 1905. (**92**).

Nevada:

22. Mammoth District: Hübnerite. This is the place of the original discovery of hübnerite. (**34**).

23. Lander Co. Ore reported. (**77**).

24. Near Atwood, Nye Co. Tungsten ore. (**125**l).

25. Tungsten Mining District, 12 miles south of Osceola, in White Pine Co. Producing. (**121**), (**122**).

26. Round Mountain. Hübnerite. Producing, 1907. (**13**), (**125**m).

27. Forty miles south of Lovelocks, Humboldt Co. Wolframite. Considerable development. Shipped 1908. (**92**), (**125**w).

Utah:

28. Little Cottonwood. Tungsten ore. No shipment in 1905. (**75**).

Idaho:

29. Patterson Creek, Lemhi Co. Hübnerite and wolframite. (**125**n).

30. Near Murray, Wallace and Mullan, Coeur d'Alene district. Producing. (**6**), (**13**), (**86**), (**101**).

Montana:

31. Near Helena. Scheelite.

32. Near Neihart. Scheelite. (**92**).

33. Missoula Co., western part. Scheelite. Shipped in 1905. (**92**).

34. Near Phillipsburg. Hübnerite. (**26**).

35. Birdie Mine, east of Butte. Hübnerite. (**125**x).

36. Near Jardine and Crevasse, Park Co. Scheelite. Produced. (**13**), (**93**).

Wyoming:

37. Jackson Hole region, near Elk. Wolframite. (**57**).

38. Fremont county, near Shoshone. Tungsten ore. (**76**).

39. Holmes (near). Wolframite. (**92**).

Colorado:

40. Boulder Co., and adjacent parts of Gilpin Co. (**117**).

41. Leadville. Several mines report wolframite and hübnerite. (**125**y).

42. Near Salida. Hübnerite in a vein worked for copper. Scheelite also occurs in Chaffee Co. (Personal correspondence). (**15**).

43. Ouray County, Uncompahgre District, Royal Albert vein. (**34**).

44. Red Mountain and Gladstone, in San Juan region. Hübnerite. Produced. (**95**), (**96**).

New Mexico:

45. Bonito. Hübnerite occurs. (**34**).

46. Steins Pass, Lordsburg and Separ. Hübnerite and wolframite shipped in 1895-6. (**15**), (**91**), (**93**).

47. Victorio district, 18 miles west of Deming. Hübnerite and scheelite. (**57**).

Texas:

48. Falls County—ore reported. (**77**).

South Dakota:

49. Lawrence Co., Durango, Sula, Harrison, Golden, Summit and Two Strike mines produced 106 tons wolframite concentrates, carrying 38-50% tungstic oxide. (**17**).

50. Near Hill City, Pennington Co. Producing. (**76**).

51. Custer County. Producing. (**15**).

52. Keystone, Pennington County. Wolframite. Producing (?) (**76**).

Missouri:

53. Madison and St. Francois Co., in vicinity of Mine La Motte. Wolframite. (**34**).

North Carolina:

54. Flowe, Cosby and Cullen mines of Cabarrus Co. Scheelite with a little wolframite. (**86**).

Virginia:

55. Rockbridge County. (**77**).

Connecticut:

56. Long Hill station. (Monroe and Trumbull are included in the reference). (**59**).

Maine:

57. Blue Hill Bay. (**34**).

IMPORTANT TUNGSTEN DEPOSITS IN THE UNITED STATES.

(Omitting Boulder County, Colorado.)

Arizona: The most important producing districts have been that near Dragoon, in Cochise county, and that at Gigas, near Arivaca, in Santa Cruz county.

In the Dragoon area hübnerite occurs unevenly distributed in vertical quartz veins, of irregular width, cutting granitic, gneissoid rocks. The production has come mainly from shallow lode workings and placer washings. In the Arivaca area hübnerite is found in most of the gold-bearing quartz veins southward into Sonora. The mineral occurs in blade-like crystals, tabular masses and bunches, and is easily concentrated. Hundreds of tons of high-grade ore were mined and piled up years ago, and are still untouched.

California: The Randsburg district, mainly in San Bernardino county, has become the second largest producer of tungsten ores in the United States. Scheelite deposits are found over an area of several square miles. The deposits owned and worked by the Atolia Mining Company at Atolia, five miles south of Randsburg, are the best developed in the district. The scheelite bearing veins occur mainly in a medium-grained granodiorite in the form of a large mass or batholith intruding ancient mica and hornblende schists. On the north border of the mass, veins occur in both schist and granodiorite, and below the surface may pass from one rock to the other. The vein system occupies a zone of shearing in which the movement was localized along certain lines. The vein matter consists of crushed granodiorite, partially silicified crushed granodiorite, calcite, fine granular quartz replacing the granodiorite, crystalline quartz and scheelite. The quartz and scheelite were apparently brought up in solution and deposited at the same time.

Nevada: The Tungsten Mining District lies along the western slope of the Snake Range south of Wheeler Peak, about 45 miles southeast of Ely. The hübnerite veins are in a granite porphyry which intrudes the Cambrian quartzites and argillites flanking the range. The veins trend northeast and southwest and pitch 55°-75° to the northwest or southeast, and range from a few inches to three feet in width. The gangue is compact quartz and hübnerite, with here and there a little fluorite, pyrite and scheelite. The hübnerite occurs: (a) irregularly distributed through the quartz, (b) in irregular masses, (c) in segregations along the vein wall. The veins were probably filled by deposition from mineralizing waters from the cooling granite porphyry.

South Dakota—Lead City, Black Hills: Wolframite occurs in flat, horizontal, but rather irregular masses, from an inch to two feet thick, and ranging in area from 20 to 30 square feet. The ore is intimately associated with the oxidized, refractory, siliceous gold ores. These ores, in their unoxidized form, consisted of secondary silica with pyrite, fluorite, barite and occasionally gypsum, and resulted from the replacement of Cambrian dolomite through the agency of uprising (thermal) solutions from the underlying pre-Cambrian schists and slates. The wolframite may be regarded as a basic phase of the siliceous ores. It also occurs as a rim around the outer edge of the siliceous ore shoots and sometimes as a cap over them. The wolframite ore is a dense, black, massive rock of fine texture, resembling a fine grained magnetite.

In the Nigger Hill and Etta tin district it occurs as a constituent of pegmatitic granites, usually of the greisen type.

A number of other deposits occur in the Black Hills region.

Colorado—San Juan: Hübnerite is found in a number of mines and prospects near Gladstone, north of Silverton; in the Tom Moore lode, one and one-half miles above Eureka, on the Animas; and in three or more properties on the slopes of Sultan Mountain. It was found in the Royal Albert vein in the Uncompahgre district, Ouray County.

The Adams claim is on the western slope of Bonita Peak, about a mile from Gladstone. The hübnerite is irregularly distributed as thin lenses, bunches and stringers in a gangue of quartz and fluorite filling a series of fissures forming a narrow sheeted zone in an altered pyroxene andesite. In Dry Gulch, a tributary of Cement Creek, below Gladstone, the Dry Gulch, Dawn of Day, Sunshine and Minnesota claims are located on a single strong lode. Hübnerite occurs in all the claims, but only the Dry Gulch and Dawn of Day show any important development. The occurrence of the hübnerite is similar to that in the Adams. A few tons of high-grade concentrates have been shipped. The Natalie and Big Colorado mines are in a gulch a short distance southeast of Gladstone. The Natalie hübnerite is in glistening black needles, prisms and blades in a quartz gangue. Amorphous silica sometimes forms smooth rounded surfaces over the quartz and hübnerite. The ore resembles wolframite, but the analysis (page 44) shows only 2.03 per cent. FeO. It pulverizes to a rich brown powder. The other metallic minerals of the Natalie include argentiferous galena, pyrite, chalcopyrite and free gold.

The hübnerite of the Tom Moore is in very small quantity and can not be regarded as at all promising. The North Star mine, the Little Dora vein and the Empire-Victoria vein are all on the slopes of Sultan mountain. All contain a little hübnerite. The ores include auriferous pyrite, galena, tetrahedrite, chalcopyrite, sphalerite, associated with fluorite, barite and much quartz. Hübnerite occurs associated with fluorite in the more quartzose portion of the veins, though occasionally it is in a kaolinized, disintegrated mass. Both fluorite and hübnerite are later than the main vein filling. The country rock is monzonite.

The conditions would seem to be favorable for making tungsten concentrates as a valuable by-product, but the showings, as yet, do not promise profits if tungsten alone is produced.

FOREIGN OCCURRENCES.

Australasia: Tungsten ores are mined in Queensland, New South Wales and the Northern Territory (of South Australia), and they are reported from various points in West Australia. In production the states stand in the order named.

In northern Queensland an area of 3,500 square miles contains several belts of tungsten deposits. The ore is almost exclusively wolframite, though scheelite is produced in one locality (Parada). Both lode and placer mining are carried on. Old Wolfram Camp is the most important tungsten mining centre. The commonest country rock of the tungsten area is granite, but deposits are also found in greisen, felsite, quartz-porphyry, chlorite schist, slate, and quartzite. "The gangue of the wolframite is usually quartz, but it also occurs with and without this mineral in greisen, chlorite, muscovite, biotite, topaz rock, fluorspar, and beryl-rock." In form, the ore bodies include quartz veins, large and lenticular bodies of quartz, irregular masses of chlorite, quartz and mica, and impregnations of greisen and granite. In the richest ore bodies, those of irregular form, the wolframite occurs in isolated patches or bunches. Bismuth and molybdenum are saved as by-products. Tin is also important.

South Australia: Tungsten ores are found in the Northern Territory, and have been extensively mined during the past two years.

West Australia: Tungsten ore occurs in the Geraldton, Pilbarra, Coolgardie and Greenbush areas.

New South Wales: Scheelite is mined at Hill Grove, and wolframite in the Mole Tableand. Producing areas are: Emmaville, Uralla Tuena, Baraba, and Farrington.

New Zealand, Otago: Scheelite occurs in the auriferous quartz reefs of Otago and Marlborough. The reef follows the planes of schistosity of the schists.

Tasmania: A few tons of wolframite are produced.

Europe:

Portugal produces a few hundred tons of ores annually, chiefly from the province of Beira Baixa, where wolframite occurs with tin ore, oxide of iron, pyrite, arsenopyrite and mica in quartz gangue in schists of Cambrian age. Portugal has become the largest European producer.

England: Wolframite, scheelite and tungsten ochre occur both in the mines and in the tin placers of Cornwall, chiefly in the high-level platforms of Bodmin Moor. But wolframite is the only commercially important ore. It accompanies tin and copper ores which occur disseminated through granites, quartz porphyry ("elvan") and slates ("killas"), and in minute veins in these rocks. As Camborne is the most important area, a brief description will be given. Metamorphic sediments varying in character from slates to phyllites overlying granites are intruded by greenstone sheets, and both slate and greenstone are cut by large granite masses having an average trend of 20° north of east. Cutting all these are dikes of quartz porphyry. The area is cut by many faults trending almost at right angles to the quartz porphyry dikes and the mineral lodes.

The lodes are commonly parallel to the dikes and in many instances occupy fault planes. The walls are irregular and impregnation of the country rock is common. The ore is irregularly distributed in the lodes in "bunches and pipe-like" masses, and there are many evidences of secondary enrichment. The mineral contents include, (1) the "veinstone," which may be quartz, feldspar and tourmaline and decomposition products from the country rock; (2) the ores or metalliferous minerals, including cassiterite, pyrite, arsenopyrite, chalcopyrite, and wolframite. Locally, ores of nickel, cobalt, zinc, lead and uranium are found in the higher levels, while antimony, bismuth and molybdenum have been produced in commercial quantity. The tungsten ore is mainly wolframite, but scheelite and tungsten ochre occur. The wolframite occurs along, and on both sides of the contact between the granite and the slate. The Camborne district is the most important tungsten producer, but shipments have been made from Tavistock, especially from the Clitters mine, and from near Liskeard.

Spain: Wolframite and scheelite occur in La Sorpresa mine, in a white quartz at the contact of Cambrian slates and granite. The tin deposits of Orense and Pontevedra carry wolframite.

Austria: Produces a small tonnage annually, mainly as a by-product of the tin mining.

Germany: A few tons of tungsten concentrates are produced annually from the old tin dumps of the Altenburg district.

Italy must be credited with a few tons.

France produces a few tons.

Sardinia: Scheelite and wolframite have been found in considerable quantity.

Russia: Tungsten ore has been mined in the Ural Mountains.

Africa:

South Africa became a tungsten producer in 1906, and in 1907 shipped 211 tons, on a 60% tungstic oxide basis.

Asia:

India: Wolframite is found in the Tenasserim district of Burma, and at Agargaon.

Siam, the Federated Malay States, Singkep and Billiton, all produce a small tonnage of tungsten ore. Most of this is obtained as a by-product of tin mining.

Siberia: Hübnerite and wolframite are reported from the gold mines.

South America:

Argentina has outstripped all other South American states.

Bolivia: Wolframite is mined chiefly in the tin-mining districts of La Paz, Oruru, Potosi, and Chorolque.

Brazil: Promising deposits have been opened near Porte Alegre, South Brazil.

Canada:

Nova Scotia: Wolframite occurs at Northeast Margaree, and hübnerite at Emerald, in Inverness county. Scheelite is found in the Molega mining district, Queens county. Wolframite, hübnerite, and scheelite are found in the tin deposits at New Ross, Lunenburg county.

Quebec: Scheelite, sometimes accompanied by tungstite (or meymacite), occurs in Marlow township, Beauce county.

Ontario: Wolframite was found in a boulder on Chief's Island, Simcoe county, and scheelite has been found at Sudbury.

British Columbia: Scheelite occurs in the Slocan district and near Barkerville in the Cariboo district. Wolframite and scheelite occur on Sheep Creek near Salmo, in the Kootenay. and wolframite occurs on St. Mary's River north of Cranbrook.

Yukon: Scheelite has been found in the placers.

The world's production of tungsten ore for 1906 and 1907: The table is arranged according to production for 1907, estimated in short tons of concentrates containing 60 per cent. of tungstic oxide: (From Mineral Resources for 1907.)

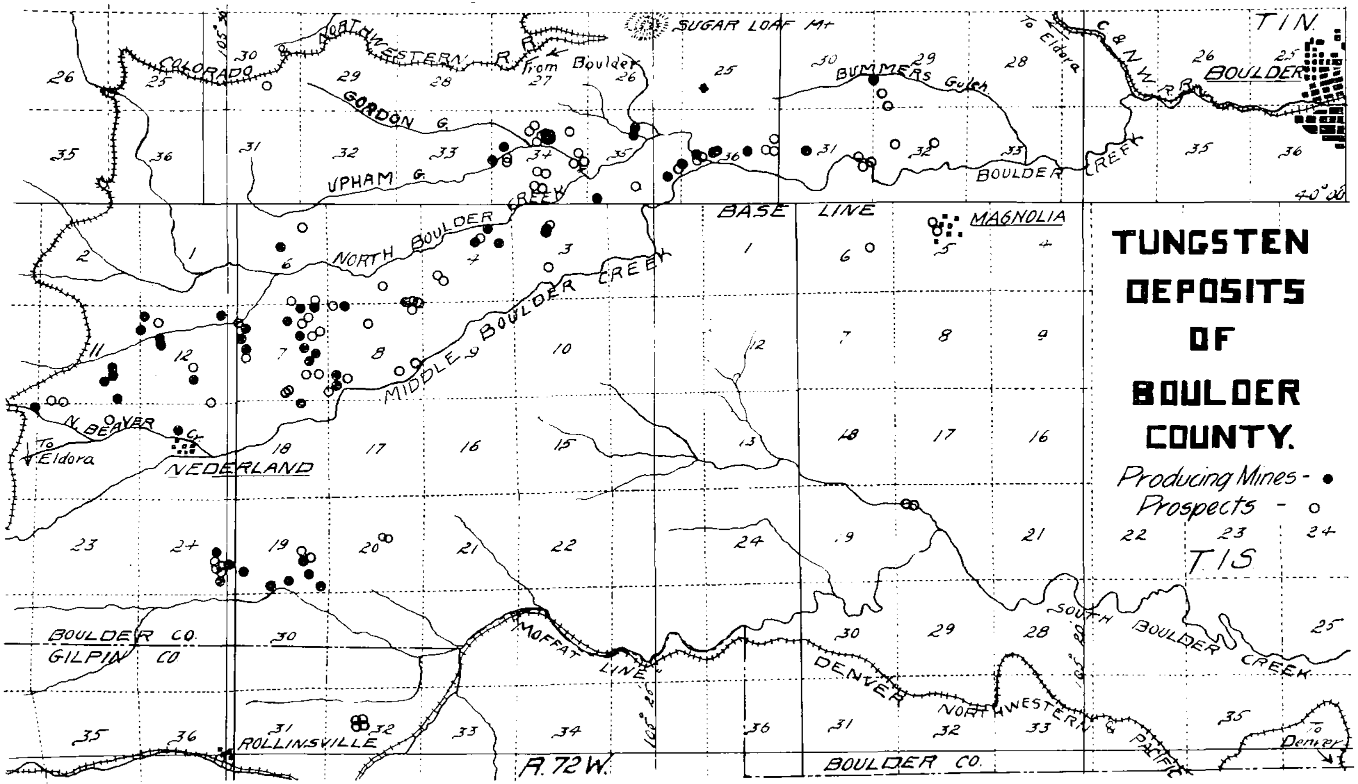
Country.	1907	1906
United States	1,640	928
Queensland	703	865
Portugal	702	629
Argentina	507	326
New South Wales	451	270
Northern Territory (Australia)	443	114
England	361	304
Spain	222	222
South Africa	211	9
New Zealand	121	121
Federated Malay States	89	151
Bolivia	75	75
Austria	63	63
German Empire	57	57
Tasmania	46	22
Billiton	41	...
Italy	28	28
France	20	20
Siam	10	...
Singkep	1	...
Total	5,791	4,204

ORE-BODIES OF BOULDER COUNTY.

Country rock: The granite, gneissoid granite, and the more granitic parts of the gneiss have proved the best ground for the prospector and miner. The majority of the mines are in the granite area of the map, but a number of the good producers lie close to the contact of granite and gneiss, and in some instances the workings are almost entirely within the gneiss. It is a noticeable fact, however, that, where the veins cut the more pronounced gneiss, and particularly the schistose bands and areas of the gneiss the ore-bodies decrease in size and not infrequently the vein becomes barren. This is due to the physical rather than to the chemical character of the rock. In the deformations and faultings which prepared the openings for the ore deposits, the gneissoid granite, the less schistose parts of the gneiss and the pegmatite were intimately fractured and formed rather open breccias. On the other hand, the schistose part of the gneiss, acting more as a plastic mass, yielded by folding, crumpling and shearing, rather than by open fracturing, and, adjusting itself to the entire space available, closed up the underground water courses. In the Nederland-Beaver Creek area a number of the veins follow dikes of coarse and fine pegmatite, but the relationship is due to structure rather than to any common genesis. The fissuring now occupied by the veins—long subsequent to the formation of the pegmatite dikes—followed the lines of least resistance, which, in several instances, coincided with the dikes. In the northeastern area pegmatite is not so abundant and there are few associations of ore and typical pegmatite.

Other veins are associated with a fine grained intrusive biotite granite which forms dikes and irregular masses such as that about the Clyde Mine, a mile northeast of Nederland. In some instances, particularly in the southeastern area, this fine-grained granite shows a tendency toward the porphyritic texture, but this seems to be merely a local variation which is not characteristic. Weathering has made the porphyritic appearance more prominent in many places, while in other instances it has given the rock somewhat the appearance of a decayed greisen. The biotite has become leached and chloritized, and a chloritized kaolin occurs in grains of considerable size. In some cases the fine-grained granite seems to grade imperceptibly into the country granite. This may be due in part to contact metamophism, for it is evident that in places, mineral changes have taken place along the line of contact, which have rendered the two rocks more alike.

PLATE II.


TUNGSTEN DEPOSITS OF BOULDER COUNTY.
Producing Mines - ●
Prospects - ○
T1N.
T1S
SUGAR LOAF Mt
COLORADO NORTHWESTERN R.R.
From Boulder
To Eldora
C & N W R.R.
BOULDER
BUMMERS Gulch
GORDON G.
UPHAM G.
BOULDER CREEK
BASE LINE
MAGNOLIA
NORTH BOULDER CREEK
MIDDLE BOULDER CREEK
N. BEAVER CR.
To Eldora
NEDERLAND
BOULDER CO.
GILPIN CO.
MOFFAT LINE
DENVER NORTHWESTERN & PACIFIC
SOUTH BOULDER CREEK
ROLLINSVILLE
R. 72 W.
BOULDER CO.
To Denver
40° 00'
105° 30'
105° 20'

The relationship of the veins to the dikes is the same in the fine-grained granite as in the pegmatite. The fractures occupied by the veins commonly follow one or other wall of the dike. Occasionally they split the dike and both walls of the vein are formed by the dike rock. In some cases the vein leaves the dike entirely and passes out into the country rock, usually at a sharp angle with the dike, leaving a thin wedge of country rock between. In the northeastern area the long line of mines and prospects roughly parallel to Middle Boulder and Boulder Creeks from near Castle Rock to Wheelmen is closely associated, in a large part of its course, with a narrow, but rather continuous dike of fine-grained granite. In places the entire width of the dike is occupied by the vein. In others, alteration in both the dike and the country rock has left the two quite similar in appearance.

Trend of the veins: There is no regular system of veins such as characterizes certain camps. But in the Nederland and Beaver Creek part of the field, a large proportion of the veins trend between north and east, ranging from due north to north 80° east. Very few take a course west of north. The average trend of eleven well-defined veins in the western part of the Nederland-Beaver Creek area is north 32° east, but the courses nearest to the average are: N. 24° E., N. 29° E., N. 40° E., N. 40° E. In the Upper Rogers Tract eight veins average N. 45° E., and one other has a trend N. 87° E. Fifteen veins of the Lower Rogers Tract range from N. 48° E., to N. 70° E.

In the Gordon Gulch area the general trend is north of east, but is much more nearly east and west than in the Nederland-Beaver Creek area.

The angle of dip of the veins is generally steep—often approaching the vertical, and rarely falling so low as 45°. The following are a few examples of the trend and dip of the veins: The Townlot—trends north and south, and dips 65° E., but flattens to 40° or 45°. The Conger trends N. 8° E., and dips at a variable, but always high degree, west. The Oregon trends N. 8° E., and dips at a high degree west. The Beddick trends N. 20° E. (general). The Elsie trends N. 62° E. and dips nearly 90°. The Last Chance trends N. 40° E.

VEIN STRUCTURE AND VEIN FILLING.

Outline of the stages of ore-deposition in the Nederland-Beaver Creek part of the field:

a. The first opening of the fissures, accompanied by much crushing and the formation of masses of angular fragments.

b. The silicification of the rock fragments and their partial cementation into an open breccia, and a slight local deposition of tungsten mineral.

c. The second movement and brecciation.

d. The first important deposition of tungsten mineral.

e. The third movement, crushing the breccia-ore, and mingling it with much rock matter, and in places forming a new breccia by pressure.

f. The second deposition of chalcedony-like silica. This was local.

g. The second important tungsten deposition, partially cementing the breccia. It is possible that this was a secondary enrichment. But no clear evidence was found.

h. The contemporaneous deposition of silica and tungsten.

i. Local solution of the tungsten and deposition of silica.

(j. In parts of the tungsten field slickensiding and very recent brecciation are found, showing that movement has occurred later than recognizable deposition of ferberite or silica.)

While the stages outlined above are not all evident in all the tungsten deposits, they are clearly recorded in several of those affording the best opportunity for investigation, and it seems probable that further study would show that for the Nederland-Beaver Creek part of the field the stages in the formation of the deposits were, in general, as here indicated. Owing to the closing of most of the mines before the field work of the northeastern area was completed, the ore bodies could not be studied in detail, but it is probable that the process of deposition was less complex and accompanied by fewer movements.

a Many of the first fissures followed pegmatite and biotite granite dikes while others cut the country rock. They were the result of tensional stresses, accompanied or followed by, both horizontal and vertical movements in which the dislocation was probably slight. When the movements ceased, the fissures were partially filled by loose, open masses of angular rock fragments, varying in size from mere grains to boulders. In the pegmatite dikes the crushing resulted in the formation of smaller fragments than in the biotite granite dikes. The large feldspars split easily along cleavage planes, and many of the fragments contain only feldspar, while others show only quartz. But the zone of fracturing was, as a rule, narrower in the pegmatite than in the dike granite, or in the country rock.

Where the fissures have followed dikes, the position of the fissure with respect to the dike walls seems to have influenced the location of the crushing. Where the fissure is within the dike, the crushing is generally on both sides of the opening, but where the fissure follows one of the dike walls, the dike rock is usually much more crushed than is the country rock. This may be due in part to the yielding of the country rock without marked fracturing along the more or less distinct foliation planes, or it may be due to the greater strength of the country rock.

b Silica-bearing waters, probably at high temperature, circulated through the rock fragments in the fissures. By a process of replacement the feldspars and the biotite of the rock fragments were slowly dissolved out, and silica in the form chalcedony-like quartz or hornstone was deposited in their place. By this substitution many of the smaller rock fragments were almost entirely robbed of their feldspar and biotite, and are not easily distinguished from the hornstone. In others, an occasional feldspar and a few semi-transparent quartz grains remained to show the original character of the rock. The larger fragments still retained cores of unaltered rock surrounded by shells, from which these minerals were more or less completely removed. That the rock fragments were fresh when the process of change began is probable from the facts: that the replacement probably took place below the zone of weathering; and that fresh feldspars and biotite are still found in the cores of the large fragments. These silica-bearing waters also deposited hornstone between the rock fragments and partially cemented them into an open breccia. The completely silicified rock-fragments and the silica cement between the fragments are a part of the hornstone ("hornblende" of the miners). It is probable that a part of the pegmatization mentioned in the discussion of pegmatites took place at this time, and that the secondary feldspars observable in some parts of the area represent the crystallization of the feldspars removed from the rock fragments. Locally, a small deposition of ferberite accompanied the silicification.

c The breccia in the fissures was still very open when the second movement occurred. This time the vein breccia with the local deposits of tungsten, more dike rock, and in places country rock, were crushed and mingled in a new mass of fragments, ready to be cemented into a new breccia. This movement was accompanied by considerable vertical displacement and dragging along the walls of the veins.

d The first important deposition of tungsten followed the second crushing movement, which seems to have been more profound than the preceding. The character of the waters which followed it was quite different from that of those which followed the first. In place of an overload of silica, these were heavily charged with tungsten salt, and either through changed physical conditions as they rose to the surface or through mingling with other solutions—probably carrying ferrous iron, ferberite was deposited. In places silica accompanied the deposition of ferberite in the earlier part of the process. This may have been the overlapping of the two processes of deposition, since the earliest tungsten precipitation began before the second movement as mentioned above.

In less open parts of the fragmental mass in the fissures the ferberite formed a complete cementation, but in the more open parts the walls of the openings were crustified and many vug-like cavities were formed by the connecting crusts of ferberite. Locally, silica deposition followed the ferberite before the third movement took place, but this was not general.

e The third movement crushed the vein filling and added dike-rock or country-rock to the fragmental mass. It now consisted of the silicified dike-rock or country-rock in varying amount, chalcedonic quartz and the ferberite. Locally this movement caused the formation of a pressure-cemented breccia. Probably silica aided the cementation.

f The second considerable deposition of hornstone silica followed the third movement and partially recemented the fragments, but this was only local.

g The second important tungsten deposition followed the third movement, and in places completed the cementation, but much open ground still remains in the veins, and vugs lined with ferberite druses are very common. It is possible that this was a secondary enrichment in which the tungsten of the higher parts of the vein was dissolved and carried down and deposited at greater depth. But no clear evidence was found in support of this. The presence of rich ore at the surface, and much float in the mantel rock are opposed to this view.

h The contemporaneous deposition of silica and tungsten.

i Local solution of the tungsten and deposition of silica, possibly producing secondary enrichment is quite noticeable.

PLATE III.

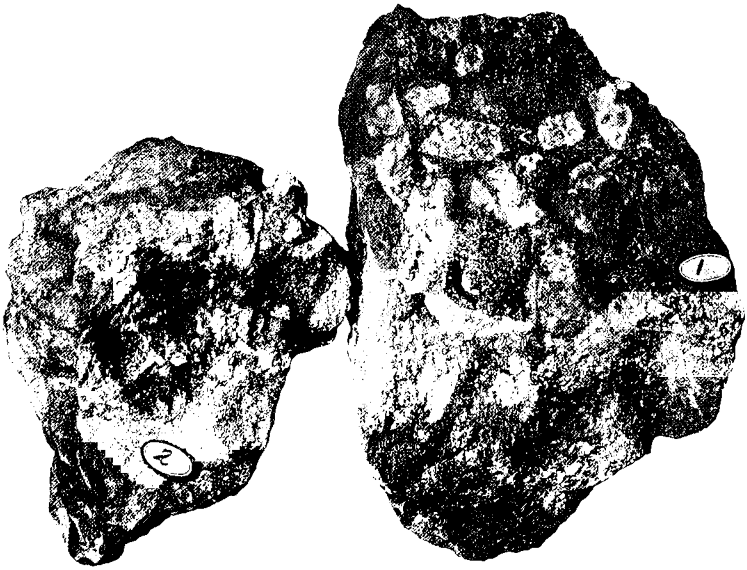


Fig. 1—Elsie Mine. Fig. 2—Mammoth Mine, Beaver Creek. Breccia ore, consisting of fragments of dike rock and country rock cemented by ferberite.

Fig. 3—Conger. Fig. 4—Townlot. A breccia showing fragments of ferberite. See fuller description of plates.

The ores: The ferberite occurs in three rather well-defined forms, which, however, frequently grade into one another. These are: 1. Well crystallized crusts and layers covering the surface of rock and hornstone fragments and cementing them into a rather open breccia; 2. Massive granular ore showing few or no crystal faces and occurring as more dense seams and masses in the wider and less brecciated parts of the vein; 3. The highly siliceous ore in which ferberite in fine grains—sometimes showing crystal forms—is scattered through hornstone or cryptocrystalline quartz. This type may occur in any of the mines, but was probably most abundant in the earlier workings of the eastern side of the region. It varies widely in its ferberite content from masses in which hornstone is but a scanty cementing matrix to those in which there is but a meager sprinkling of minute ferberite grains in the hornstone.

DESCRIPTION OF PLATES.

Plate II, Figs. 1 and 2.—A very common type of ore—that formed by the cementation of rock fragments by ferberite. In these specimens there are fragments of both the dike rock along which the vein is formed, and the country rock cut by the dike. This is common when the vein follows one wall of the dike. The dike rock is a quartz-rich granite in which the original minerals are still visible in spite of a considerable development of secondary quartz and the alteration of a part of the biotite to muscovite. Some of the fragments have lost much of the mica and feldspar from their outer borders. The country rock is a fine grained gneissoid, or almost schistose rock, showing many small flakes of biotite. In some of the fragments, ferberite fills cavities formed by the solution of some of the rock-making minerals. The cementation by the tungsten ore was incomplete and vugs lined with ferberite are shown. The specimens are from the Elsie and Mammoth mines on Beaver Creek.

Figs. 3 and 4.—These specimens are breccia-ore of different character from that shown in Plate III. It is the result of one of the later movements—the third—and contains the products of earlier movements and earlier depositions. There are fragments of country rock, of hornstone, of pegmatite, and of ferberite. It is almost an auto-breccia—a breccia in which there is no distinct matrix—but a later deposition of ferberite has filled a few openings left by the crushing and squeezing. The country rock was much altered before the movement, and had lost a large part of its feldspar, while that which remained was kaolinized and now forms a dense, very fine-grained matrix for the quartz grains. This type of ore is common in the Nederland-Beaver Creek part of the area.

PLATE IV.

Fig. 5—Townlot Mine. Same general features as Figs. 3 and 4, Plate II, but the breccia is more open.

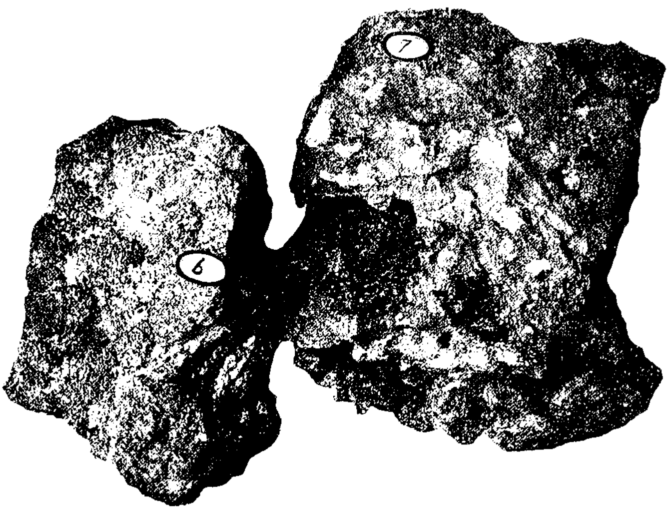


Fig. 6—Drusy ore from Elsie Mine.
Fig. 7—Drusy ore from the Grayback.

Plate III, Fig. 5.—This specimen from the Townlot mine shows the same general features as are brought out by Plate II, Figs. 3 and 4, but the breccia, while finer, is more open and contains more seams of ferberite deposited after the brecciation.

PLATE V.

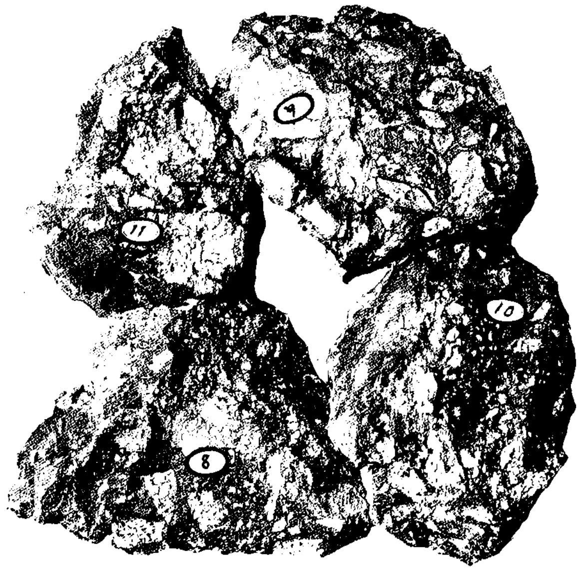


Fig. 8—Home Run. Figs. 9, 10—Boulder Falls. Fig. 11—Rogers Tract. See description of plates.

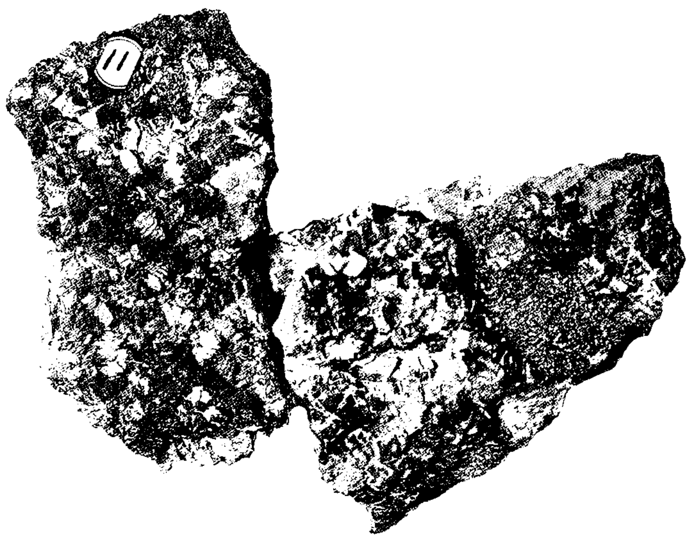


Fig. 11 A—Crystallized ferberite.

Plate III, Figs. 6 and 7.—These specimens from the Elsie and the Grayback show the drusy linings of cavities. The rock-frag-

PLATE VI.

Fig. 12—Shows contemporaneous deposition of quartz and ferberite.

Figs. 13 and 15—Clyde Mine. Fig. 14—Beddick Mine. See description.

PLATE VII.

Fig. 16—Conger.
Fig. 17—Townlot.

Fig. 18—Conger, reduced one-half.

ments in 6 include both country rock and pegmatite, while those in 7 show highly silicified country rock and hornstone.

Plate IV, Figs. 8, 9, 10 and 11.—Figure 8 shows a piece of ore from the Home Run mine of the Crucible Steel Company. The rock-fragments are fragments of the country rock, and many of them are so completely silicified as to be almost indistinguishable from the hornstone. Figures 9 and 10 show ore from Boulder Falls, and Figure 11, ore from the Rogers Tract. These ores present a breccia of dike rock, country rock and hornstone, with a ferberite cement. The ore shown in Figure 9 is from Boulder Falls, and consists of a breccia of dike rock fragments, many of which are so highly silicified as to be almost indistinguishable from the hornstone. In Figures 10 and 11 the dike rock fragments are but slightly silicified, though biotite is almost absent.

Fig. 11 (lower) shows crystallized ferberite.

Plate V, Fig. 12.—Very open ore, showing dike fragments varying from slight to complete silicification. The ferberite cement is also highly siliceous and films of quartz cover the drusy ferberite in some of the openings. Slickensiding shows movement since the deposition of the ore.

Fig. 13.—A breccia of hornstone, highly silicified dike rock and ferberite, with a small amount of cementing silica. The brecciation followed the deposition of ferberite.

Fig. 14.—A stringer of breccia ore in pegmatite. The rock-fragments are highly silicified pegmatite, coated with drusy ferberite. Hornstone has completed the cementation.

Fig. 15.—A stringer of ferberite between a wall of altered pegmatite and a wall of hornstone. The dividing line between the ferberite and the hornstone is just above the number.

Plate VI, Fig. 16.—A breccia of hornstone and dike rock in varying stages of silicification. The last event was the deposition of drusy quartz and secondary feldspar.

Fig. 17.—A breccia of kaolinized and talcose dike rock with a ferberite cement.

Fig. 18.—A stringer of breccia composed of hornstone, pegmatite and ferberite, reduced one-half. The last event was ferberite deposition along the fissure walls. A previous movement brecciated an earlier deposition of ferberite.

PLATE VIII.

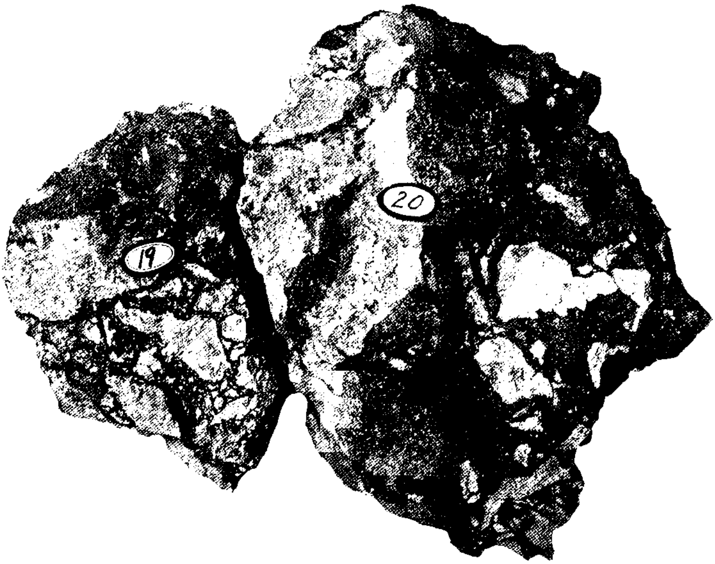


Fig. 19—Colorado Tungsten Corporation No. 4.
Fig. 20—Grayback Mine.

Fig. 21—High-grade ore from various mines.

Plate VII, Fig. 19.—Dike rock—much decayed—cemented by crystalline-granular ferberite.

Fig. 20.—Breccia of altered country rock cemented by granular ferberite.

Fig. 21.—High-grade ore from various mines.

Plate VIII, Fig. 22.—Crystallized ferberite from Lone Tree mine.

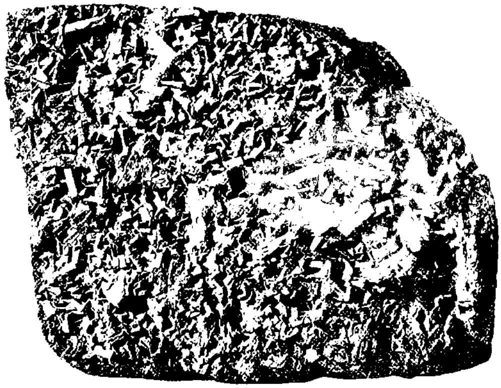


Fig. 22—Crystallized ferberite, Lone Tree Mine.

PLATE IX.

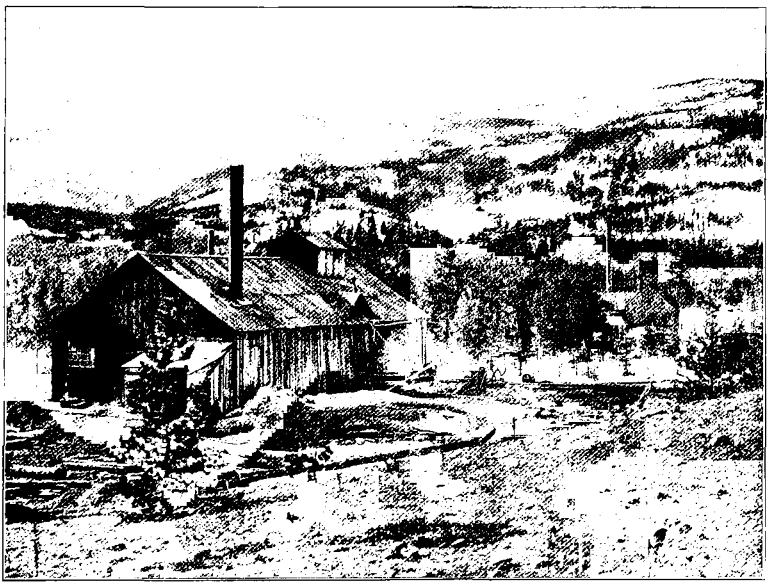


Fig. 23—Conger and Beddick shaft houses.

Fig. 23.—Conger and Beddick shaft houses.

Gangue: In the ores of the first two types the gangue materials depend largely upon the character of the rock in which the vein is formed. If the vein is in pegmatite the gangue may include fragments of the pegmatite, together with more or less deposited hornstone, a part or all of which may be in angular fragments. In the granite dikes and masses, fragments of granite will take the place of the pegmatite, while in the veins cutting the granite and gneissoid granite these rocks furnish their share of the gangue. In the shallower workings much of the rock matter is highly altered. In places this alteration has gone only to the extent of the kaolinization of the feldspars and the removal of the dark minerals or their alteration to a pale green talcose chlorite. Such ores are the most easily concentrated. In other cases the alteration has included the replacement of the greater part of the feldspar by cryptocrystalline quartz or hornstone almost indistinguishable from the hornstone deposited from solution. Below the surface weathering, the rock fragments are fresher, silicified fragments are also numerous, and hornstone may be objectionably plentiful. These last conditions increase the difficulties of concentration and make a high percentage saving very hard to secure.

Other vein minerals: The Boulder veins are unusually free from the minerals which commonly accompany tungsten ores. *Scheelite* is occasionally met with in the form of beautiful druses of dull honey-yellow crystals having perfect pyramidal terminations. *Pyrite* occurs in very small amount in the gangue, but rarely, if ever in the ferberite. The amount is so small that many analyses do not show even a trace of sulphur. *Galena* is a very rare mineral in the tungsten veins, and when found is generally in minute cubical grains except in one of the tunnels near Magnolia where an appreciable quantity occurs. *Sphalerite* is associated with the galena near Magnolia, and is reported in minute quantity from one or two other localities. *Molybdenite* in minute flakes is found very sparingly in the gneissoid granite, but is exceedingly rare. A specimen of ore from the Clyde mine shows a small flake or two. *Magnetite* forms small, irregular grains and imperfect crystals in both the pegmatite and the granite dikes, but the amount is very small. Most of the ore shows a very little magnetite, but it is almost impossible, even with a very weak magnet, to get a sample which will not react for tungsten. *Fluorite* has been reported, and is possibly locally present in very minute grains in both the hornstone and silicified dike rock, but it has not been possible to isolate it. Minute hollow cubes may have contained fluorite, and a rare isotropic grain in the gangue materials may be fluorite. Ferberite is found with the telluride ore in the Graphic mine at Magnolia, and a mine near Sunshine shows sylvanite associated with ferberite. The Wheelmen Tunnel—driven for gold—shows both ferberite and sylvanite. While the relative age of the ferberite and sylvanite is not always clear, specimens of the Magnolia ore leave little doubt that so far as the occurrences there are concerned, the telluride is older. Porous quartz contains a sprinkling of sylvanite well below the surface, while a crust of drusy ferberite covers the surface. The ferberite contains no telluride. The relations in the Wheelmen Tunnel appear to be much the same. Secondary *feldspar* having the form and appearance of adularia occurs in groups of tabular and prismatic crystals in a few places.

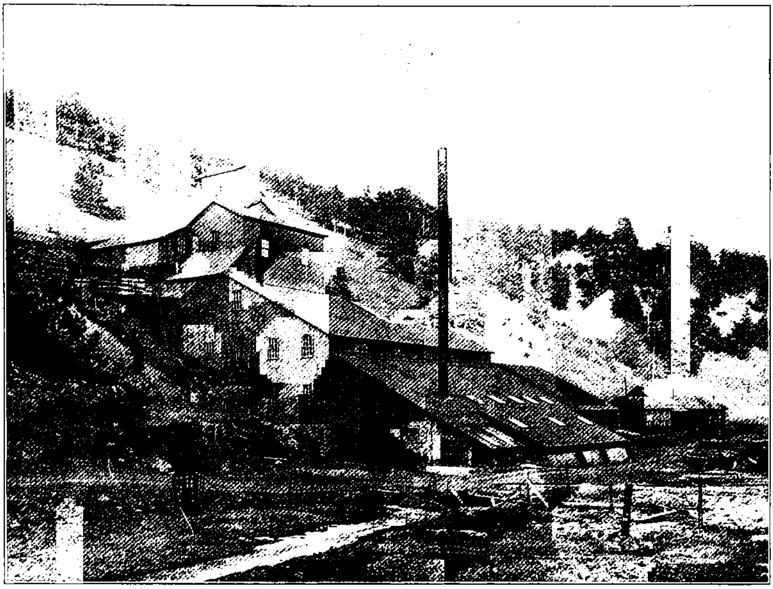
MINING.

In the early days of tungsten mining in Boulder County open pits and trenches were numerous, and in places "gopher mining" for float was profitable. At present the larger mines are well-equipped and well managed. Leasing is very common, especially on those tracts held under homestead entries. In many instances this method has proved profitable to both owner and leaser.

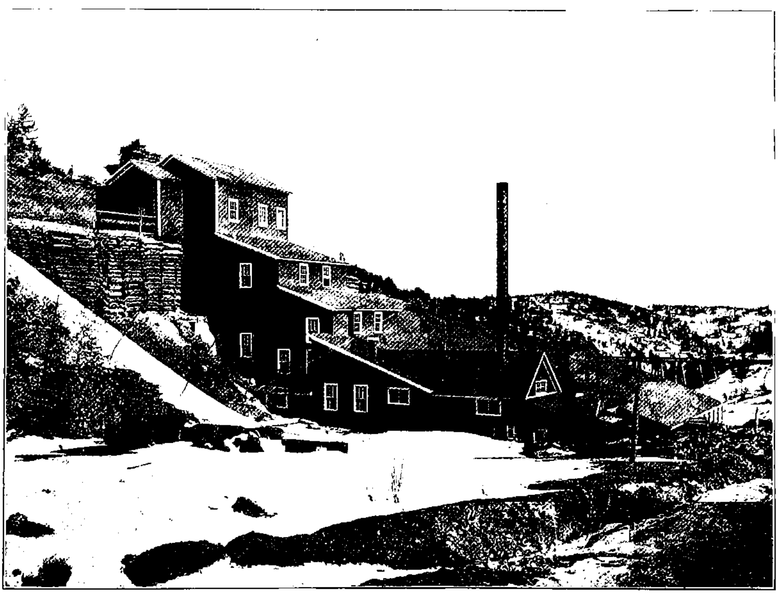
CONCENTRATION.

Mills: There are five mills in the district for the treatment of tungsten ores. With one exception these are partially or wholly made-over gold and silver mills. Experimenting in various lines has suggested many modifications and improvements, and several of the mills have reached a creditable degree of efficiency considering the difficult character of the tungsten ores. The Wolf Tongue mill at Nederland has treated the Company's own ores and has of late been the largest handler of custom work. The Cardinal mill at Cardinal has treated mainly the ores of the Cardinal Company. The Clarasdorf mill, below Nederland, was built by the Philipp Bauer Company to treat the ores of the Rogers tract which they held under lease. The Primos mill at Primos in the northeastern area has handled the Stein-Boericke production and a good deal of custom ore. The Lehigh Tungsten Mining and Milling Company has remodeled the old Coburn mill on Boulder Creek, but it has not yet treated

PLATE X.

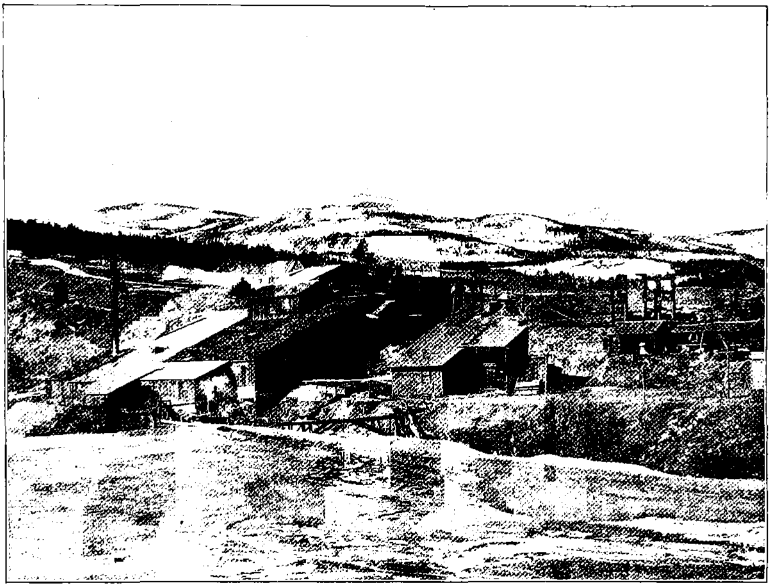


Primos Mill, Primos.

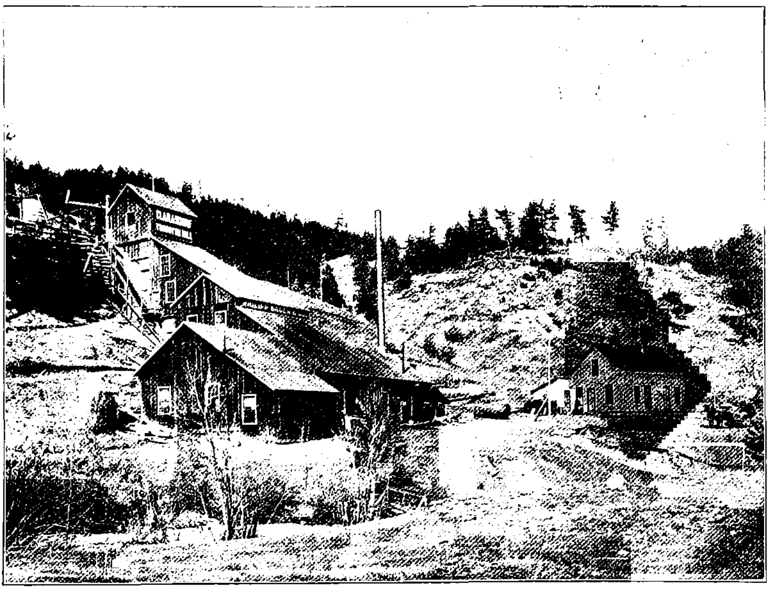


Cardinal Mill, Cardinal.

PLATE XI.



Wolf Tongue Mill, Nederland.



Clarasdorf Mill.

much ore. The Boyd mill in Boulder was used by the Colorado Tungsten Corporation, both for its own and for custom ores. A few hundred tons of ores have been treated by Henry E. Wood at his plant in Denver, and other mills have treated small quantities from time to time.

Difficulties: The concentration of the Boulder County ores presents some difficult problems. Ferberite is a rather soft mineral with one perfect cleavage, and generally one or more prominent partings. As a result the mineral is extremely friable even in the massive and massive-granular forms. Much of the ferberite was deposited as aggregates of loosely arranged crystals and crystal grains, forming crusts over the surfaces of rock fragments. One crust succeeded another until in many places the opening was filled. In other places the cavities remained open, but the walls were lined in the same manner. The crystal grains composing these crusts average not more than one-eighth of an inch in length and about one-sixteenth of an inch in diameter. In much of the ore where the crust is broken the crystal grains are easily separated from one another. When to this ready crumbling of the mass is added the extreme friability of the grains and crystals themselves, it is easy to understand the excessive sliming. The finer parts of the slimes form an almost impalpable mass which when stirred in water gives it an inky appearance, and the water remains turbid for ten days to two weeks. To save these slimes is one of the difficult problems with which the tungsten mill-man has to contend. As a result of the metallurgical methods now used in the preparation of metallic tungsten and ferro-tungstens, there seems to be but a limited demand for non-concentrated high grade ore. This makes it necessary to concentrate even the high grade ore, and consequently adds to the loss, by disproportionately increasing the slimes. The Primos Mining and Milling Company (formerly the Stein-Boericke and Cardinal Companies) sorts rather carefully, sacks and ships ores running twenty-five per cent. or over, and the Wolf Tongue Company ships ores exceeding thirty-five per cent. of tungstic oxide, but other producers have not been so favorably situated in this respect.

Another difficult problem is the successful treatment of the highly siliceous ores. In almost all the tungsten mines, there is a certain amount of highly siliceous ore consisting of minute grains of ferberite in a matrix of chalcedonic quartz or hornstone. The percentage of ferberite varies widely. Outside of certain limited areas this type of ore is fortunately not very abundant, and rarely amounts to twenty per cent. of the product. Various methods of treatment have been tried, but none has given entirely satisfactory results. Even very fine crushing leaves a large part of the ferberite with particles of quartz attached. In concentrating, these grains consisting of quartz and ferberite will be disposed of according to their specific gravity. Those in which the quartz is largely in excess will go with the tailings and ferberite will be lost, and those in which the ferberite is abundant will go with the concentrates and help to make a low grade product.

In discussing with the mill-men the methods of concentration best suited to the ferberite ores, a number of questions have arisen. Some of these are as follows:

(1) Is the stamp mill the best means of crushing the ores?

(2) Would coarse crushing the unsorted ore, jigging and regrinding (or stamping) the tailings pay?

(3) Would close sorting and separate treatment of the higher grade ores result in an increased saving which would pay the extra cost?

(4) Would chemical treatment of the low grade and the highly siliceous ores be feasible?

(5) If direct chemical treatment of the low grade and highly siliceous ores is not feasible, would it be possible to treat a low grade concentrate from them?

(6) Is magnetic separation feasible?

The writer does not pretend to be a mill-man, and his observations have not the backing of practical experience. But a few things are certain. Ferberite is exceedingly friable, and a large proportion of the particles into which it breaks are thin and flat—the best possible form to remain a long time in suspension whether on the tables or in settling tanks. Its friable character is responsible for unavoidable sliming, and its high specific gravity tends to keep it longer in the mortar, and to bring it under the stamps more frequently. The vertical screens in use are unfavorable for the quick escape of the pulp. The result is that a large part of the ore is reduced to a very fine slime. Again, much of the gangue is hornstone and highly silicified country rock which are anything but friable, and are not readily crushed to pass the screen. The rock grains aid in reducing the ore and so increase sliming.

Various tests of concentrates have shown the extreme fineness to which the ferberite is reduced. The following are given as examples, and they do not differ in any important way from the average results:

a Sample of 4 pounds from Wilfley tables:

58.57%	passed	a	150-mesh	sieve.
77.14%	"	"	100-mesh	"
82.85%	"	"	70-mesh	"
94.28%	"	"	40-mesh	"
99.28%	"	"	20-mesh	"

The discharge from the stamps in this mill was through a vertical 12-mesh screen. The sample did not contain the saving from special slimers or from stationary canvas.

b Sample of 3 pounds of mixed concentrates:

59.4%	passed	a	150-mesh	sieve.
78.9%	"	"	100-mesh	"
83.0%	"	"	70-mesh	"
94.1%	"	"	40-mesh	"
99.2%	"	"	20-mesh	"

A few ounces of clean concentrates which passed a 100-mesh screen were thoroughly shaken up in a gallon bottle of water and the bottle was allowed to stand. At the end of two weeks the water was still turbid, and when filtered yielded a perceptible amount of ferberite slime.

A method of crushing by which the fines would be at once screened out and carried beyond the reach of the machine would prevent a large part of the sliming. If the stamp mill is used, inclined screens would aid in this. The ferberite ores are in several respects similar to the zinc and lead ores of the Joplin District. Ferberite is probably a little more friable than galena. Much of the gangue of the Joplin galena (and zinc blende) is chert, and therefore very similar to the more siliceous gangue of the ferberite. The Joplin method of coarse crushing by means of a Blake (or similar machine), then screening, and roll-crushing the oversize and jigging the entire product removes at once a very large proportion of the values and correspondingly reduces sliming. This would be equally true of the tungsten ores. The tailings could be reground to the size made necessary by their character. But this also should be done in a mill which would at once release the fines.

Separate treatment of the high grade ores would undoubtedly reduce sliming, since a very large part of the values could be removed after coarse crushing.

The chemical method of treatment is as follows: The pulverized ore or concentrate is mixed with soda ash and fused. Under proper conditions a sodium tungstate is formed and the extraction is complete. The mass is dissolved in water and separated by filtration from the oxides of iron, aluminum, manganese and silicon. The addition of hot acid in excess precipitates tungstic acid, H_2WO_4, which separates as a yellow powder. This is washed from soda salts, and dried. In drying, water is given off and tungstic oxide, WO_3, remains.

So far as the composition of the Boulder county ores is concerned, there is nothing to complicate the process, but to treat the raw ore in this way would require a very large amount of soda ash. A low grade concentrate could be formed from the ore, and this could be treated more cheaply. Highly siliceous concentrates and ores are treated by this method in Europe.

The magnetic separator is successfully used on the complex tin-tungsten ores of Cornwall. There should be no great difficulty in applying this to the simple Boulder county ores, which contain practically no metallic mineral except the ferberite. Mr. Henry E. Wood has successfully applied this method, but regards it as better suited to the treatment of water-made concentrates than to the treatment of raw ore. Tests made for the writer on ores from Gordon Gulch and Boulder Falls showed a very perfect separation of material rejected by a 60-mesh screen. But with the pulp which passed the 60-mesh screen, the separation was not so perfect—rock powder came over with the ferberite. Coarse crushing would seem to be desirable for this method also.

The methods of concentration in use in the tungsten field are illustrated by the following examples:

1. *The Boulder County Mill of the Primos Mining and Milling Company:* The ore that passes 1½″-grizzlies goes to the stamp feed bin, while the over-size goes to a Blake crusher, and from this to the feed bin. The stamps weigh 750 pounds and have a drop of 6 inches seventy times per minute. The pulp passes from the mortar by a 12-mesh screen and is conveyed to Wilfley tables which recover about 70 per cent. of the total saving. The overflow goes to classifiers which make three sizes and pulp. The coarsest goes to a Frue vanner with a corrugated belt; the mid-

dlings and fine go to Frue vanners with smooth belts. The overflow from the last two tables goes by pump to a V-shaped settler, from which the pulp is delivered to four Frue vanners with egg-shell belts. The overflow from these goes to stationary canvas tables 12′ by 40′ with a slope of 1 to 12, and from these to another set of the same form and size. The sand from the corrugated Frue vanner goes to a Huntington mill, where it is reground to pass a 60-mesh sieve and is delivered to the canvas tables.

2. *The Clarasdorf mill of the Philipp Bauer Co.:* The ore goes to a Traylor crusher, from which it falls onto a 16-mesh screen. From this point it is a wet process. The over-size passes through a Hodge crusher, then to rolls, and the product returns to the screen. The pulp from the screen goes to the first Wilfley table, and the oversize returns to the rolls. The tailings from that part of the table nearest the concentrates are reground in triplex rolls to pass a 40-mesh screen, and with the overflow from the Wilfley pass to a Traylor classifier, which makes four products. The coarsest—mainly about 40-mesh—goes to the second Wilfley, the intermediate—mainly about 60-mesh—to the third, and the finest—mainly about 80-mesh—to the fourth Wilfley. The slimes are treated on two Traylor slimers.

3. *The Colorado Tungsten Corporation's mill* (*the Boyd Mill, Boulder*)*:* The equipment consists of: A jaw crusher, ten 1,000-pound stamps, four standard Wilfley tables, two Wilfley slime tables, eight Monell slime tables, and stationary canvas. The mines of the company furnished ores of two rather distinct types. For one of these a 16-mesh screen was used, and for the other a 20-mesh screen.

The pulp was classified and passed to the four standard tables. The coarse tailing from the first table, carrying about 0.4 per cent. of tungstic oxide, was discarded. The tailings from the second table were reground. The tailings from the third and fourth tables, mixed, went to four Monell tables. The tailing from these went to a settling spitzkasten, from which the coarse material went to two more slime tables, and the slime to the stationary canvas. The tailings from the last two tables went to another large settling and sizing spitzkasten, from which the finer deposit went to two or more slime tables, and the overflow to the stationary canvas. There were many changes, from time to time, in the methods of classification and distribution, but the above is the plan during the last month's operation.

The mill practice of the Atolia Mining Company, San Bernardino Co., Cal., working on scheelite ore, is as follows: The ore is fed into a Blake crusher, from which it passes by an automatic feeder into a Huntington mill and is crushed to 20-mesh. It then passes to Frue vanners. The high-grade ore is sorted, cobbed and sacked. (125r.)

Australian method: Stamp crushing is used at Koorboora on wolframite ore running 4 per cent., but the Huntington mill is more generally used (1906), and it is believed that it causes less sliming.

Cornish tungsten ore dressing: At the East Pool, Clitters and South Crofty mines, all of which are relatively rich in wolframite, magnetic separators have been installed to remove the wolframite. The East Pool ore carries cassiterite, arsenopyrite, wolframite, and chalcopyrite so evenly distributed in the veins as to make hand sorting impossible. The pulp from the stamps is classified into sands and slimes. The sands go to Frue vanners or to Wilfley tables (preferably the latter on account of their greater speed). The concentrates contain the tin ore, wolframite and arsenopyrite, while a middling product contains the chalcopyrite and some tin ore. After being calcined to remove the arsenic, the concentrates are classified, and the sands are passed over Wilfleys which yield a product containing about three parts of tin ore to one of wolframite, and about five per cent. of iron oxide.

The slimes from the first classifiers go to rag frames and the product of these passes over Acme tables, from which the concentrates go to the calciner. The calcined residues pass over Acme tables. These concentrates and those from the sand are leached with sulphuric acid, washed, dried, and passed through a Humboldt-Wetherill magnetic separator where a conveyor belt carries the material under a magnet strong enough to remove the iron oxide, but too weak to affect the wolframite. The remainder, containing tin ore and tungsten ore, passes on to a stronger magnet which removes the wolframite. The tin ore and other nonmagnetic materials are left. The object of the sulphuric acid leaching is to prevent tin ore from adhering to the wolframite and passing into the tungsten concentrates in the magnetic separator.

The Elmore vacuum process has been installed at the Dolcoath mine, but the ores contain very little tungsten.

Sale of ore and concentrates: The concentrates (and high-grade ores) are sold by the "unit" of tungstic oxide, which is one per cent. of a short ton, or 20 pounds. At present the standard concentrate carries 60 per cent. of tungstic oxide (commonly called "tungstic acid"), and must not exceed 0.25 per cent. phosphorus, nor 0.01 per cent. sulphur. Concentrates falling below this standard are penalized a few cents for each per cent. they fall below this figure in tungstic oxide, and for any excess of phosphorus or sulphur. A bonus is sometimes allowed on concentrates carrying over 60 per cent. of tungstic oxide.

POSSIBLE EXTENSION OF THE AREA.

Rocks of the same types, and in the same relationship as those of the tungsten area occur far to the north and to the south. To the north, however, there is a gradual increase in the metamorphic structures such as the gneissoid and schistose which, when pronounced, seem to be unfavorable to tungsten deposition. To the south, in Gilpin county, granites and gneissoid granites prevail for some distance, and are cut by pegmatite and granite dikes of the same type as those of the known tungsten area. While the gold and silver deposits and the tungsten deposits are not intimately associated, the two seem to conform roughly to the trend of the belt of intruded porphyries which extends from the middle of Boulder County in a southwesterly direction into Gilpin, Clear Creek, Summit and Lake counties. Tungsten is known within this belt in Boulder, Gilpin and Clear Creek counties.

Future of the district: The present development offers but few data on which to base opinions as to the future of the deposits. The workings are shallow, the ore is distributed along the veins in bunches and pockets or rarely shoots, and up to the present nothing has occurred to suggest that the downward distribution is less regular than the lateral. In fact, a considerable number of the best ore bodies have had greater vertical than lateral dimensions. This is natural when it is remembered that the deposition took place from uprising solutions, and not from solutions moving mainly in a horizontal direction. The deepest workings in the camp are showing ore bodies of dimensions and quality quite equal to those of any yet discovered.

PRODUCTION.

The preparation of a satisfactory statement of the production of the district has proved a very difficult task, but the producers have very kindly placed their mining and milling records at the disposal of the Survey. These have been compared, checked and arranged, and it is believed that the following table is reasonably accurate:

		Tons.	Average price per unit.	Value.
1900	High-grade ore, 63% WO_3	40	$1.30	$ 3,216.00
1901	High-grade ore and concentrates, averaging 65% WO_3	65	2.25	8,775.00
1902	Ores and concentrates	166	2.50	24,900.00
1903	Mainly concentrates	243	2.50	36,317.00
1904	Ores and concentrates, averaging about 55% WO_3	375	5.50	125,000.00
1905	Mainly concentrates	642	6.00	231,120.00
1906	Mainly concentrates	789	6.54	309,603.00
1907	Mainly concentrates	1,146	8.33	573,643.00
1908	High-grade ore 180; Concentrates 407	587	....	164,220.00

CHAPTER III—TECHNOLOGY AND USES OF TUNGSTEN.

THE METAL AND ITS METALLURGY.

The metal: There is still a notable lack of agreement among chemists regarding the properties of tungsten. The statements following are compiled from the latest publications. Metallic tungsten is generally produced in the form of a black or grayish-black powder. The fused metal is slightly darker than metallic zinc, and is distinctly lustrous. It is brittle, and non-ductile (some say ductile and malleable), but may be welded, filed and forged. Sulphuric and hydrochloric acids attack it slowly, nitric more vigorously, and a mixture of nitric and hydrofluoric acids readily dissolves it. Aqua regia oxidizes the powder form, but does not act upon the fused metal. Under ordinary atmospheric conditions it is very slowly oxidized, but at red heat it is rapidly changed to tungstic oxide. The fused metal has a specific gravity variously estimated from 16.6 (Stavenhagen), to 18.7 (Moissan), and 19.13 (Remsen). The melting point is placed at 2,800° C. by Wartenberg, but as high as 3,080° C. by Waidner and Burgess of the Bureau of Standards, Washington.

Metallurgy of tungsten: The following three examples may be regarded as representing the methods of obtaining tungsten from its ores: 1. The ore is ground to pass an eight or ten-mesh sieve, and is brought to a cherry-red heat and fused with sodium carbonate (soda-ash). The sodium tungstate thus formed is dissolved in boiling water, filtered from the solid impurities, and treated with hot hydrochloric acid (or nitric), in earthen vessels. This precipitates tungstic acid, H_2WO_4. The liquid is drawn off and the tungstic acid is washed to remove sodium salts, and is then converted into tungstic oxide by drying. The dry oxide is mixed with pure carbon and placed in crucibles and heated to a very high temperature in a gas furnace. The carbon and the oxygen of the ore unite and pass off, leaving a black or gray-black metallic powder, which usually contains a small amount of carbon.

2. The tungstic oxide is produced by the same method, but the reduction with carbon is effected in an electric furnace. This method is said to produce a metal quite low in carbon.

3. The pulverized ore is mixed with pure carbon or placed in carbon-lined crucibles, and reduced in an electric furnace. The impurities, chiefly iron and manganese, and the oxygen unite with the carbon, and metallic tungsten is left.

Other methods, some of which have been used on a commercial scale, are:

1. The tungstic oxide is reduced in a current of hydrogen, which unites with the oxygen of the oxide, forming water and leaving a black powder of metallic tungsten.

2. The Goldschmidt or alumino-thermite process: The oxide of the metal is mixed with finely powdered aluminum and a readily ignited substance such as barium peroxide, in refractory crucibles. The mass is ignited and the intensely heated aluminum unites with the oxygen of the tungstic oxide, and the heat of the reaction forms a metallic bath in the crucible. The aluminum is oxidized to the form of corundum, (Al_2O_3). By proper adjustment of the charge the ore is completely reduced and the aluminum is entirely oxidized. This produces a carbon-free metal.

3. The tungstic oxide is mixed with powdered zinc and heated to redness until the zinc is distilled off. The mass is freed from zinc oxide by hydrochloric acid, and from the remaining tungstic oxide by sodium hydroxide.

4. Powdered tungsten, powdered manganese, tungstic oxide and manganese dioxide are mixed, compressed and heated in a stream of hydrogen. A mass of tungsten and manganese (not strictly an alloy) is formed, from which the manganese is removed by acids.

5. Powdered tungstic oxide is heated with one-tenth its weight of sugar charcoal in the electric furnace. With care, this yields an almost carbon-free metal.

6. Tungsten concentrates are reduced to lower oxide form by means of carbon in an electric furnace. Silicon carbide is added and the reduction is completed. (Becket process.)

7. The Greene and Wahl ferro-silicon method has also been used.

USES OF TUNGSTEN AND TUNGSTEN COMPOUNDS.

Introduction: Pure metallic tungsten is but little used in finished industrial products. But, alloyed with other metals, and in various chemical compounds, the use of tungsten has recently become important. Many of its physical and chemical properties have been known for decades, but until recently the supply of tungsten ore was so uncertain and irregular that there has been little inducement to develop industries dependent upon a supply of tungsten. The discovery of the Australian deposits and those of the U. S. has given manufacturers reasonable assurance that an increasing demand would be met.

The certainty of a supply of ore encouraged a more thorough study of the metal and its possible uses. And the development of the gas and electric furnaces for metallurgical purposes made the production of metallic tungsten much less expensive. As a result, the demand for tungsten has increased very rapidly, and the metal has taken its place as a necessary factor in a number of important industries.

Tungsten is employed chiefly in the following forms:

The metal is used: (1), for the making of alloys with various metals, such as iron, aluminum, nickel, copper, titanium, tin and others. (The alloys will be discussed below.) A small amount of tungsten is mixed with the magnetite in the electrode of the "magnetite arc" lamp; (2), for filaments in the tungsten incandescent lamp, and has been tried as an electrode in arc lamps.

There are at least a hundred patents recorded for the preparation of incandescent lamp filaments in which tungsten is the important metal. In most of these, metallic tungsten powder forms part of a plastic mass or paste, which is made into a filament by forcing it through a die having an opening of the required size. The substances used for the paste are different in the different processes, but various gums, sugar, syrup and other viscous liquids form the binding materials with which the metallic tungsten powder and some form of carbon are mixed. When the filaments come from the die they are dried and gently heated away from air. They are then ignited by an electric current in an atmosphere of hydrogen (or other reducing gas) and sufficient oxygen (or water vapor) to dispose of the carbon. They are hardened at very high temperatures.

The General Electric Company has patented a process in which the binding mass is an alloy of 42 parts cadmium, 5 to 10 parts of bismuth and 53 parts of mercury. With 35 parts of this alloy are mixed 65 parts of metallic tungsten and a refractory oxide such as that of thorium. The filaments are finished by electrically heating them in an atmosphere of hydrogen. In one process, metallic tungsten is mixed with an oxide of one of the metals: titanium, thorium, zirconium, or vanadium, or with a mixture of the oxides of two or more of these. Filaments having a coating of tungsten over a core of another metal have been tried, as have also hollow filaments made by coating a carbon filament with tungsten in an atmosphere consisting of a halogen or an oxyhalogen of tungsten. The carbon core is removed by burning the filament in an atmosphere containing nitrogen and hydrogen. A partially metalized filament is made by packing carbon filaments in oxides of tungsten and heating them in a vacuum furnace. The oxides are partially vaporized, and entering the carbon, are reduced to metallic tungsten.

The brittleness of the tungsten filament is probably due to the presence of a carbide (or an oxide) of tungsten. In most of the methods of manufacture there would be little danger of an oxide remaining, but the carbides, W_2C and WC may be present in the metallic tungsten powder used, and under certain conditions the carbide W_2C may be formed in the making of the filament.

It is interesting to note that two or more of the large manufacturers of incandescent lamps specify that Boulder County tungsten must be used in the filaments. Most of the foreign tungsten deposits are associated with, or contain, minerals carrying one or more of the following elements: sulphur, phosphorus, tin, arsenic and antimony, all of which render the metallurgy more complex, and make the production of a pure metallic tungsten more difficult. Even a small trace of sulphur, phosphorus, tin or arsenic is said to be very detrimental to the filament, and it is very reasonable to suppose that sulphur and phosphorus are as objectionable in ferrotungsten and tungsten steel as they are in ordinary steel. Probably the only foreign tungsten deposits which compare in purity with the Boulder County ores are those of Saxony and Bohemia.

Some of the claims made for the tungsten filament are: brilliant white light; increasing resistance with increasing heat; an efficiency of 1 to 1.2 watts per (Hefner) candle power; (the ordinary carbon lamp uses from 3.5 to 4. watts per candle power); an average efficient life of 1,000 hours; that it is but little affected by irregularity of voltage. (**116.**)

Tungstic oxide, WO_3, has but few direct commercial uses. Certain metallurgical processes for the production of metallic tungsten, ferrotungsten, tungsten steel and other alloys, may be said to start with the tungstic oxide, while in others, such as the fusion-lixiviation method, its separation from the sodium tungstate is one of the steps in the process. It is the essential part of certain mordants used in dyeing textile materials and fabrics. It is also used in paper staining and printing. But in both these uses a tungstate (usually the sodium paratungstate), is used as a source of the oxide, and it is probable that tungstic acid, H_2WO_4, rather than the oxide, is the form in which tungsten takes part in the reactions. Sodium- and barium-tungstates are used in glass-coloring and pottery glazing. The colors obtained include various shades of yellow and blue.

The tungstates are the chief ores of the metal, and are therefore the primary source of tungsten in whatever form it may be used in the industries. The insolubility (in water) limits the direct use of the natural tungstates except as sources of the metal and its commercial compounds. Scheelite is used in the Roentgen ray fluoroscope. Tungsten forms soluble tungstates with sodium and potassium. Those of sodium are by far the most important, and are made by fusing powdered wolframite, hübnerite or ferberite with sodium carbonate. Sodium paratungstate, the commercial sodium tungstate, $Na_{10}W_{12}O_{41}.28H_2O$, is the most important artificial tungstate. It is used as a mordant in dyeing and calico printing, and for rendering vegetable fibers and fabrics uninflammable. Sodium tungstate and other tungsten compounds characterized by rich color tones are used in the manufacture of stained papers. Tungsten salts are also used for weighting silk fabrics.

The partial decomposition of the sodium and potassium tungstates yields a series of tungsten bronzes of very beautiful colors and high lusters. A fusion of potassium tungstate and tin yields "bronze powder." These tungsten bronzes and bronze powder are much used for decorating. Lead tungstate was sometimes substituted for white lead as a pigment.

ALLOYS OF TUNGSTEN.

Various alloys: Tungsten forms useful alloys with many metals. It unites in almost any proportions with iron and steel. (The iron and steel alloys will be discussed more fully below.)

Platinoid contains copper, zinc, nickel and a small percentage of tungsten. Its high electrical resistance does not decrease with heat. "Wolfram-aluminum" is a very useful alloy, which may be rolled, spun and woven. It is used for military appliances. A light and very strong alloy of tungsten and aluminum, called partinium, is used in automobile manufacture. An alloy of tungsten, aluminum and copper, having great tensile strength and elasticity, is used for propeller blades. Sideraphite contains much iron, with nickel, aluminum, copper and 4 per cent. of tungsten. It is malleable, ductile, and resists acids. Minargent is an alloy of tungsten, nickel and copper. An alloy containing 73-75% tungsten, 23-25% nickel, a small amount of iron, carbon and silicon finds a ready market. The so-called alloys with manganese are unstable, and are probably not true alloys, since the manganese can be dissolved out, leaving a tungsten web or network. There are several alloys with iron and nickel; with nickel alone, and with iron and chromium. Alloys of tungsten and titanium and tungsten and zirconium have been used with good success as filaments for incandescent lamps. Alloys of tungsten, with copper and iron; iron, copper and aluminum; iron, titanium and carbon; iron, columbium and tantalum, are available.

Carbides of tungsten and chromium are extremely hard, and resist acids well.

Iron and steel alloys: The alloys of tungsten with iron and steel are by far the most important. Those with iron are known as ferro-tungstens, and ferro-alloys. Their chief use is in the manufacture of tungsten steels. Those with steel are known as tungsten steel, wolfram steel, high-speed steel.

Ferro-tungsten: The ferro-tungstens commonly carry from 30 to 85 per cent. of tungsten. They are sometimes classed according to the percentages of carbon and tungsten into: *a*, high carbon and medium tungsten; *b*, high carbon and high tungsten; *c*, low carbon and high tungsten. Those having the higher percentages of tungsten are favored. The following are typical:

	W	Fe	C	
1.....................	60.92	28.38	...	
2.....................	83.90	12.10	3.30	
3.....................	78.80	10.90	3.20	
4.....................	84.30	14.90	.72	
5.....................	85.79	13.50	.60	
6.....................	85.15	14.12	.45	
7.....................	71.80	24.35	2.58	Mn .78

The temperature required for the making of ferro-tungsten cannot be reached in the blast furnace. There are several methods of manufacture in use: 1. The direct reduction of the tungsten concentrates (with scrap iron, or iron ore if necessary) in a Moissan or other electric furnace; 2. The Rossi method, which combines the electric furnace and a modified aluminum process. A graphite-lined furnace is so arranged that the lining becomes the cathode, and a carbon electrode dipping into the furnace cavity forms the anode. Scrap or bar aluminum is charged into the furnace and the current turned on. The aluminum forms a molten bath in which the tungsten concentrates, consisting mainly of Fe WO_4, (or FeO. WO_3), are placed. The iron oxide is reduced to a metallic bath in which the tungsten dissolves. The aluminum takes up the oxygen of the concentrates, forming a slag on the surface of the molten ferro-tungsten. This produces an alloy low in carbon. 3. The crushed ore or concentrate is mixed with the proper amount of iron, either metallic or in the form of an ore, and ten to fifteen per cent. of charcoal, a like amount of pulverized quartz, and five per cent. of scrap glass. With rich ores or concentrates, a small percentage of resin or pitch should be added. The mixture is placed in graphite or clay crucibles and fused in a crucible furnace, or a gas regenerative furnace.

Tungsten steel: The effect of tungsten as a steel-hardening metal was known as early as 1855, but it was not until Robert Mushet, an English iron master, placed his "special steels" on the market a few years later, that any commercial use was made of the knowledge. The Mushet steels contained tungsten in varying percentages from 6.4 up to 10. They were known as self hardening, or air hardening, or high-speed steels. It was later discovered that tools made of the Mushet steel, reheated to a yellow heat, and cooled in a current of air, possessed greater hardness and greater cutting-efficiency. The Mushet steels contained less tungsten and more manganese than the average high-speed steel of to-day. The special qualities given to steel by the addition of tungsten depend upon a nice balancing between the carbon (manganese) and tungsten. Several contain chromium also. With 3% of tungsten and 0.9% carbon, the tenacity of the steel reaches its maximum, and its ductility is not materially decreased. As the percentage of tungsten rises from 9 to 16, the steel becomes very hard and brittle, but its efficiency in cutting tools is greatly increased. Beyond 16% of tungsten, the steel becomes softer and tougher and the cutting efficiency decreases.

Taylor and White, of Bethlehem, Pa., recommend the following steels:

	W	Cr	C
1. For cutting hard steel..	8.5	4.0	1.25
2. For cutting soft steel...	8.5	3.0	0.75 to 1.0

The analysis of one of their best high-speed steels, the "A. W.," shows: Tungsten, 13.5%; chromium, 3.5%; carbon, 0.55%.

H. M. Howe (Iron, Steel and Other Alloys) gives the following ranges for many of the tungsten steels:

W	3.44 to 24.00
Cr	0.00 to 6.00
C	0.40 to 2.19
Si	.21 to 3.00
Total	4.05 to 35.19

Nickel is also added to some tungsten steels.

In an iron-working machine, when a cutter made of hard carbon steel develops a temperature, through friction, of about 500° F., it begins to lose its temper. This fact limits the speed at which the machine may be run. The tungsten steel cutters do not begin to soften until a temperature of 1,000° F. to 1,200° F. is passed. The tools are completely restored by reheating to a very high temperature and cooling in an air blast. They are, therefore, not strictly self-hardening. It is also found that the higher the temperature used in reheating, the higher may be the temperature developed by friction before the tool will soften.

The uses of tungsten steel: 1. The tougher grades are being used for armor plate, and the harder for heavy projectiles. Edge tools and various other kinds are being made of tungsten steel.

2. The harder grades are used for cutters for steel- and iron-working machinery.

3. Car springs of high carrying power are made of the more elastic grades. Tungsten steel has also been used with excellent results for railway frogs and rails in places where the wear is very heavy.

4. Tungsten steel will retain a high degree of magnetism for a long period, and is therefore used for "permanent magnets," such as compass needles, and calibrating instruments.

5. Sounding plates and wires for musical instruments, made of tungsten steel, give a more powerful response.

6. It is reported that heavy guns, car wheels and the wearing parts of heavy machinery are being made of tungsten steel.

7. An alloy containing 35% tungsten and 65% iron is used for shells for lead bullets to increase their penetrating power.

Manufacture of tungsten steel: Probably the earliest method of making tungsten steel was by adding tungstic oxide to the molten steel in the crucible. Later, Mushet mixed roasted wolframite with pitch and added it to the crucible. The product of these methods would be irregular in the percentage of tungsten, and would be likely to contain unreduced tungstic oxide in damaging amount. Then followed the methods described below, and now in use:

1. Powdered metallic tungsten is added to the steel in the crucible until the desired percentage of tungsten is reached.

2. Ferro-tungsten of known composition is added in proper amount. Several other processes have been patented, of which the following may be regarded as a type; tungsten concentrates (or ore), metallic zinc and iron are heated in an electric furnace. The zinc reduces the oxides of iron and tungsten, forming zinc oxide, which is carried away. (**124a.**)

The first method is favored in Germany and is largely used in America. The second method is more used in England, and the following reasons are advanced in its favor: The powdered metal oxidizes readily at red heat, and is likely to carry tungstic oxide into the steel; the ferro-tungsten unites more readily with the steel and with less loss; the powder is more likely to carry impurities than is the ferro-tungsten; the ferro-alloy costs less per unit of tungsten than does the powder. The lack of uniformity in the earlier tungsten steel is believed by Hadfield, of Sheffield, to be due to the fact that more or less oxide was introduced with metallic tungsten.

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ABBREVIATIONS.

A. I. M. E.—Transactions of the American Institute of Mining Engineers.

Am. Chem. Jou.—American Chemical Journal.

Am. Jou. Sci.—American Journal of Science.

Ec. Geol.—Economic Geology.

E. M. J.—Engineering and Mining Journal.

Eng. Mag.—Engineering Magazine.

J. A. C. S.—Journal of American Chemical Society.

Jou. I and S. I.—Journal of the Iron and Steel Institute.

J. S. C. I.—Journal of the Society of Chemical Industry.

Min. and Geol. Mus.—Mineral and Geological Museum.

Min. Ind.—Mineral Industry.

Min. Jou.—Mining Journal.

M. R.—Mineral Resources.

Min. Rep.—Mining Reporter.

Quar. Jou. Geol. Soc.—Quarterly Journal of Geological Society.

Soc. of Engs. and Mets.—Society of Engineers and Metallurgists.

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- **(h)** "Scheelite Mining in New Zealand." Queensland Govt. Min. Jou., Feb., 1906.
- **(i)** Wolframite in Northern Part of Queensland. E. M. J., 78, p. 724.
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- **(k)** Tungsten in California. E. M. J., 83, p. 1063.

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THE MONTEZUMA MINING DISTRICT

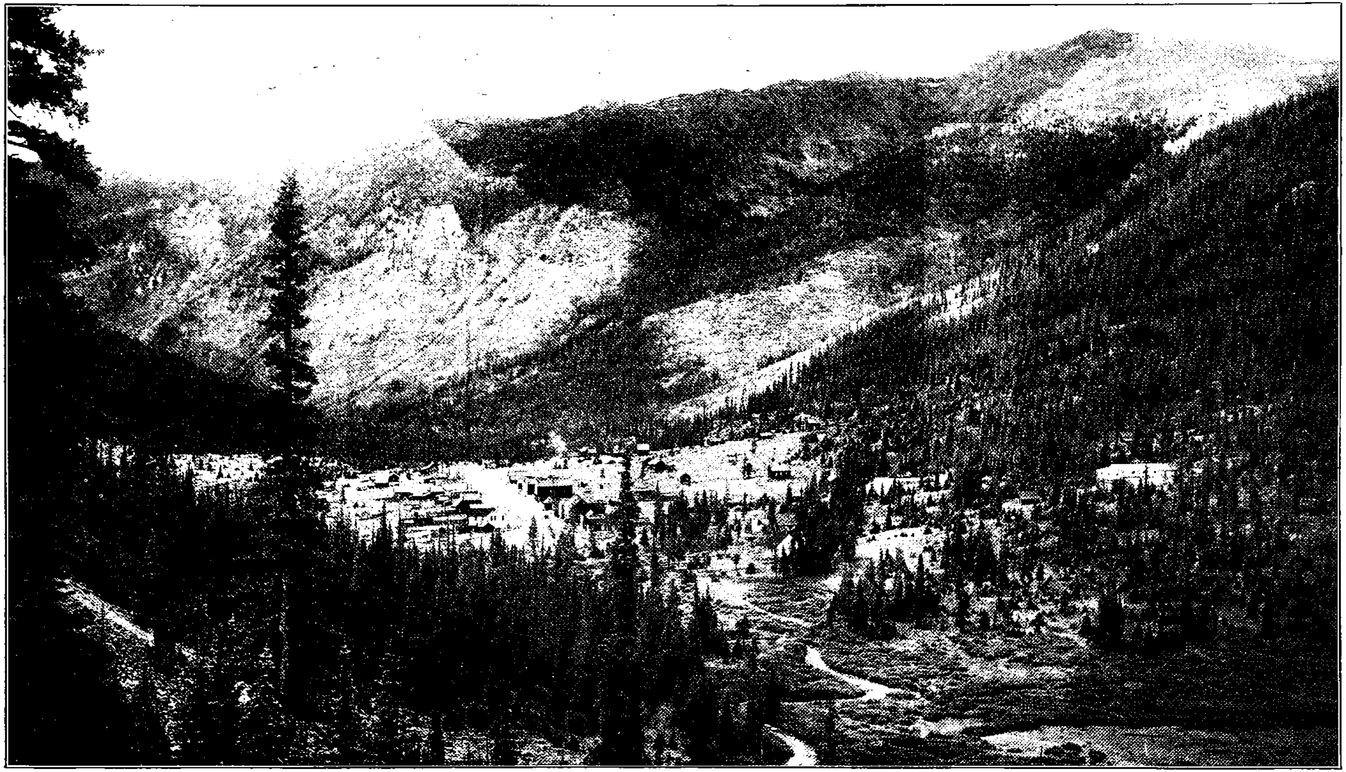
OF

SUMMIT COUNTY COLORADO

By HORACE B. PATTON

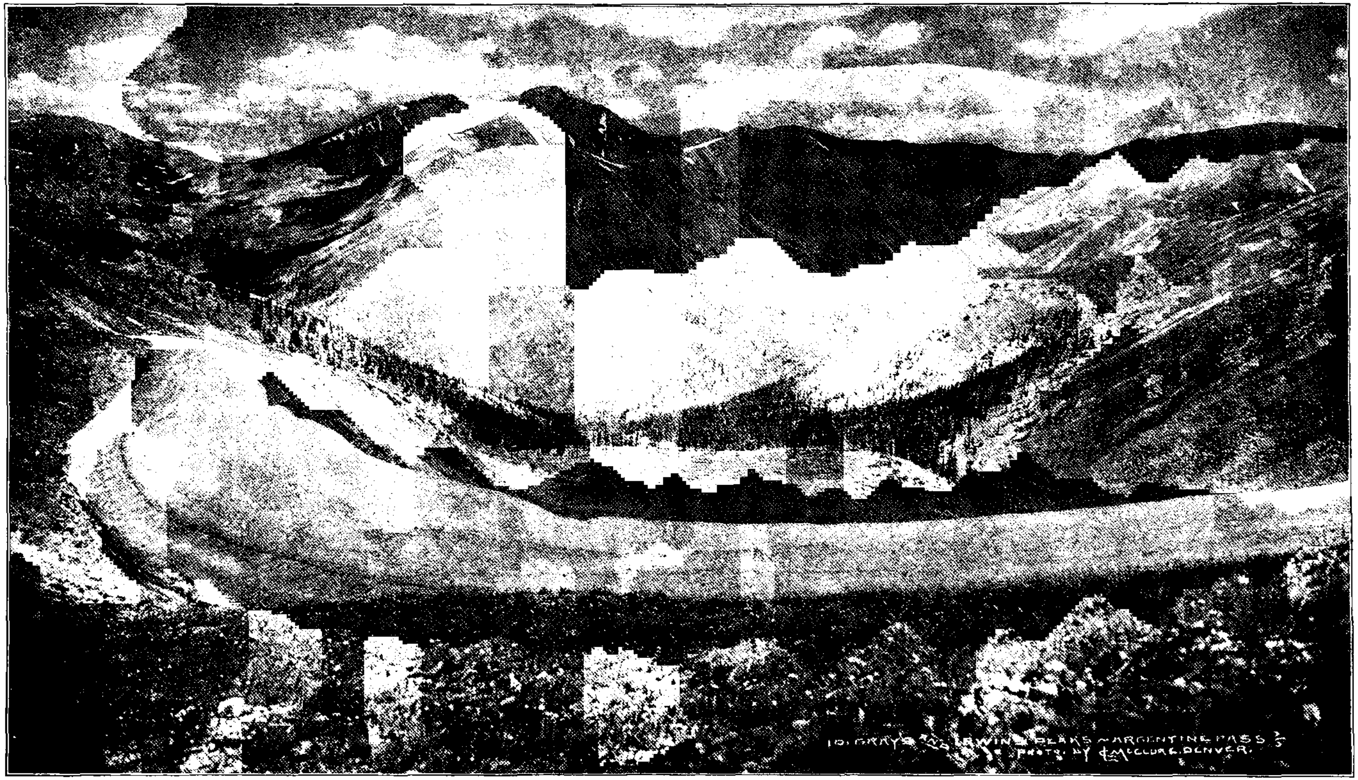
CONTENTS.

PLATE XII.



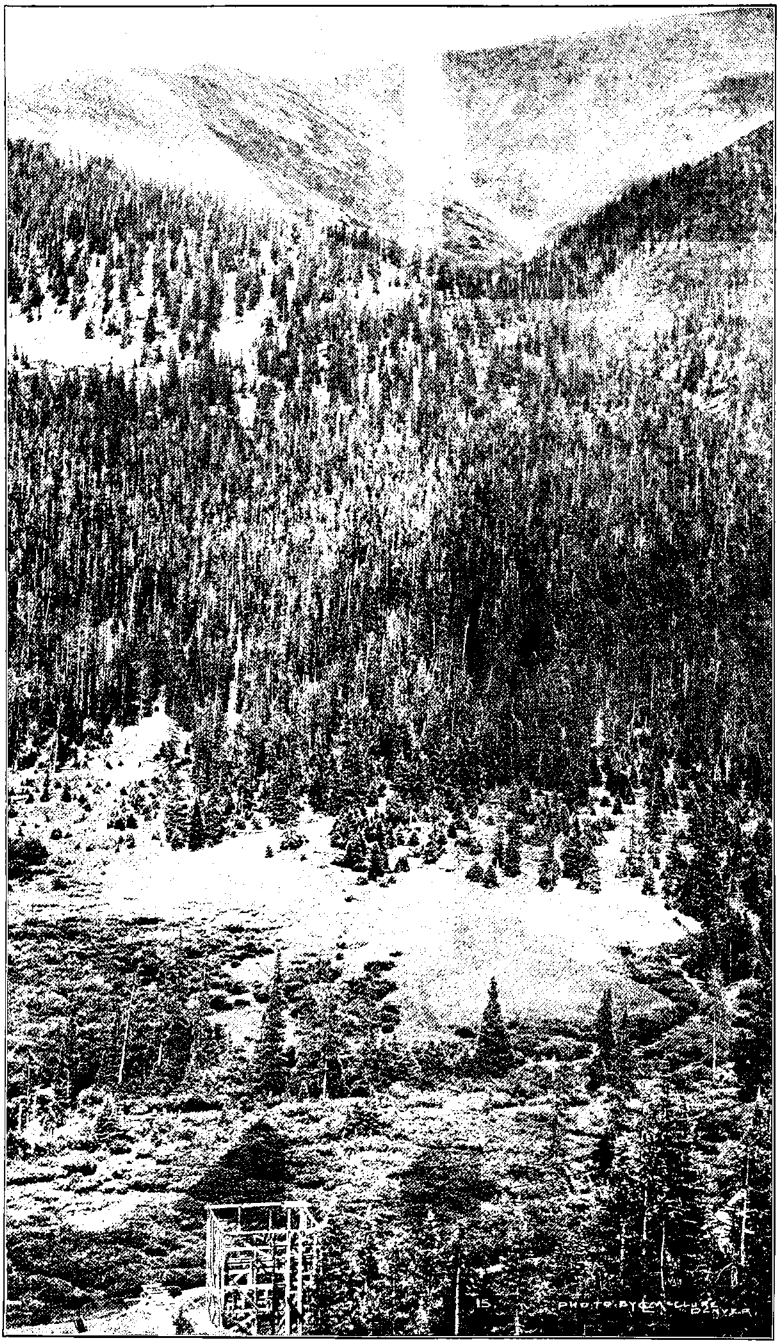
View of Montezuma and the Snake River Valley, looking north.

PLATE XIII.



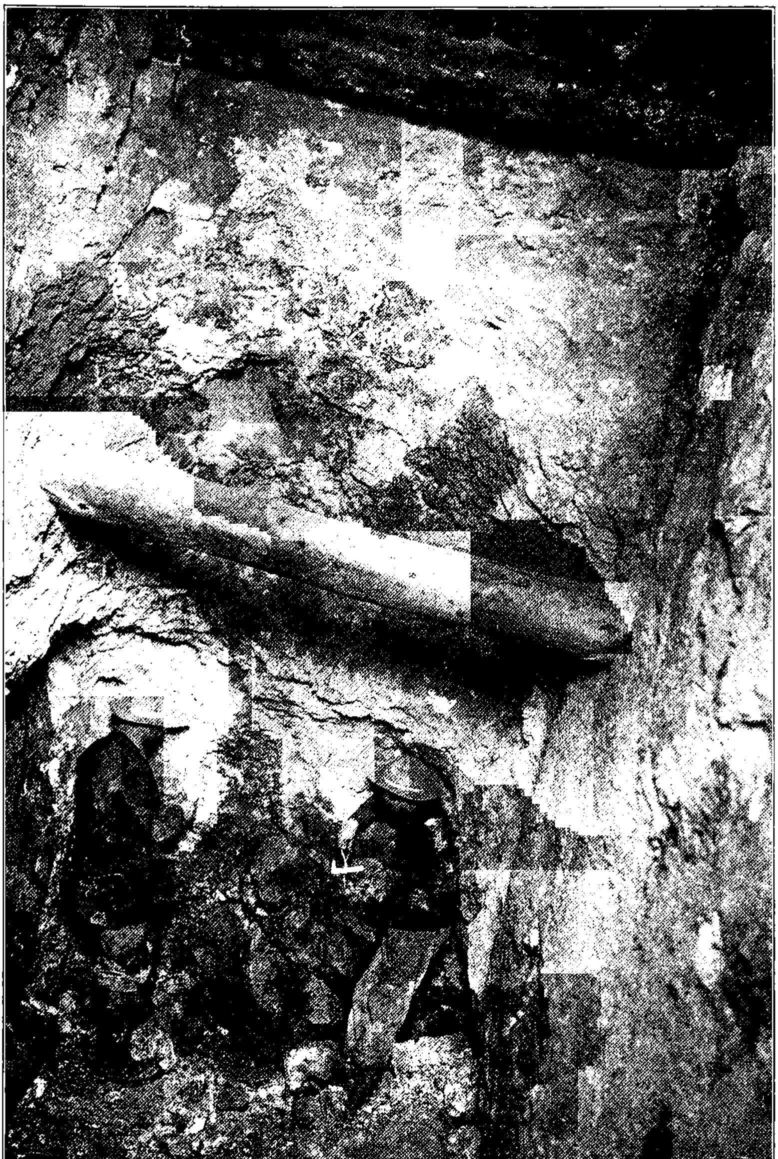
Gray's Peak, looking northeast from near Montezuma.

PLATE XIV.



View across Snake River Valley, from the Silver Princess Mine, showing the lower wooded slope and the bare upper slope with the Sarsfield Mine near the summit of Collier Mountain.

PLATE XV.



The Silver King Vein, showing a large body of milling ore.

INTRODUCTION.

Location and History.

The territory covered by this paper and by the accompanying topographic and geologic maps embraces an area of twenty-two miles, being a tract four miles from east to west and five and one-half miles from north to south, situated in greater part to the east and south of the town of Montezuma, Summit county, Colorado. This town lies only a few miles from the Continental Divide, near the head of the Snake river.

As great activity has been manifested during the past year or two in this old and long-neglected mining camp, it was the purpose of the State Geological Survey to include as large an area as circumstances would allow in this investigation. It was found impossible, however, in the time available to cover all the ground between Montezuma and the Continental Divide to the east, although, because of the mining operations past and present in this region, such an extension would have been very desirable. It was necessary, therefore, to make the boundaries of the map rather arbitrary. In so doing, however, nearly all the more important properties that have received recent attention have been included.

This region is really one of the earliest developed mining districts in the State, dating from the early sixties, when rich silver ores were discovered near Chihuahua in what was called at that date the Snake River Mining District. That the district did not develop more rapidly is due in part to the distance from the market and to lack of transportation facilities; in part, doubtless, to the discovery of still richer ores at Leadville, to which most of the miners were attracted. As the vital matter of proper transportation facilities is likely soon to be solved, the rapid development of this camp may be confidently expected.

Field Work and Acknowledgments.

The field work was carried on for eight weeks during the months of July and August, 1908, under the direction of the writer. Unfortunately no accurate topographic map of the district was available, and such maps as did exist were utterly inadequate for the purpose of a geological survey. It became necessary, therefore, to prepare an accurate topographic map, and the greater part of the time in the field was required for this purpose. The topographic work is essentially that of Mr. T. Dyer Benjovsky and of Mr. William M. Lewis, both students in the Senior class of the Colorado School of Mines, who carried out this work as a part of their graduation thesis. The work was done under the supervision of the writer and of Professor Charles E. Smith. The triangulation survey that necessarily preceded the topographic survey was likewise carried out by the aforementioned students, notes of which will be found below.

The map is made on a scale of 1 to 18,000; or 1,500 feet to the inch, with contour intervals of one hundred feet. Owing to the extremely inaccurate location of the government section corners, it has been deemed inadvisable to put on the map the customary section lines. Instead of these are to be found parallels of latitude and meridian lines, each one minute apart. One section corner, however, that is readily accessible, and to be found almost in the exact center of the map, has been put on for the convenience of those who may wish to tie up to a corner. This corner is located on the first correction line, and is between sections 35 and 36.

The writer wishes to acknowledge his great indebtedness for many courtesies shown by Mr. J. R. Roots, resident manager of the Montezuma Mines Development Company, especially for valuable information given as to the various mining properties and for the free use of the company's office accommodations. Acknowledgments are also due to Mr. E. W. Fairchild and Mr. Chas. E. Shaeffer for further courtesies, and to Mr. Etienne A. Ritter and to The Engineering and Mining Journal for the use of a map and illustrations published in the Journal, and to Mr. D. F. C. Moor, of the United States Geological Survey, for advance information as to certain geodetic co-ordinates.

Topography.

The topography of the Montezuma district is very marked, there being an extreme difference in elevation of about 3,800 feet between the highest and lowest points. The Continental Divide runs diagonally through the southeastern part of the map for a distance of six or seven miles, measured along the serpentine course of the crest. To the south and east of this divide small portions of Park county and of Clear Creek county are included within the area surveyed.

The best known and perhaps most conspicuous peak on the map is Santa Fe Peak, located on the Continental Divide about opposite the center of the map. The highest peak, also on the divide, attains an elevation of 13,483 feet. To this peak the name Landslide Peak has been given by the writer because of two conspicuous landslides to be seen on its flanks, one on the north and one on the west side. While the mountains of the district are not extremely rugged and actual precipices are not extensive, nevertheless most of the mountain slopes are very steep and the aspect of the country is decidedly mountainous. The town of Montezuma lies in the valley of the Snake river at an altitude of 10,300 feet.

TRIANGULATION SURVEY.

As a foundation for the triangulation system a carefully measured base line was laid out in the Snake River valley where it passes through the town of Montezuma. Courses and distances of the base line and computations made from definite points in it will be found in the field notes which follow.

Base Line.—Field notes.

Station	Course	F. S.	Distance	Elevation
A	N. 25° 35′ 44″ W.	B1	260.0	177.48
B1	N. 25° 35′ 44″ W.	B	410.5	168.43
B	N. 25° 40′ 20″ W.	E	2,379.4	119.8
E	N. 22° 14′ 20″ W.	G	1,381.1	44.71
G				00.0

Elevation of E above G = 44.71 feet.
Elevation of B above G = 119.8 feet.
Elevation of B above G = 168.43 feet.
Elevation of A above G = 177.48 feet.

Note: Elevations of different stations on base line above station G were determined by using an engineer's level.

Ends of base lines are marked with blocks of stone and the elevations cut in the stone, also the letters S. G. S. All calculations refer to G as zero.

Triangulation from the Base Line.—Field notes. (All angles turned to right.)

Sta.	B.S.	H.A.	V.A.	H.D.	Elev.	F.S.	Remarks
A	B1	47° 51′	14° 8′	6,037.9	1,588.4	1	Monument Tip Top Peak.
A	B	175° 44′	13° 8′	7,253.	1,869.5	11	N. end Teller Mt.
E	G	226° 47′	24° 12′	2,984.	1,341.	19	Cragg on Glacier Mt.
E	G	287° 53′	16° 0′	5,535.	1,592.	21	N. ridge Bear Mt.
G	E	32° 25′	18° 57′	4,056.	1,392.	19	Located.
G	E	93° 31′	17° 10′	5,297.	1,636.	21	Located.
G	E	273° 23′	19° 51′	4,898.1	1,768.6	1	Located.
G	I	84° 1′	9° 20′			11	Located.

Calculations for Point 1:

Side A-G = 4.428.
Angle 1-A-G = 50° 40′
Angle 1-G-A = 84° 58′
Horizontal distance A-1 = 6,037.9
Horizontal distance G-1 = 4,898.1
Elevation of 1 above A = 1,588.4
Elevation of 1 above G = 1,768.6
Average elevation 1,767.5

Calculations for Point 19:

Side G E.............................. 1,381.
Angle G E 19..........................133° 13′
Angle E G 19.......................... 32° 25′
Calculating—
Side E 19............................. 2,983.6
Side G 19............................. 4,056.2
Calculated from G, elevation of 19.... 1,392.7
Calculated from E, elevation of 19.... 1,384.9
Average of two calculations.......... 1,388.8 (Above G)

Calculations for Point 21:

Side G-E .... 1,381.
Angle E-G-21 .... 93° 31′
Angle G-E-21 .... 72° 7′
Calculating—
Side G-21 .... 5,297.
Side E-21 .... 5,555.
Calculated from G, elevation of 21.... 1,636.
Calculated from E, elevation of 21.... 1,636.7
Average 1,636.35

Field Notes for Stations 11, 23, 26, 29, H, and 30:

Sta.	B.S.	H.A.	V.A.	H.D.	Elev.	F.S.	Remarks
1	G	287° 1′	0° 31′	12,074.	1,356.4	11	Located.
1	A	331° 23′				11	Located.
1	11	40° 2′	1° 58′	11,672.	4,008.	23	Monument on Glacier Mt.
1	11	83° 52′	2° 0′	16,383.7	572.1	26	U. S. G. S. Monument on Independence.
21	1	86° 20′	4° 45′	6,373.	529.6	23	Located.
21	1	207° 31′	6° 1′	6,658.1	701.7	26	Located.
21	1	32° 40′	4° 59′	14,220.0	1,240.	29	Monument on Santa Fe Pk.
23	1	40° 9′	3° 30′	11,572.	707.79	29	Located.
23	1	269° 16′	0° 51′	11,347.	168.4	26	Located.
30	29	324° 33′	7° 47′			H	Stump in town with flag.
1	30	60° 27′	20° 20′	4,655.		H	
1	H	299° 33′	1° 41′	18,578.	545.97	30	Monument on Teller Mt.
1	H	8° 39′	19° 53′			G	
H	1	255° 33′		760.		G	
H	1	105° 35′	7° 43′	16,778.		30	Located.

Calculations for 11:

Side A-1		6,037.9
Angle 11-A-1		127° 53′
Angle A-1-11		28° 37′
Calculating—		
Side 11-1		12,074.
Side A-1		6,038.
Calculating from A, elevation of 11	1,692.	
Calculating from 1, elevation of 11	108.9	
Referred to G the elevation of 11	1,869.5	
Referred to G the elevation of 11	1,876.4	
Average	1,872.95	

Calculations for 23:

Side 1-21		10,195.
Angle 1-21-23		86° 20′
Angle 23-1-21		33° 1′
Calculating—		
Side 23-21		6,373.
Side 1-23		11,672.
Elevation of 23 above 1	400.8	
Elevation of 23 above 21	529.6	
Elevation of 23 referred to G	2,165.9	
Elevation of 23 referred to G	2,168.32	
Average	2,167.12	

Calculations for 26:

Side 1-23		11,672.
Angle 1-23-26		90° 44′
Angle 23-1-26		43° 50′
Calculating—		
Side 23-26		11,341.
Side 1-26		16,383.7
Elevation of 26 above 1	572.1	
Elevation of 26 above 23	168.23	
Elevation of 26 referred to G	2,339.6	
Elevation of 26 referred to G	2,335.42	
Average	2,337.51	

Calculations for 29:

Side 21-23		6,373.
Angle 23-21-29		53° 4′
Angle 29-23-21		100° 49′
Calculating—		
Side 21-29		14,220.
Side 23-29		11,572.
Elevation of 29 above 21	1,240.	
Elevation of 29 above 23	707.79	
Elevation of 29 referred to G	2,876.35	
Elevation of 29 referred to G	2,874.91	
Average	2,875.63	

Calculations for H:

Side G-1	4,898.
Angle H-G-1	67° 5′
Angle G-1-H	8° 39′
Calculating—	
Side 1-H	4,655.
Side G-H	760.09
Chained side G-H	760.
Elevation by level of H above G	61.1

Calculations for 30:

Side H-1	4,655.
Angle H-1-30	60° 27′
Angle 1-H-30	105° 35′
Calculating—	
H-30	16,778.
1 to 30	18,578.
Elevation of 30 above station 1	545.97
Elevation of 30 above station H	2,268.5
Elevation of 30 referred to G	12,592.03
Elevation of 30 referred to G	12,590.5
Average	12,591.2

Elevations referred to sea level. All points referred to Independence Peak as 12,610 feet, by U. S. G. S.

Station	Elevation	Remarks
1	12,038.53	Tip Top Peak.
21	11,906.38	Station on ridge of Bear Mountain.
29	13,146.66	Santa Fe Peak.
30	12,585.2	Teller Mountain.
23	12,438.15	Glacier Mountain.
19	11,666.0	Crag on Glacier, visible from Montezuma.
G	10,271.1	Lower end of base line.
A	10,448.5	Upper end of base line.
H	10,317.53	On base line.
11	12,144.05	North end of ridge on Teller Mountain.

Geodetic observations on Independence Peak.
Latitude N. 39° 34′ 55″ .04.
Longitude W. 105° 54′ 34″ .93.

The elevation, latitude and longitude of Independence Peak, given above, was furnished by Mr. Daniel F. C. Moor of the United States Geological Survey, from original data secured during the summer of 1908.

Climate and Vegetation.

Owing to its high altitude Montezuma and the surrounding country has a most delightful and bracing summer climate, and the heavy snows of winter are attested by the great snowdrifts that remain till far into the summer on the upper slopes and on the shaded mountain sides even at the level of the town.

The lower parts of the mountains are clothed with a heavy and beautiful forest of fir trees that extends to an altitude of above twelve thousand feet, and is found at the very doors of the town. This combination of rugged and lofty mountains with heavy forested bases and green, grass-covered upper reaches presents mountain views of entrancing beauty and endless variety.

CHAPTER I.—GENERAL GEOLOGY.

Introduction.

The Montezuma Mining District lies in the region of Archæan crystalline rocks that form the Front Range of Colorado. These consist of various schists and gneisses penetrated by numerous igneous rocks of both plutonic and effusive types. The schists and gneisses cover the larger part of the area in question, but in some parts of the field are cut by a great profusion of intrusives. These last are mostly porphyritic rocks in the forms of dikes from an inch or less up to one hundred feet or more across. With a few exceptions these igneous rocks are acidic in type and sometimes extremely so. In a few cases rocks as basic as diabase occur. The plutonic rocks are to be found in the northern and eastern part of the area mapped. They are also acidic, being granites of greatly varying appearance and composition. They, too, are cut by acid intrusives of somewhat varying character, but invariably different from those found in the gneisses and schists. Finally, pegmatite veins are profusely developed in the schists and gneisses, and to some extent also in the granites.

With the exception of quaternary deposits, sedimentary rocks are completely absent from this district, the nearest sedimentaries being found some eight miles below on the Snake River. The quaternary deposits are chiefly confined to glacial drift and moraines that hide to a great extent the rocks in the valley bottoms and extend up the mountain sides nearly to, or in places well above, the timber-line.

The rocks of this district, both schistose and igneous, are undoubtedly closely akin to, and in many cases perhaps identical with, those in the so-called Georgetown Quadrangle that lies over the range to the east, and that has recently been studied and mapped by Sidney H. Ball of the United States Geological Survey. It would undoubtedly be very desirable to make use of the same names for identical formations in the two districts, and such was the expectation of the writer. Unfortunately, however, the publication of Mr. Ball's paper has been delayed, and inasmuch as it has been deemed desirable that the Montezuma report be included in the first annual report of the State Survey, no time has been available for direct study of the rock formations of the Georgetown Quadrangle on the part of the writer. A letter from Dr. C. W. Hayes, Chief Geologist of the United States Geological Survey, gives the information that, owing to the absence of Mr. Ball from the country, it has been found impossible to select samples of rocks and thin sections from among those collected and prepared by Mr. Ball that might be serviceable in making a comparison between the rock formations of the districts in question. The writer is obliged, therefore, to fall back upon a paper published nearly three years ago by Mr. Ball, giving a preliminary description of some of the rocks of the Georgetown Quadrangle.*

There can be no doubt as to the identity of what Mr. Ball designates the Idaho Springs Formation with one of the schistose series represented in the Montezuma district. This name, therefore, is adopted in the present paper.

It is not so clear, however, as to the identity of other formations with those of the Georgetown Quadrangle, so that it has been found advisable to make use of local names for other rocks.

The geologic field work is essentially that of the writer, who was assisted part of the time by Professor Charles E. Smith. The mapping of the formations on Bear Mountain was done under the writer's supervision by Messrs. Benjovsky and Lewis.

SCHISTOSE ROCKS.

Idaho Springs Formation.—The Idaho Springs formation occupies, together with the instrusive rocks inclosed within it, about one-third of the area surveyed, and is to be found in the southeastern part of the map. It is a schistose series of greatly varying color and texture. Upon the whole gray is the prevailing color of the fresh rock, but the altered and weathered portions may be red, yellow or nearly white. Green colors are almost completely absent. The rocks are extremely schistose or, at least, thin-bedded, and split frequently into slabs under the influence of the weather.

*Sidney H. Ball, Pre-Cambrian Rocks of the Georgetown Quadrangle, Colo. Am. Jour. Sci., 4th Ser., Vol. 21. pp. 371-389, May, 1906.

The minerals most abundantly represented in these schists are quartz, biotite and sillimanite; less abundant, but sometimes locally strongly developed, are microcline, orthoclase, acid plagioclase, muscovite and magnetite, also the alteration products of these minerals. The dominant and characteristic rock of the series may be designated a mica-sillimanite schist. The sillimanite is colorless and occurs in delicate needles more or less intergrown with quartz. They sometimes form parallel fibrous aggregates, but more often felted aggregates that appear as whitish spots or knots thickly strewn through the light to dark gray rock. On the weathered surface these sillimanite knots stand out in strong relief in raised lumps that may readily be mistaken for quartz. An examination with a pocket lense, however, readily discloses the characteristic fibrous structure. The centers of these knots are often composed of pure sillimanite, but invariably quartz is intergrown with the sillimanite at the outer edge. These sillimanite-quartz patches often make up a very considerable proportion of the rock—from one-quarter to one-third. The other constituents associated with the sillimanite are almost invariably biotite, muscovite and microline, and not infrequently orthoclase and an acid plagioclase. The muscovite, while always present, is never abundant. In general it may be noted that the feldspars largely disappear when the sillimanite is very abundant, presumably for the reason that the sillimanite has been formed by alteration of the original feldspathic ingredients. Typical mica-sillimanite schists are unusually well developed on the north and south slopes of Geneva Peak, not far from the summit.

The normal mica-sillimanite schists grade by insensible graduations into biotite schists or biotite-muscovite schists, or all of these into more dense and less schistose quartz-feldspar gneisses with perhaps little or no mica, either white or black. But even when the rock appears to be entirely free from sillimanite, this mineral can usually be found by careful search; or if perchance it be missing completely from one narrow bed, it will be found in adjacent beds of the same series.

To a very slight extent hornblende schists and biotite-hornblende schists are represented in this Idaho Springs formation, and form very dark-colored, narrow bands strictly interbedded with the rest of the schists. Usually both biotite and hornblende are present in varying amounts, together with quartz and feldspars. But these locally developed hornblende rocks are very different in appearance from the markedly banded rocks described below as forming the hornblende-gneiss series.

Very extensive alteration of the schists of this formation has taken place over wide areas. This alteration takes the form of further silification and is accompanied by the leaching out of the iron and the consequent disappearance of the ferruginous minerals, such as biotite. Eventually the rock may pass into a felted aggregate of quartz grains. These bleached, nearly white schists, both with and without sillimanite, are found in many places, but are very extensive in the vicinity of Webster Pass. Not infrequently in connection with the removal of the iron from the rock interior a portion of the iron may be deposited in thin films along the seams or joints of the rock in the form of red hematite. Eventually the rock breaks up under the action of the frost and the surface becomes strewn with the red-coated fragments so as to give an intense red color to a whole mountain side. This is very marked on Red Cone to the southeast of Webster Pass; also in a broad belt stretching northeasterly from the flat just north of Santa Fe Peak. It should be noted, however, that red painting of the rock surfaces is not characteristic of the sillimanite schists, as the same intense red colors may be noted on porphyry or on other rocks within the belt of alteration.

The schists of the Idaho Springs formation, as Ball remarks of the similar rocks in the Georgetown Quadrangle, are an intensely metamorphosed series, and were doubtless originally sedimentaries.

They are certainly among the oldest rocks in the district, being cut by all the igneous rocks, both plutonic and effusive. The extent to which they are injected with these igneous rocks is astonishing and is possibly due to the comparative ease with which they are split by the upward pushing lavas.

Strike and dip of the schists vary greatly. In general it may be said that the dip is steep and often vertical. In places contortion is very much in evidence, so that the dip, and, to a less extent, the strike, vary every few feet or less. The strike is apt to be fairly constant over considerable areas. In the southeastern corner it is about northwest and in the central and eastern portions northeast. A very sudden change in the strike occurs in the short space between the summits of Santa Fe Peak and Geneva Peak, the change being from northeast to northwest. This sudden change in strike is quite possibly due to the intrusion of the extensive granite mass in Geneva Gulch. As stated elsewhere, the porphyry dikes largely conform in strike to that of the schists, influenced thereto, doubtless, by the ready parting of the schists along the cleavage planes.

The Hornblende-Gneiss Series.—The second series of metamorphic schists that are to be found on the Montezuma map occupies the western and southern third and is designated the hornblende-gneiss series from the marked predominance of the mineral hornblende. In the northern part these rocks come into contact with the Montezuma granite, which has been intruded into the schistose rocks, and in the middle and southern portions with the Idaho Springs formation. The contact line between these two schistose series is a very irregular one and bears no direct relationship to the direction of schistose cleavage, although the rock cleavage is the same for both series at the line of contact. No definite proof was found that the hornblende-gneiss is intrusive in the mica-sillimanite schists, as both have been so extensively metamorphosed as to greatly change what must have been their original relations.

These hornblendic rocks present an infinite variation in composition and structure. In addition to their being strongly marked by the presence of hornblende, they are further characterized by a beautifully banded structure, light and dark-colored bands alternating with each other in rapid succession. There is every conceivable combination in color and width of the bands and a corresponding variation in the mineral components of the different bands. The darker bands may be almost black—or, rather, green-black—owing to an excessive amount of hornblende. In addition to hornblende, these dark-colored bands contain plagioclase feldspar in varying amount. Often these two minerals constitute the entire rock, but there is likely to be some quartz, and epidote, also biotite; but no muscovite. Then again biotite may be the prevailing dark-colored constituent, in which case quartz becomes also more abundant and plagioclase less so, and orthoclase may put in an appearance. Rarely does hornblende entirely disappear. These dark-colored streaks, taken by themselves, might therefore be designated in different places as amphibolite, biotite-hornblende schist, hornblendic biotite schist, or simply biotite schist.

The light-colored bands may be almost white, but more customarily some shade of gray, depending upon the proportion of the light and dark-colored minerals composing them. In general they may be said to consist of a mixture of quartz, feldspar and biotite, with occasional but very subordinate yellowish green epidote. White mica may be recognized to a very slight extent under the microscope, but hardly in the hand specimen. The feldspar consists at times of both orthoclase and microline, with or without plagioclase. These light-colored bands usually have at times a very marked parallel arrangement of the biotite so as to cleave readily parallel to the bedding. At other times there is much less parallelism manifested, or even none at all.

The dark-colored, hornblendic bands are rarely very thick, a few inches to a foot or two being the customary limits, but occasionally heavier beds of amphibolite are met with. On the other hand, lighter colored gneissic rocks do occur without the presence of hornblendic streaks in certain parts of this series, and may continue with but little variation for several hundred feet. To such parts of the series the name granite gneiss would be appropriate. Indeed, it is in many cases practically impossible to distinguish these from granites that have undergone more or less crushing.

This entire series is penetrated by numberless large to small veins of pegmatite, from a quarter of an inch up to many feet in width. These veins cut the gneisses in all directions and not seldom follow the direction of the bedding, so as to make it difficult to distinguish the veins from the older natural light-colored bands. The nature of these pegmatite rocks will be found discussed below under the head of pegmatites.

Dikes of porphyry and of other effusive igneous rocks are to be found cutting these gneissic rocks, but are very much less numerous than is the case with the mica-sillimanite schist series. Furthermore, the direction of the dikes does not appear to be influenced to any great extent by the strike of the gneisses. In this respect there is a marked distinction between the gneiss series and the schists of the Idaho Springs formation.

These hornblende gneisses are sometimes considerably contorted so that strike and dip are constantly changing. In general the strike is northwesterly, as on Bear Mountain and on Teller Mountain. At the head of Deer Creek it swings around to north and south, and on the east slope of Glacier Mountain a strike of north 25 degrees east is recorded. The dips are usually steep.

IGNEOUS ROCKS.

General.

The igneous rocks of the Montezuma district are perhaps of more than ordinary interest from an economic point of view because, as will appear later, there is undoubtedly some direct connection between them and the ore veins. Both plutonic and effusive rocks are represented in great profusion, there being several distinct varieties of granite and many types of porphyries and other effusive rocks in dike form. Surface flows and intercalated lava sheets are entirely wanting. In spite of the great variety shown in effusives, with the slight exception of a very few small dikes of diabase, no distinctly basic igneous rocks, either plutonic or effusive, occur.

Plutonic Rocks.

Montezuma Granite.—Covering about one-quarter the area, and extending clear across the northern end of the district, is a very beautiful and characteristic granite which has been named the Montezuma granite because of the fact that the town is built in part and perhaps entirely on the area covered by this rock. This granite, in accordance with the usage of petrographers, is more properly to be designated a granite, in that the mica present is black mica or biotite, and white mica or muscovite is entirely wanting. The color of this granite is a pinkish gray, owing to the presence of many large flesh-colored orthoclase feldspar crystals. These orthoclase crystals give to the rock a very striking and beautiful appearance. They average from three-quarters of an inch to one inch in diameter, and may be larger than this, but seldom smaller. They are usually so thickly imbedded in the rock that an ordinary hand specimen of three by four inches will disclose on one face four or five or more of these crystals. They are almost invariably twinned after the Carlsbad law. Their external forms are not very sharply defined, so that the crystals do not weather out from the rock.

The rest of the rock is composed of quartz and biotite and of a grayish or greenish gray feldspar. Under the microscope this last mentioned feldspar is seen to be composed of an acid plagioclase with considerable additional orthoclase, but no microline. The plagioclase is distinctly the oldest among the light-colored minerals, and is to be seen inclosed in the large flesh-colored orthoclase crystals. Titanite is present very abundantly as an accessory mineral. The minerals of this granite have not undergone crushing to any appreciable extent.

The Montezuma granite would doubtless make a very beautiful building stone, particularly suitable for decorative stones, such as columns, and likewise for monuments. With proper railway facilities provided, a market for the stone ought to be readily found.

Santa Fe Granite.—This granite is so named because it forms the highest point of Santa Fe Peak, and for the further reason that on this peak this rock occurs in well-defined dikes, which method of occurrence, as will be seen later, is a striking peculiarity of this granite as compared with the Montezuma granite. This type of granite was nowhere seen except in contact with the Idaho Springs formation, although it is in places penetrated by porphyry dikes and in one case in Geneva Gulch by an unusually large mass of porphyry. The largest continuous mass is to be seen on the Continental Divide forming the summit of Landslide Peak and extending to the south and to the northwest from that point. This mass measures about three-quarters of a mile in width and twice that distance in length. Another mass of somewhat smaller dimensions on the map, but possibly extending considerably beyond the area surveyed, is to be found in Geneva Gulch.

A very remarkable characteristic of this granite is the tendency to send out into the surrounding schists numerous dike-like apophyses, at times very narrow, even down to a foot or two, at times several hundred feet wide. One such arm extends from the Geneva Gulch stock northwards to a distance of over three thousand feet, with a width of from four hundred to six hundred feet. These apophyses, where long and narrow, are usually parallel in their course with the cleavage of the schist, but this rule is far from universal, for they may break through the schists in most irregular fashion. In some places where the schist and granite come together, the two rocks interlock with long, slender fingers.

Within a distance of about half a mile from the boundary of the larger granite masses with the schists of the Idaho Springs formation, this Santa Fe granite occurs in numerous dikes that, like the narrow apophyses, usually arrange themselves parallel to the schistose cleavage. These dikes are often much too close together to map separately on a map of the scale here used. They may oscillate with the schist every few paces, as is the case along the ridge running southeast from Santa Fe Peak.

No metamorphism of the schists has taken place at contact with this granite. Neither do the schists appear to have produced any effect on the granite, such as is often the case. This last is true not only of the larger bosses, but also of the apophyses and isolated dikes. There is no appreciable diminishing of the size of the grain in the dikes on approaching the contact, nor the slightest tendency towards a porphyritic structure. It is true that upon the whole the texture is not so coarse in the smaller dikes as it is in the larger masses, but it never loses the hypidiomorphic texture characteristic of the plutonic rocks, nor does it approach in appearance any of the numerous porphyries of the district.

The Santa Fe granite is what may be called a normal granite; that is, it contains both biotite and muscovite. The rock is of a grayish color, never reddish or pinkish; although, of course, they may be, and often are, superficially stained with iron oxides, yellow or brown. The grain is very uniform, mostly quite fine, never showing individual grains of feldspar more than one-quarter of an inch long, or thereabouts. The feldspar is all of one uniform whitish or grayish white color. In the coarser grained portions the feldspar is inclined to be tabular. The tablets have Carlsbad twinning and very commonly show a more or less parallel arrangement. In case such a parallel arrangement is to be seen in a narrow dike, the feldspar tablets have their flat sides parallel to the contact lines.

In the hand specimen feldspar is distinctly the most abundant and conspicuous constituent. Quartz is also abundant, and black mica fairly so. The muscovite is sometimes quite inconspicuous, but may always be seen on close examination.

In thin sections the feldspar is seen to consist of microline, orthoclase, an alkaline plagioclase and probably microperthite. Microline is very abundant in some cases, while in others it may be almost wanting. In the fairly coarse-grained rock that forms the summit of Santa Fe Peak, and also on the north slope of Landslide Peak, the large tabular grains with Carlsbad twinning prove to be microline and not orthoclase. The biotite has much sharper forms than is the case with the muscovite, and among the feldspars the microcline appears to be the oldest constituent.

This Santa Fe granite very frequently shows marked crushing of the constituents. This is almost always to be seen on the quartz grains, much less pronounced on the feldspars.

As to age, the Santa Fe granite is clearly younger than the Idaho Springs formation, and older than some of the porphyries. It is more than likely that, as the crushed constituents indicate, it has undergone more or less folding along with the schists since its intrusion into the latter. As this granite does not come into contact with the Montezuma granite, it is impossible to state with certainty their relative ages. However, the absence of crushing in the Montezuma granite would indicate a younger age for it as the intrusion must have taken place after extensive orogenic movements had ceased.

Bear Mountain Granite.—On the summit of Bear Mountain a granite occurs that closely resembles the Santa Fe granite in color, grain and general appearance. Its chief difference lies in the fact that it is a granitite—that is, a biotite granite instead of a biotite-muscovite granite. The feldspars are somewhat larger than in the Santa Fe granite, have a marked parallelism, and consist mainly of microline. This granite is not well developed within the area of the map, occurring only in more or less crushed isolated patches or dikes, that can not always readily be distinguished from granite gneisses. Further west on Bear Mountain this granite has a much greater development.

Effusive Rocks.

Granite Porphyry.—Intimately associated with the Montezuma granite is a rock that occurs in large dikes, or possibly in necks, that measure from one hundred to five hundred feet or more in width and several times these amounts in length. They are to be found either inclosed within the Montezuma granite or at the margin of the same. In the mineral components the rock is identically like the Montezuma granite and in outward appearance it is often difficult to distinguish it from that rock. Outwardly the distinctive feature is the absence of, or scarcity of, the large pink orthoclase crystals, and in general a distinctly finer grain. That these dikes are distinctly effusive rocks and are younger than the granite is definitely settled by the fact that at the margin of each dike there is a gradual transition to a very much finer grained rock which, at the actual contact, may not appear much coarser than many felsitic porphyries. For the above reasons, and also because of certain characteristics of the ground mass as seen under the microscope, this rock has been called a granite porphyry. Inasmuch as it is undoubtedly derived from a similar magma and has the same components and similar appearance, it might perhaps as well be called the Montezuma granite porphyry.

The color of these granite porphyries is a pinkish gray. In the coarser parts the rock can not with certainty be distinguished in the hand specimen alone nor in the thin section from the Montezuma granite. In the finer grained parts the ground mass is pinkish and contains distinct, but never large, phenocrysts of black biotite and of grayish green plagioclase.

Under the microscope the porphyritic structure comes out very clearly in the finer grained portions. The groundmass is very plainly holocrystalline and composed of irregular grains of quartz and orthoclase. The plagioclase phenocrysts are often sharply defined, as are also the biotite crystals. A slight tendency for mutual penetration of quartz and orthoclase in the groundmass, producing what is called micropegmatitic structure, is occasionally to be noted. As is the case with the Montezuma granite microcline and muscovite are missing, and titanite is an abundant accessory mineral.

This rock resists weathering better than does the Montezuma granite, and is therefore frequently to be seen forming a prominent cliff or a mountain summit. The prominent peak called Morgan's Peak, for instance, is composed of this rock in the form of a pronounced dike.

A half mile or so southwest of Morgan's Peak, at the southern edge of the Montezuma granite, occurs one of these granite porphyry masses that is in contact likewise with the schists of the Idaho Springs formation. This mass sends out into the schists numerous dikes of varying size, some only a few feet thick, others a hundred feet or more across. There are also apparently independent dikes of this rock close to this contact that may possibly connect with the main mass below the surface. These small outlying dikes and offshoots are, when small, often very fine grained and resemble closely the rock described below as aplite.

Biotite Aplite.—The term aplite is usually applied to fine-grained muscovite granite occurring in dikes, but the term biotite aplite, as recognized by Rosenbusch, can well be applied to the rocks in question. These rocks occur in large dikes, one of which is not less than one thousand feet wide, in the Montezuma granite. These are gray or pinkish gray, medium to fine-grained rocks, consisting almost entirely of quartz and orthoclase with a very little biotite, and showing no porphyritic structure. Under the microscope the panidiomorphic structure characteristic of these rocks is well developed. Close to the contact the aplite becomes much finer grained and may then develop very beautiful micro-pegmatitic structures through the intergrowth of quartz and orthoclase. Muscovite and microcline are wanting.

There is no doubt a close relationship between the biotite aplite and the granite porphyry. In fact certain portions of the aplite closely resemble the granite porphyry, and transitions between the two rocks are undoubtedly present. The relative age of the two rocks could not be determined, as no case was observed where one cut the other.

Other Aplites.—In different parts of the area surveyed occur dikes, usually quite small, and not infrequently associated with pegmatites, of uniformly fine grain and of white or nearly white color. They consist of quartz, orthoclase and microcline with perhaps plagioclase and muscovite. They have not been studied with sufficient care to justify a more detailed classification, but in some cases, at least, may be considered as normal aplites. They occur frequently in the schists of the Idaho Springs formation and in the gneisses of the hornblende-gneiss series. They also occur cutting the Santa Fe granite. It is not easy to distinguish them from fine grained pegmatites.

Porphyries.—The rocks here designated as porphyries all occur in dikes of greatly varying width and with an almost infinite variety of structure. They are extremely abundant in the Idaho Springs formation, are by no means rare in the hornblende-gneiss series, are occasionally met with in the Santa Fe granite and appear to be entirely lacking in the Montezuma granite. They vary from extremely fine grained felsites to coarse and markedly porphyritic porphyries of the so-called microgranite type. There is undoubtedly considerable variation in the acidity of these porphyries, as is indicated by the varying mineral composition; but none of them are basic rocks as is shown by the presence of comparatively acid plagioclase crystals, and by the universal presence of quartz. The last named mineral does not, to be sure, always occur in recognizable porphyritic individuals, although it is rarely entirely lacking as such. It does, however, invariably occur in the groundmass to a greater or less extent.

Owing to the fact that most of the porphyries have undergone extensive alteration, it is difficult or perhaps quite impossible to determine with great accuracy their mineral composition, and it is therefore difficult to assign variety names to them. They appear to fall under at least three heads that may be provisionally designated as quartz porphyries, syenite porphyries and monzonite porphyries. Structurally they vary from felsites—that is, porphyries with few if any phenocrysts (visible porphyritic crystals) and then very small and inconspicuous, and with a groundmass or body flint-like in texture and composed of minutest fragments of quartz and feldspar—to the so-called micrograuites—that is, to porphyritic rocks with few or many phenocrysts and with a groundmass comparatively coarse and granite-like in texture.

The very fine-grained porphyries and felsites occur naturally in mostly very narrow dikes—ten feet or less—and appear to be invariably greatly altered. In certain sections they are very numerous, so that it is impracticable to map them without greatly enlarging the scale of the map. The felsitic type of porphyry is very abundant on what is generally called Collier Mountain, more particularly in that part of the mountain composed of the schists of the Idaho Springs formation and lying between the Quail, Bullion and Silver Wave mines. The felsitic porphyries are usually of a uniform gray or drab color, but are often bleached to nearly white.

The coarser grained porphyries of the microgranite type are to be found mostly around Webster Pass and between that pass and Landslide Peak, also in various places cutting the hornblende-gneiss series. They are gray to light gray and sometimes grayish pink in color and markedly porphyritic. The dikes are usually quite large. The rock forming the prominent summit immediately west of Webster Pass is apparently of this type, but the alteration here is so great that the original character of the rock cannot be satisfactorily established.

Some of these microgranite porphyries are quite fresh, so that one is enabled to determine the nature of the basic minerals as well as that of the acid ones. These rocks, judging from the fresh samples studied, are quartz-orthoclase-plagioclase-biotite porphyries. In addition to biotite a little hornblende or pyroxene, or both, may at times be seen. The feldspar constituents fluctuate greatly, but the phenocrysts are usually plagioclase. Quartz may almost or quite fail as a phenocryst. The coarser grained varieties show feldspars from a quarter of an inch to half an inch in diameter and biotite crystals one-eighth inch or more across.

The connection of the porphyries with the ore deposits will be commented on under the head of "Economic Geology."

There is no direct evidence within the bounds of the Montezuma district indicating the age of the porphyries, except, of course, that they are younger than the rocks that they cut. In the paper above quoted, Ball considers that the porphyries of the Georgetown Quadrangle are of late Cretaceous age. If he is correct in this, undoubtedly the porphyries in the Montezuma district are of the same age.

Diabase.—In two localities occur a few very sharp narrow dikes of extremely black diabase, that cut through all other rocks. One of these localities is on Bear Mountain at the summit closest to the town, and also a thousand or more feet northeast of this summit. The dikes have absolutely sharp contacts and cut through the hornblende-gneiss series and granite, also probably through porphyry. The second locality is a little southwest of the summit of Santa Fe Peak. Here the diabase is in equally sharply defined dikes that penetrate the schists of the Idaho Springs formation and cut through pegmatite veins, the Santa Fe granite and porphyry.

This rock, consisting originally of augite, plagioclase and magnetite, has had the augite almost completely altered to hornblende with associated epidote and chlorite. The plagioclase remains fairly fresh. It is in the customary thin tablets that appear in thin section as laths. The structure of the rock at the center of the dikes is distinctly ophitic, but at the margin it becomes extremely fine grained and the plagioclase crystals show up as minute but sharply defined phenocrysts.

PEGMATITES.

The name pegmatite is customarily given to the very coarse-grained aggregates that occur in dike or vein form and that consist usually of some kind or kinds of feldspar with quartz and either white or black mica. The mica may perhaps be altogether wanting and locally the relative percentages of feldspar and quartz may greatly fluctuate. They may even pass insensibly into veins of pure quartz. In point of origin they are now generally considered to be deposits in fissures through the instrumentality of water and vapors or gases escaping from intruded granitic or other analogous rocks while in the process of cooling. Such rocks are very often found around the margin of granite masses and especially in connection with the thoroughly crystalline metamorphics at the base of the Archæan series. They are very common indeed throughout the area of the hornblende-gneisses, and to a somewhat less extent in the schists of the Idaho Springs formation.

In the case of the hornblende-gneisses this pegmatitic material is often injected through the rock in a series of branching and interlacing veins and veinlets, and, as mentioned in connection with the description of the gneisses, may appear to merge into the substance of the lighter, feldspathic bands of the gneiss. Again, the pegmatites may be found in dike-like masses fifty or more feet across, and in this case are very coarse grained. In the Montezuma district the pegmatites, as a rule, are very white and do not contain much mica, the feldspathic ingredient is very largely microcline, at times, however, plagioclase, or both together, but not often orthoclase. The coarse-grained intergrowths of feldspar and quartz, called graphic granite, are not common, but the similar structure on a minute scale, as brought out under the microscope, is very common in the finer grained pegmatites.

Pegmatite veins were not observed in the Montezuma granite, but are occasionally found in the Santa Fe granite. They are very frequently met with in the Idaho Springs formation at contact with the dikes of Santa Fe granite, particularly where great disturbance of the rocks is manifest. In such cases the granite seems to be more or less impregnated with pegmatite substance, so as to make it difficult to determine whether the rock is granite or pegmatite. One case of typical pegmatite with muscovite crystals one to two inches across was observed entirely within the Santa Fe granite on Landslide Peak.

Quaternary Geology.

General.—Owing to steepness of all the valleys and to the proximity to the continental divide, no extensive alluvium deposits occur within the area mapped, and inasmuch as all the valleys have been extensively glaciated, no attempt has been made to map alluvium deposits, but all such areas are represented as glacial drift material. In the upper slopes of the mountains above timber-line the surface is often covered with rock detritus that probably has been accumulating from before glacial times. No attempt has been made to map this material but the underlying rock, so far as this could be reasonably determined, has in each case been mapped.

Glacial Geology.—Without doubt the entire area comprised within the bound of the Montezuma map was deeply buried beneath ice and snow during glacial times, and strong glaciers descended all the valleys to some distance below the lowest point on the Snake River, shown on the map. Two main glacial streams, one coming down the Snake River valley and the other following the equally extensive Deer Creek valley, met at the point of Teller Mountain, forming the main glacier of the district. This glacier was joined farther down by a large ice stream from St. John's valley, opposite the town of Montezuma. At this point the glacier filled the entire valley up to a level of over 11,300 feet, or one thousand feet above the town on the east side, while on the Bear Mountain side the ice stream stood at a still higher level, owing to the accession of accessory glacial streams from Bear Mountain. This glacier of the Snake River valley joined itself to a still more formidable glacier that came down Chihuahua Creek from the vicinity of Argentine Pass and Gray's Peak.

This period of maximum extension of the ice is marked on both sides of the valley by a glacial moraine that consists usually of several more or less sharp, hummocky, parallel-running ridges. The material of these moraines consists of partially rounded and sometimes scratched boulders of rocks, such as may be found in each case along the sides of the valley farther up stream, and that may be, therefore, and often are, quite different from the rocks upon which the moraine may lie. As the boulders forming a given moraine are necessarily composed only of rocks found on the same side of the valley higher up stream, it follows that the material of two moraines on opposite sides of a valley may be very different from each other. This is very plainly the case with the lateral moraines on the east and west sides of the Snake River, opposite the town of Montezuma. On the left or west side the material is composed entirely of rocks of the hornblende-gneiss series, while on the east side the morainal material is composed of sillimanite schist with frequent granite and porphyry fragments. Farther down on this side there naturally appears mixed with the aforementioned rocks also blocks of Montezuma granite and aplite. The moraines of the Chihuahua valley, on the contrary, are composed to a very large extent of Montezuma granite, as this rock extends some ways up this valley on both sides.

A second series of morainal ridges is likewise to be seen at an elevation of about 300 feet above the town, or 700 feet lower than those just described. These lower moraines represent the upper limit of the ice stream at a later glacial epoch. Such a moraine is well developed at the 10,600-foot level on the east side of the valley, opposite the Fisherman mine, half a mile below town.

Between these two lines of lateral moraines the valley sides are naturally covered to a greater or less extent with glacial drift, as is also the case with the valley bottoms below the level of the lower moraines, where the material may assume the characteristics of a ground moraine. Higher up the valleys the upper limit of the ice and of the drift naturally rise until they are at or above timber-line.

All this morainal material, whether as distinct moraines or as scattered drift, is mapped as such only in case the underlying rock is so deeply buried that its character can not reasonably be determined.

Landslides.—Three landslides within the district have taken place within comparatively recent times—so recent, in fact, that vegetation has not been able to get a foothold. All three of these occur on or near Landslide Peak. One lies on the north and east slope of this peak on the Geneva Gulch side; another lies on the west slope of the same peak; and the third near the west base of the ridge that extends southerly along the continental divide from Landslide Peak. The first two slides are composed entirely of Santa Fe granite, and the last or most southerly of the three mainly of this same rock. In each case an immense mass of rock has broken bodily away from the very steep mountain side and slid downwards, breaking into smaller fragments as it descended. The material now lies heaped up in a jumbled mass of broken fragments of rock.

CHAPTER II.—ECONOMIC GEOLOGY.

INTRODUCTION.

The Montezuma District lies in the midst of a broad zone, frequently referred to as the "sulphide belt," that runs in a northeast to southwest course, beginning with the mines of Gilpin and of Clear Creek County and continuing past Georgetown and Silver Plume to Breckenridge and Leadville and beyond. In all this belt the ores are characterized by great diversity of mineral contents and by the production of several metals, namely, gold and silver among the precious metals, with lead, zinc and copper furnishing the bulk of the product.

As already stated, the Montezuma District was first worked in the early sixties, but has never been mined on an extensive scale, owing in part, doubtless, to lack of transportation facilities. In the earlier days naturally only the richer pay streaks carrying high values in silver or gold were worked, while the much more extensive low-grade or milling ore was either not mined at all or was left stacked in the stopes to await the time when it could be handled at a profit. In other cases there was thrown over the dumps much ore that should be available for milling purposes.

Within the past two years there has been a healthy revival of interest in the camp, and several extensive development projects have been started that involve the running of tunnels of considerable length, the furnishing of electric power, and the providing of suitable milling facilities.

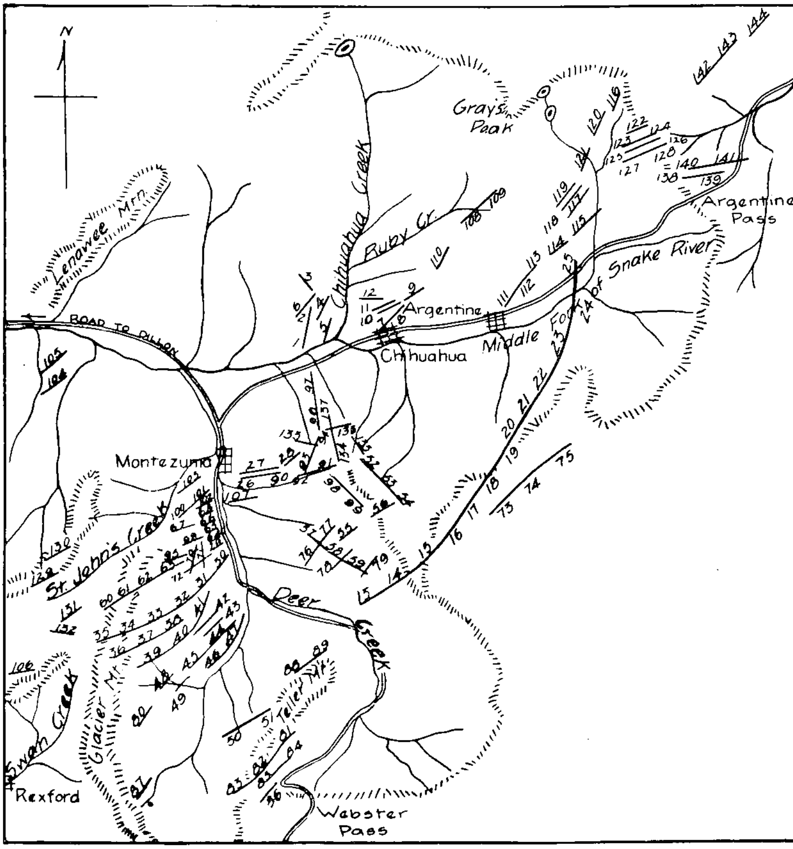
The amount of development work thus far done in the district is not such as to permit a very thorough study of the ore deposits, but sufficient has been accomplished to allow a fairly accurate presentation of the essential features. Owing to the exceptional steepness of the mountain slopes, mining has been done almost entirely through adits, usually run in on the vein. This is also largely true of the prospecting, prospect shafts being very few and insignificant. For this reason no attempt has been made to map prospects unless they are tunnels. Tunnels are represented by a Y, the stem pointing in the direction of the tunnel at the mouth, but not necessarily indicating the direction of the vein. Many small prospect tunnels and probably some important ones, may be missing from the map, as it was impossible in the time available for the survey to locate all tunnels, especially in the heavily wooded portions.

The Vein Systems.

There are two distinct vein systems in this district, one having a general northeast-southwest direction, very strongly marked, running across the entire area mapped and extending well beyond the confines of the map to the region between Gray's Peak and Argentine Pass; the other striking between northeast and north, and mostly confined to the central and northern part of the district. The first system of veins has a more nearly east and west strike in the western part, as, for instance, at the Wild Irishman Mine west of the northern end of Glacier Mountain; while towards the northeast, especially beyond the area mapped, the system changes to a more northerly strike.

Most of the ore bodies occur in this northeast-southwest system, although the other system of veins sometimes has good ore, especially at their junction with the main system, as is illustrated by the Bullion Mine. Some of the veins of the first system are very persistent and have been worked at intervals for several miles. The most pronounced of these is the vein of the Silver Wave Mine on Santa Fe Peak, which is continued as the Silver Cord vein on the east side of the divide, and has been traced to and beyond the Pennsylvania mine near Argentine, beyond the limits of the map. The veins of this system vary in dip from vertical, as at the Silver Wave Mine, to about 45° at the Chautauqua Mine. The direction of dip is generally northwesterly. Most of the dips are very steep.

For the accompanying map, showing the vein systems of the district the survey is indebted to the courtesy of Mr. Etienne A. Ritter, who prepared the map, and to The Engineering and Mining Journal, which published it in connection with a paper on the Montezuma Mining District.



MAP OF MONTEZUMA MINING DISTRICT, SHOWING LOCATION OF MINES.

1 Grand Union, 2 St. Lawrence, 3 Maid of Orleans (Madof Orleanse), 4 Chihuahua, 5 Rosalie, 6 Pella, 7 Bertha, 8 Fifth of July, 9 Grey Eagle, 10 Little Chief, 11 Chicago, 12 Buda, 13 Climax, 14 Lucky Baldwin, 15 Silver Wave, 16 Silver Chord, 17 Mary Ann, 18 Great Republic, 19 Challenger, 20 Sunrise, 21 Delaware Extension, 22 Delaware, 23 Pennsylvania, 24 Pennsylvania Extension, 25 Lone Jack, 26 Waterloo, 27 Old Settler, 28 Surprise, 29 Silver Wing, 30 Eureka, 31 California, 32 Sunburst, 34 Wild Irishman, 35 Silver Prince, 36 Centennial, 37 General Teller, 38 Marxon, 39 Condor, 40 Woodchuck, 41 Walker, 42 Little Emma, 43 Eclipse, 44 Itaska, 45 Scotia, 46 Defiance, 47 Chautauqua, 48 Sampson, 49 Rustler, 50 Radical, 51 Radical, Jr., 52 Carrol, 53 Braganza Extension, 54 Braganza, 55 Atlantic, 56 Sarsfield, 57 Yellow Jacket Extension West, 58 Yellow Jacket, 59 Yellow Jacket Extension, 60 Arctic, 61 New York, 62 Potosi, 63 Tunnel Lode No. 7, 64 Old Timer, 65 Silver King, 66 Moscow, 67 Denver, 68 Celtic, 69 St. Elmo, 70 Tiger, 71 Windsor, 72 St. Coud, 73 Best, 74 Baltic, 75 Revenue, 76 Bullion Extension, 77 Bullion, 78 Aorta, 79 Waukegan, 80 Erie, 81 Champion, 82 Bertha, 83 Cyvert, 84 Cashier, 85 Venus, 86 Silver Medal, 87 Charles Comstock, 88 Red Jacket, 89 Red Jacket Extension, 90 Thunderbolt, 91 Arapahoe, 92 Botts, 93 Tip Top, 94 Monitor, 95 Tunnel Lode No. 5, 97 Ballarat, 98 Rose, 99 Quail, 100 Harrison, 101 Yorkshire, 102 Adder, 103 Fourth of July, 104 Don Pedro, 105 Hunkidori, 106 Erickson, 107 Meteor, 108 Rudolph, 109 Howard, 110 Sylvia, 111 Gold Bug, 112 Rotschild, 113 Rotschild No. 2, 114 Peruvian, 115 National Treasure, 116 Silver Ledge, 117 Minerva, 118 Whale, 119 Silver Falls, 120 Baalbec, 121 Tenth Legion, 122 Rip van Winkle, 123 Little Chief, 124 Little Chief Extension, 125 Lone Star, 126 Lone Star Extension, 127 Queen of the West, 128 Queen of the West Extension, 129 M. & N., 130 Liberty, 131 Marion E., 132 Yankee Doodle, 133 Cross, 134 Florence-Belle, 135 Lelia, 136 Susy, 137 Maggie T., 138 Golden Rule, 139 Simon, 140 Bullion King, 141 Flossie, 142 Santiago No. 9, 143 Santiago, 144 Centennial.

CHARACTER OF THE VEINS.

General.—The veins of this camp are mostly replacement veins; that is, the country rock has been to a greater or less extent mineralized, and the original minerals replaced by the ores and gangue material, by means of circulating water. The ore-bearing water has found its way along fracture lines in the country rock and penetrated the rock on each side of the fissure for a varying distance. In some cases, however, the water, finding an open space, has filled the space with ore, thus forming a true fissure vein. Such veins often show a marked crustified structure. They may vary in width from a fraction of an inch to two or three feet, and are likely to contain high-grade smelting ore. This is the case with the Silver Wave Mine, which shows a streak of smelting ore several feet wide. Usually the "pay streak" is much narrower, perhaps an inch or two, and is to be found sometimes on one side, sometimes on the other, or, again, in the center of a vein. At times more than one such rich streak of ore may occur in the same vein, in which case the two streaks may be of different character, as in the Chautauqua vein, where two three-inch streaks occur, one of galena and the other of zinc blende, separated by several feet of milling ore.

The replacement products are more apt to be ores of a milling grade. Naturally, in a camp without proper transportation or milling facilities, this class of ore has not been extensively worked, and hence little opportunity is given to study such ores. It is impossible to say, therefore, to what extent these ores may exist in the camp. Such a body of ore has been well exposed in the Silver King vein of the Silver Princess Mine, where the vein measures not less than ten or twelve feet in the stope, as now exposed. (See plate No. XIV.) As will be seen from the description of the ore given below, the successful mining of this large body is a question of proper milling treatment.

Nature of Gangue.—The most abundant gangue material is quartz. In the case of the fissure veins this mineral is usually more or less well crystallized, and is to be found lining vug holes and larger fissures. In the replacement products the quartz is apt to make up the great bulk of the rock, although in such cases it may be mixed with other alteration products or with remnants of the original rock minerals. Other gangue minerals usually associated with the quartz, but in greatly varying amounts, are siderite, the carbonate of iron, and barite or heavy spar, as it is more commonly called by the miners, a sulphate of barium. These last two minerals may be entirely wanting or else present in one part of a vein and sparingly present in other parts. Again, one or the other may locally occur nearly pure, as was noted in the case of barite at the Silver Wave Mine.

The siderite occurs in light brown to dark brown, also gray and pinkish. The pink color is probably due to the admixture of some manganese, as is also the fact that this mineral weathers blackish on exposure to the air. It usually occurs in minute crystals that measure from 1-8 to 1-16 of an inch in diameter and shows the form of warped rhombohedrons. In a northeastern extension of the Silver Wing Mine this mineral is disclosed in a test-pit associated with lead and zinc sulphides and occurring in a solid streak five or six inches wide. The mineral is of a deep brown color and is coarsely crystalline, the individual grains measuring half an inch to an inch in diameter.

The barite occurs in thin, milk-white tablets, or in coarse-grained aggregates of the same. It is very apt to occur in streaks of ore rich in galena.

The Metal-Bearing Minerals.—The principal values in this camp have been in the past silver and gold, especially the former, while the bulk of the metals are in the form of lead and zinc with subordinate copper. The silver occurs as ruby silver, brittle silver and native wire silver, the first named being the one characteristic of the district. Silver, likewise, occurs to some extent, replacing lead in the galena, which is more or less argentiferous. Silver and gold have also been produced in connection with bismuth. The gold does not occur in visible form, but in small amounts inclosed in or associated with the sulphides of silver, lead and zinc, and especially of copper.

Lead and zinc, in the form of the minerals galena and sphalerite, are usually intimately mixed together, but they may occur even in the same vein in separate streaks, which may perhaps unite and separate again. Zinc is much the more abundant of the two metals, and large bodies of the zinc sulphide are known to occur as in the Tiger Mine on the north end of Glacier Mountain.

Copper is usually present in comparatively small amounts and invariably in the form of chalcopyrite. It is interesting to note, however, and also encouraging, that in some of the deeper mines, as at the Silver Wave, the chalcopyrite seems to be coming in in much greater amounts.

The milling ore of the Silver King vein, above referred to, is an interesting as well as artistically beautiful ore. Its interest as well as its beauty lies in the association of practically all the more common minerals of the gangue and of the ore proper. It consists of crystallized quartz, barite and pinkish siderite, with which are associated dark, resinous-looking sphalerite, coarse, granular and sometimes crystallized galena, and a small amount of crystallized chalcopyrite.

Mineral Output.—Reliable information as to the mineral output of the camp in the past or as to the average richness of the more prominent veins is not available. This is due to the fact that there was practically no mining done from 1893 to about a year or a year and a half ago, and since mining operations were started only a few carload lots have been shipped to mill or smelter, the ore having been stacked to await the erection of a suitable mill and the construction of a railroad. The following data furnished by Mr. J. R. Roots, resident manager of The Montezuma Mines Development Company, may be of interest as showing the nature of the milling ore of the Silver King mine, referred to above. These are smelter returns on fifteen carload lots shipped in 1892.

	Au	Ag	Pb	Zn
Car 1	0.17	25.8	62.9	3.8
Car 2	0.03	53	45	8.9
Car 3	0.03	54	41	12
Car 4	0.08	46.5	33	..
Car 5	3.80	92	37.8	..
Car 6	0.82	21.5	65	..
Car 7	0.05	38	32	10
Car 8	0.12	14	7.9	6.9
Car 9	0.05	37	25.5	14.7
Car 10	0.04	38	25	15.9
Car 11	0.05	30	21	17.4
Car 12	0.05	34	27	16.9
Car 13	0.05	31	30.5	15
Car 14	0.02	40	40.6	13.7
Car 15	0.04	34	39.5	13.4

Mr. Roots also informs the writer that three cars of ore were shipped from the Sarsfield mine in 1908, from which smelter returns gave an average of $42.30 per ton.

Aside from the data given above, all other available information consists of individual assays and statements made from recollection by old-time miners. These statements, while hardly reliable enough for publication, agree in the fact that the camp produced, in the early days before the fall in the price of silver, much very rich ore.

One authentication of this statement has recently been published by Professor Frank R. Van Horn, in a paper entitled "Occurrence of Proustite and Argentite at the California Mine, near Montezuma, Colorado."* Prof. Van Horn describes some sections of veins recently given to the Case School of Applied Science coming from the above named property. Referring to proustite, he says:

> "In September, 1902, the largest pay streak of the vein widened to about 21 inches and assumed a distinctly banded structure, with galena and sphalerite irregularly mixed on each side; these were followed by siderite, also symmetrical, while in the center was a streak of massive proustite with finely intermingled quartz, which was more or less drusy. This streak was usually about 2 inches wide, but in one instance amounted to 14 inches."

As to the argentite, he says that the specimens vary from 2 to 3 inches in width, and are usually massive and finely granular, but in some cases are quite coarsely granular.

Origin and Geologic Position of the Veins.—The ore bodies have not as yet been developed to a sufficient depth to justify any very sweeping deductions as to the origin of the ores, or as to the probable extent of the deposits. There is a certain amount of oxidation products to be seen in some of the workings, and to some extent, at least, the ore has been leached out close to the surface by descending waters, as is shown by the iron cap of some of the veins. But upon the whole, the effect of descending waters does not appear to be very great, as the sulphides come in most cases either to the surface or close to it. Certainly a secondary sulphide enrichment has not taken place to any great extent. This is particularly marked in the copper ore, which invariably consists of chalcopyrite, never of chalcocite, as would be expected if a secondary enrichment had taken place. It is, of course, possible that such bodies may have once existed only to be planed off by glacial action, and it is more than possible that this is the explanation of the scarcity of oxidation products. It would seem, therefore, that the ores of this camp have been de-

*Bull. Geol. Soc. of Am., Vol. XIX, 1908, pp. 93-98.

posited by rising waters alone, or essentially so, which fact would be very favorable to their continuance to great depth.

Geologic Position and Age of the Veins.—The veins of the Montezuma District are not confined to any one rock formation. They are found in both of the schistose series, in the intrusive porphyries, in the granite porphyries and aplite, and in both the Montezuma and Santa Fe granites. It is undoubtedly true, however, that the ore-bearing veins are much more abundant in the vicinity of the porphyry dikes than where such dikes do not occur or are only occasionally seen. For this reason, perhaps, they are more abundant in the area covered by the schists of the Idaho Springs formation than elsewhere. A vein of ore is very apt to run along beside a porphyry dike, but it does not necessarily occur at the contact nor continue along the direction of the contact, but it may cut across the dike and leave it altogether.

Again, the veins do not have any direct connection with the strike and dip of the schists and gneisses. In fact they seem to be entirely independent of the schist cleavage, as a vein frequently strikes at a very small angle with the strike of the schist or gneiss. Likewise there appears to be no connection with the pegmatite veins except insofar as they may happen to cut one of them. They must be younger than the porphyries, as they cut through them. Their period of formation, then, must be later than that of the youngest of the rocks of the district. If the porphyries are of late Cretaceous age, the period of ore-formation can not have begun until the Tertiary.

The ore bodies lie along lines of extensive rock jointing, and, perhaps, of faulting, and therefore along lines of weakness. It is along these same lines of weakness that the porphyry dikes occur. Possibly this is the only reason for the close connection between the ore veins and the porphyry dikes. There is probably, however, a closer connection than this. It is a well-known fact that most regions where the precious metals abound are also regions of extensive igneous rocks. This is especially true of Colorado and other western mining regions. The waters escaping from great igneous intrusions, or the waters brought in contact with such intrusives, are supposed to bring up the ores from the depths and to deposit them along water courses on the way up. Without entering into a discussion of the different theories that attempt to explain these generally admitted facts, it may suffice to point out that the presumably heated waters that deposited the ores may have derived their heat, and possibly their mineral content, from the granite masses now visible on the surface, but more likely from extensive igneous masses below the surface, but connected with the various dikes of porphyritic rocks.

As stated above, the veins may, to a greater or less extent, be faulted, but if so the faults are strike faults—that is, the direction of slipping is parallel to that of the vein. Cross faults that fault the vein in the ordinary sense, and cause portions of a vein to be disconnected, appear to be altogether wanting in the camp. Miniature slips of a few inches, or perhaps a very few feet, have been noted in the rock formations, but no faults great enough to materially interfere with the following of a vein.

Iron Ore Deposits.

Near the head of the Snake River, and likewise at the head of Geneva Gulch, occur bog-iron ore deposits of some considerable extent. These lie on the surface, being covered only by a few inches, or at most by a very few feet, of soil and vegetation. They are mostly soft and friable, of a light to dark-brown color, and are usually very light and porous. The deposit in Geneva Gulch extends only a little ways into the territory covered by the map, being mostly east of the district surveyed. In the Snake Valley is a long, slender, irregular area, about a mile long, covered by this deposit, and another very small patch a little further up stream. These bog-iron or limonite deposits have not been extensively developed, only a few carloads having been shipped out for use by the smelters as a flux. Test-pits sunk at different points indicate a deposit from two or three feet to eight or ten feet in depth. Exact analyses are not at hand, but the ore is said to be extremely pure. As the covering is very light, they could doubtless be worked at low cost for mining.

These iron ore deposits are clearly of very recent origin. They are in fact still accumulating. The source of the iron oxide is to be sought in the red stain so prominent on the surfaces of the rock fragments that cover the mountain slopes above these deposits. It is this iron oxide stain that causes certain parts of the mountains to assume a brilliant red color. These films of red oxide of iron are attacked by the carbon dioxide of the air and the iron in the form of the carbonate carried down in solution and precipitated in the bogs at the base of the mountain slopes.

THE FOOTHILLS FORMATIONS OF NORTH CENTRAL COLORADO

By JUNIUS HENDERSON

CONTENTS.

THE FOOTHILLS FORMATIONS OF NORTH CENTRAL COLORADO.*

The ages, or stratigraphic positions, of the formations which compose the foothills of North Central Colorado, have long been in doubt. Early explorers, finding few fossils or none in these beds, and hence unable to make exact correlations, gave them tentative names, based upon lithological resemblance to formations found elsewhere whose positions in the geological column were supposed to be known. Later workers in the field continued the use of those names, often without cautioning the reader as to existing doubts, but gradually those doubts became more prominent in the growing and scattered literature of the subject.† Fossils found both north and south of this area in formations supposed to be synchronous made caution in nomenclature desirable until correlation of our formations with those of adjacent areas could be established. Some fossils reported from the northern portion of the field seemed of sufficient importance to suggest the advisability of further work in that region and the tracing of the formations thence southward. Consequently two parties working under the Colorado Geological Survey spent ten days or more in the field in June, 1907, between the Cache la Poudre and the northern boundary of Colorado, and in October of the same year work was resumed at that stream and pushed southward to Boulder.

The results of this work, coupled with that done by others further south, somewhat change the geologic map of Eastern Colorado and definitely determine the age of at least the lowest of the sedimentary formations of the region. The topographic sheets of the United States Geological Survey for Boulder, Niwot, Mt. Olympus, Loveland, Ft. Collins, and Livermore Quadrangles were used as a base map. The last three were not then published, but photographic copies were kindly furnished by the Survey. A considerable portion of the work in Livermore Quadrangle was done by Professor R. D. Crawford, Dr. James Underhill, Mr. G. S. Dodds, and Mr. B. H. Jackson. Mr. H. W. Clatworthy assisted

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*The numbers refer to the bibliography at the end of this paper.

†For discussion of the history of Carboniferous problems in Colorado, in the main correct, see Girty, U. S. Geol. Sur., Prof. Paper No. 16, pp. 97-121.

for several days in Loveland Quadrangle, Mr. S. A. Rohwer in Livermore Quadrangle, and Mr. Albert Dakan accompanied the writer to Perry Park and Manitou Park, where his knowledge of the region and its geologic features greatly expedited the work.

Topography.

The topography from Boulder northward nearly to Bellevue is, on the whole, simple, but more complex and quite different from Bellevue northward. The foothills rise abruptly from the plains into long, high, usually north-south ridges, the persistence of which exposes to view certain horizons for long distances, making it possible to actually trace the strata from the northern boundary of the state far southward without losing sight of the resistant horizons except for a few rods where streams from the mountains have cut through the ridges and covered their valleys with debris. Even the softer strata in the intervening valleys may be traced for considerable distances, though exposures are not as continuous. These ridges and intervening valleys form the dominant features of the foothills landscapes, and bear a well-defined relation to lithology, while their strike bears definite relation to the direction of the dip. The plains slope gently from the base of the foothills eastward into the South Platte valley, which is comparatively shallow, over one hundred miles wide next to the foothills, but masked to a great extent by the minor valleys of its tributaries. Where the streams emerge from the foothills, particularly in the Boulder District, they have cut to some depth into the yielding Cretaceous shales, swinging to and fro as the cutting progressed, and thus forming fine series of terraces, commonly called "mesas."

North of the Cache la Poudre several large folds, with axes running in various directions, have spread out the foothills into a broad and flat area as compared with the Boulder Quadrangle, the topographic sheets clearly showing the difference. The best exposures of the entire series from granite to "Dakota" are east of Box Elder post-office at the Wyoming line, at Owl Canyon north of Bellevue, and a little south of west from Loveland.

Folds and Faults.

The Normal Monocline.—The sedimentary rocks are upturned at varying angles upon the basal slopes of the Rocky Mountains, flattening out as they pass under the plains (Figs. 1 and 2). At Boulder the dips are very strong, and in places the strata are vertical or even overturned, but northward the dip in some places is less than twelve degrees. This monocline is persistent throughout the region, except where it becomes a limb of a syncline, and everywhere any change in the direction of the dip finds instant expression in a change in the direction of the strike of the ridges. Usually the strike is approximately north-south and the dip easterly, but in the Livermore Quadrangle two east-west synclines produce northerly and southerly dips, with approximately east-west strike for many miles in the limbs of the folds which correspond to the normal monocline.

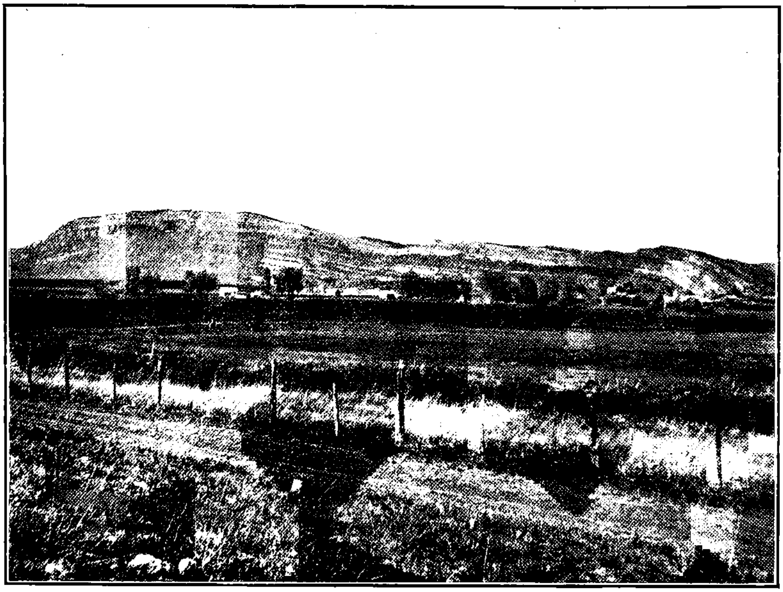
Echelon Folds in the Southern Area.—Nearly all of the folds south of Bellevue are distinctly echelon and result in throwing the foothills several miles to the eastward north of Boulder. The most important of these folds are at Arkins (northwest of Loveland), Carter Lake (west of Berthoud) and Rabbit Mountain (northeast of Lyons). There are some smaller ones of the same type. In the west limb the dip is almost invariably much stronger than in the east limb, but not in the east member of the double fold at Rabbit Mountain, where we find the east limb with much stronger dip. The Rabbit Mountain and Arkins folds form a prominent headland projecting into the plains for some distance. The latter is the larger, and the anticline has been eroded so as to expose the quartz-schist core in the form of a high mountain flanked by the remnants of the sedimentaries. At the northern end of this fold are two faults of importance; one, if not both, with a throw of hundreds of feet, and strike west of north.

The Carter Lake fold is rather complex, especially to the northwest, but affords a beautiful example of a narrow north-south anticline standing out as a long hill with steep sides, its apex eroded away and a deep valley excavated along the longitudinal axis, cutting well into the Fountain.

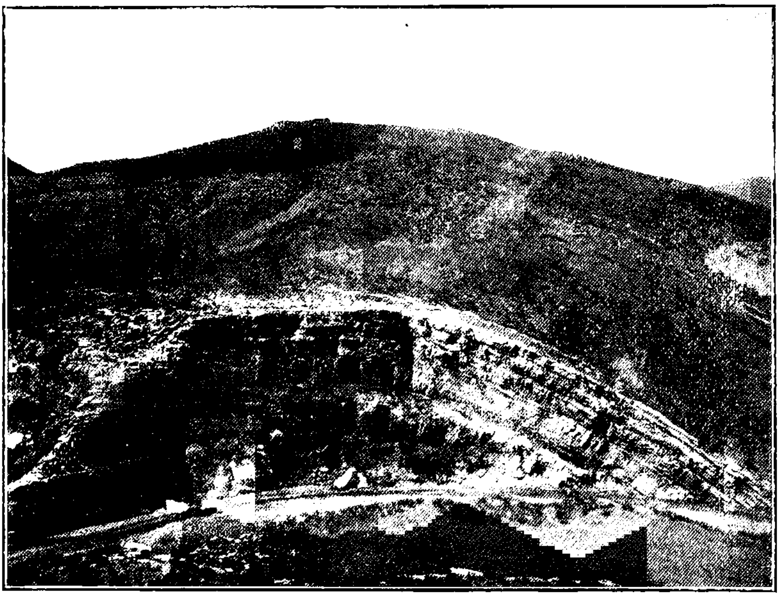
Folds of the Northern Area.—The Bellevue fold, west of Ft. Collins, is a dome. The Cache la Poudre has cut through the overlying formations deep into the Fountain, leaving the east limb of the fold exposed in a fine cliff.

North of the Cache la Poudre the Livermore and Red Mountain synclines extend far back into the mountains. The anticlines which connected the two, and also connected them with the normal monocline to the north and south, have been eroded away, leaving the granitic cores exposed. In the western part of the Red Mountain syncline denudation has been carried to such an extent that even the lower Fountain is represented only by rem-

PLATE XVI.



Bellevue fold, looking north of east, with the village at south end of fold. Lyons formation at the top of cliff, Fountain at the base.



Sand Creek fold, looking south. The cliff is the Lyons formation, with a little Fountain at the base, and the Lykins sloping upward from the top of the cliff to the top of the hill.

nants, so that we have now exposed virtually the original sea-bottom upon which the sedimentaries were deposited, somewhat dissected by recent erosion.

Southeast of Box Elder post-office, a short distance south of the Wyoming line, is the Sand Creek fold, a very fine, narrow anticline, forming an elongated hill, its longitudinal axis about north by east. As in case of the folds in the southern area, the dip of the west limb is much greater than that of the east limb. Sand Creek cuts directly through the anticline very nearly at right angles with the longer axis, cutting through the Lykins and Lyons and into the Fountain. The syncline to the west is a valley occupied by the Lykins. This vicinity affords perhaps the best place in the region to study the entire series from the granite to the "Dakota."

There are numerous minor folds and faults. All of the folds of any importance announce themselves before the traveler reaches them by changes in the strike of the dominant ridges, except the Sand Creek anticline. The folds are shown in detail in the accompanying maps, from which a better idea may be obtained than from any possible description.

The uniformity in the direction of the dip in the normal monocline through thousands of feet of strata from the granite to the upper part of the Cretaceous, with the almost total absence of discovered unconformity, indicates a very long period of deposition upon a somewhat uniformly subsiding sea bottom.

STRATIGRAPHY.

The succession of formations in the region, as now understood, is as follows:

Cenozoic	Quaternary—Alluvium and terrace gravels.		
	Tertiary—Miocene	Arikaree sandstone.	
		Brule clay	
Mesozoic	Cretaceous	Laramie	
		Montana	Fox Hills
			Pierre
		Colorado	Niobrara
			Benton
		"Dakota" (?) (Probably partly Comanche)	
	Jurassic	Morrison	
		Sundance	
	Triassic (?)—Lykins (in part)		
Palæozoic	Permian (?)—Lykins (in part)		
	Carboniferous	Pennsylvanian	Lyons
			Fountain
		Mississippian	
Proterozoic	Algonkian		
	Archean		

The formations designated Fountain, Lyons, Lykins, and Morrison, have usually been grouped together under the name Jura-Trias, or "Red Beds," the latter referring to their dominant color, but the Fountain of this region is now known and the Lyons confidently believed to be Pennsylvanian.

These formations vary somewhat and are not always separated by sharp lines, owing to the fact that it was apparently a long period of continuous deposition, but in a general way they may be readily distinguished on both lithologic and topographic grounds.

PRE-CARBONIFEROUS.

Archean.—The sedimentaries usually rest upon a floor of eroded and often much weathered granite and gneiss forming part of the granite-gneiss complex of the Front Range. In the vicinity of Box Elder the granite has a decided tendency to develop toad-stool forms in weathering. That the erosion of these Archean rocks has furnished most of the material for the deposition of the "Red Beds" is manifest.

Algonkian.—From South Boulder Canyon southward and southwestward to Coal and Ralston Creeks, a distance of about twelve miles, is found a very ancient quartzite. It has not been carefully studied as yet, and its exact boundaries have not been defined except at the contact with the Fountain formation from South Boulder to Coal Creek. It has been briefly noted by Marvine (35, p. 139), Fenneman (13, p. 21), and Van Hise (37, p. 325), but apparently only the northern end was examined by the two latter. Toward Coal Creek it is in contact with the Fountain.

This quartzite is mostly white, in some places coarsely conglomeratic, exhibiting both true bedding and cross-bedding planes and plainly showing that it consists of metamorphosed sandstones and conglomerates. In places thin strata have developed into beautiful quartz schist, while occasional small lenses are very little altered and closely resemble portions of the Fountain. The dip is quite uniformly southeast, but varies in angle from 28° to 90°. The dip of the overlying Carboniferous and Mesozoic formations is nearly east and about 28°. Clearly the quartzites were somewhat tilted and then planed off before the Carboniferous beds were laid upon the upturned quartzite edges. Furthermore, the direction of the shore lines of the more ancient period were probably quite different from those which prevailed from the Carboniferous to the final retreat of the sea at the close of the Cretaceous.

West of Loveland and Berthoud is another large area of quartzite and quartz-mica schists, long ago noted by Marvine (35, p. 140). It is much more schistose than that at Coal Creek and South Boulder, with interpolated granite masses which increase in importance to the westward. In a general way, the dip of these schists is to the northeast and the angle is very high, while the overlying formations dip to the east at a lower angle, affording another fine example of unconformity where the actual contact is exposed, though the dip of the older formation is quite different from that at Coal Creek.

Carboniferous.

Fountain Formation—Pennsylvanian.—This formation consists chiefly of variegated conglomerates and sandstones, with occasional bands of limestone in some places, all resting upon a granite-gneiss floor except where the quartzites and schists intervene. It is mostly red and pink, but with white patches, streaks and spots, perhaps resulting from unequal original distribution and subsequent leaching out of iron oxides which furnish most of the coloring matter of the Red Beds. At a little distance the white so tones the red as to give the whole formation a uniform pinkish color, sharply contrasting with the purer red of the overlying Lyons formation from Lefthand northward.

Eldridge (12, p. 53) has noted that in the Denver Basin the conglomerates are usually loosely agglomerated, but in some places are hard and compact and difficult to distinguish from the granite, from the debris of which they are formed. The same is true of those beds in the region north of the Denver Basin. At Boulder the conglomerates are quite resistant, forming the second ridge or series of "hog-backs," including the well-known "Flat Irons" back of the Chautauqua grounds. There the Lyons, instead of crowning the ridge, as it does further north, rests some distance down its east slope, and the valley, instead of cutting into the Fountain, as it does further north, cuts into the granite or the granite-Fountain contact. (Compare Figs. 1 and 2.) The Fountain conglomerates being quite friable north of the Denver Basin, their erosion uniformly forms a valley back of the Lyons escarpment, and, in fact, is chiefly responsible for the existence of the escarpment. In the Ft. Collins and Loveland Quadrangles and northern part of Boulder Quadrangle the Fountain forms the base and usually the Lyons the top of the escarpment, the cliff being produced by the undermining of the more resistant

Lyons formation, while the more gentle east slope follows approximately the dip. In Livermore Quadrangle the Pennsylvanian limestones, which are assigned partly to the upper Fountain and partly to the Lyons formation, and do not extend south of the Cache la Poudre, often form the crest of the escarpment, with the upper Lyons well down on its east slope. On Left-hand Creek and at some other places we find a compromise, the upper Fountain being non-resistant, with a resultant valley, while

PLATE XVII.

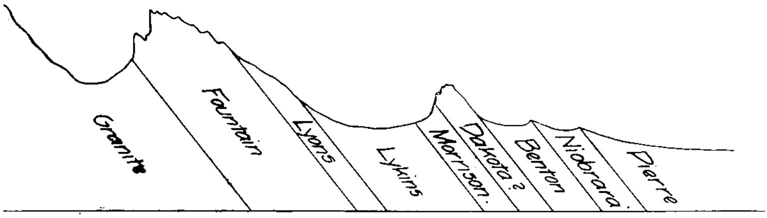


Fig. 24. Generalized section at Boulder.

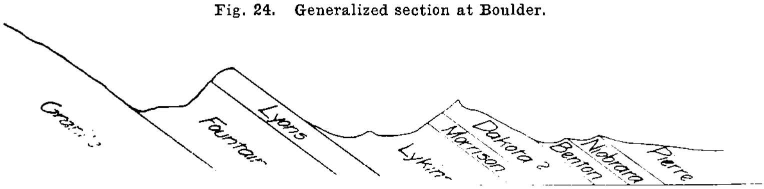


Fig. 25. Generalized section in Northern Larimer county.

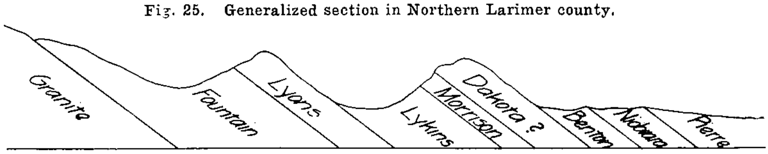


Fig. 26. Generalized section at Left-Hand Creek.

the lower Fountain is resistant and extends well up the granite slope of the mountains, as shown in Fig. 3. Possibly the lower beds in such places represent an earlier period of deposition, or at least the earlier filling in of the troughs of the eroded granite surface when subsidence of the sea-bed began and before it had progressed sufficiently for general deposition to commence, the strata overlapping and advancing shoreward with continued subsidence. Emmons (12, pp. 18-19) suggested that the basal deposits where these conglomerates and sandstones are thickest might be Carboniferous, equivalent to the Fountain; but the upper portions and the overlying Lyons are now considered Upper Carboniferous and equivalent to the Fountain, which leads to a strong suspicion that the lower deposits in such places may be Lower Carboniferous, a suspicion emphasized by the finding of

Lower Carboniferous fossils at the base of the conglomerate, only 400 or 500 feet below the Lyons formation in Livermore Quadrangle. The conglomerate was deposited upon an eroded granite surface, and, therefore, as the shore began to subside, deposition would first commence in the troughs of the uneven surface, which would be first invaded by the encroaching sea. Consequently, the formation varies from a few hundred to many hundred feet in thickness. The planing of the original relief by shoreline erosion as the sea advanced in the Boulder District and Denver Basin has been discussed by Fenneman (14, pp. 205-214; see, also, Crosby 2, p. 144), the discussion applying with equal force, however, to the entire region from Denver to the Wyoming line. The actual contact of the basal conglomerate and granite is usually concealed by debris from the west slope of the contact valley, but when it can be seen it often shows the uneven surface. At Red Mountain, north of Livermore, the sedimentaries, including most of the Fountain, have been stripped from the granite by erosion for a width of three miles, leaving thin remnants scattered over a plain slightly dissected by recent erosion, but clearly exhibiting a portion of the original sea-bottom upon which the conglomerates were laid. The condition of the feldspar in the arkose portions of the conglomerate indicates deposition at a rate approximating the disintegration of the granite of the adjacent shore, and doubtless the upward building of the formation and the subsidence were about equal. In Livermore and Fort Collins Quadrangles, much of the conglomerate is calcareous, effervescing freely in dilute hydrochloric acid, but further south it is much less so, or not at all.

In the Boulder District and Denver Basin no fossils have been found in the Fountain and Lyons formations and none northward in Colorado except in northern Larimer County, where brachiopods of Paleozoic type are uniformly found. Emmons and Eldridge, in the Denver Basin Monograph, placed the Fountain, Lyons, and Lykins formations together in the Triassic system, under the name Wyoming* subdividing it into Upper Wyoming (= Lykins) and Lower Wyoming (= Lyons + Fountain). Fenneman, in his Boulder Bulletin, gave to the Upper Wyoming the local name Lykins and subdivided Lower Wyoming into two members, correlating the basal conglomerates with the Fountain formation of Whitman Cross (4) and calling the over-

*This must not be confused with the Wyoming conglomerate of the Fortieth Parallel Survey, which is Tertiary or Quaternary.

lying "Creamy Sandstone" the Lyons. He still retained all three in the Triassic system, but with a query and footnote (p. 20), quoting Darton (per Eldridge) to the effect that Lower Wyoming is of Pennsylvanian age. Girty (17, pp. 101, 107, 109, 110) fails to distinguish between Upper and Lower Wyoming, and supposes that the Fountain is entirely below the Wyoming, for which supposition the reason does not appear. The Denver Monograph and Boulder Bulletin touch only the southern portion of the area now under discussion, where no fossils have been found to aid in ascertaining the age of these formations. There seems no doubt about the Fountain as recognized by Fenneman at Boulder being the same as the conglomerates underlying the Lyons and resting upon granite and quartz-schist from Boulder to the north line of the state, as I have followed the formation the entire distance and found it everywhere fairly exposed. Consequently, if Dr. Fenneman's correlation of the Boulder District conglomerates with the Fountain is correct, as it appears to be, then all of the conglomerates below the Lyons in the area now under discussion are Fountain. Darton, who was familiar with the Fountain in the region from which it was first described, also considers our conglomerates Fountain.

White (39, p. 176) found no fossils in these formations at Spring Canyon, southwest of Fort Collins, or at Box Elder, near the Wyoming line (though we now know two fossil horizons at the latter place), but in a later paper (40, p. 134) he reports the following species from northwest of Bellevue: *Retzia woosteri* (=*Eumetria woosteri*), *Spirifer rockymontanus*, *Spiriferina octoplicata*, *Spirigera subtilita*, *Hemipronites crenistria* (=*Orthothetes crenistria*), *Axophyllum rudis* (= *A. rude*) and an undetermined gasteropod, all discovered by Mr. L. C. Wooster. He quotes Mr. Wooster thus:

> "They were obtained from some pebbles in a conglomerate resting upon the eroded face of the granite, 32 miles west and 18 miles north of Greeley, Colorado. A portion of the pebbles of this conglomerate was evidently derived from the granite upon which it rests."
> Dr. White then adds:
> "He found no Carboniferous strata *in situ* in that region, but it is evident that the 'pebbles' which contain the fossils here noticed have not been transported to any considerable distance from the ledges from which they were derived."

This implies that he considered the "pebbles" transported remnants of an older formation, a matter discussed further on, here only pausing to say that it would be interesting to know just what those "pebbles" were, as it is not impossible that they were chert concretions formed *in situ*, instead of being pebbles from older formations.

The same material, which was in very poor condition for identification, has been re-examined by Girty (17, pp. 226-227), who assigns the fossils to the Mississippian stage (Lower Carboniferous), and identifies the species as follows: *Zaphrentis* sp., *Orthothetes inaequalis*, *Spirifer centronatus*, *Spirifer* sp., *Seminula humilis?*, *Eumetria woosteri*, and *Pleurotomaria? sp.*

Cannon (1 pp. 224-234) has described the occurrence of Carboniferous fossils in loose chert boulders widely scattered along the plains adjoining the foothills of the Front Range in the Denver Basin, which I have examined, and which appear to be identical with those at Perry Park and perhaps came from that region originally. They are of the same character as those found near Box Elder, hereinafter described.

Darton (8, pp. 80-82) has the following to say of the Northern Colorado foothills:

> "The Fountain, or Lower Wyoming, extends for many miles along the Front Range, lying directly on the irregular surface of the crystalline rocks for the greater part of its course. * * * The Upper Carboniferous limestone, which is found in the northern portion of the Front range near the Wyoming state line and in the Culebra Range, appears to merge into the Fountain red beds, which I believe are precisely equivalent to the Lower Wyoming of Eldridge and the Badito formation of Hills, and represent the Amsden formation and overlying Tensleep sandstone of the Bighorn Range and the Minnelusa of the Black Hills. The gray sandstone which generally marks the summit of the lower red beds appears to be the same as the Tensleep sandstone of the Bighorns and the sandstone which usually occurs at the same horizon (Upper Minnelusa) in the Black Hills. Upon this sandstone there lies the principal upper series of red beds, the Upper Wyoming of Eldridge, a formation clearly separable in the Front Range zone in Central and Northern Colorado. This series has been found to contain, near its base, a persistent and characteristic layer

of limestone, usually very thin in Colorado, which separates a thin series of fine-grained red beds below from a thick overlying mass of fine-grained gypsiferous beds above, presenting precisely the succession of Opeche and Spearfish red beds with intervening Minnekahta limestone found in the Black Hills and Eastern Wyoming. This sequence is clear at La Porte, Lyons, Boulder, Morrison, Perry Park, and the Garden of the Gods, in Colorado; but, approaching the Arkansas River, the region of the typical Fountain formation, this upper gypsiferous series appears to thin and end. * * * In Box Elder Valley, in the foothills of the Rocky Mountains, at the Wyoming state line, there are exposures of limestones containing Pennsylvanian fossils, overlain by fine-grained gypsiferous red beds of the Chugwater formation, which in turn are capped uniformly by the Sundance formation, or marine Jurassic. These upper red beds continue far to the south, but the Pennsylvanian limestone rapidly gives place to coarse sandstones, mainly of red color, which extend for many miles south as the basal member of the sedimentary series. These coarse beds are always separated from the Chugwater formation by a sandstone which overlies the Pennsylvanian limestone in Wyoming, where I have designated it the Tensleep sandstone. This sandstone is mostly a fine-grained, regularly bedded rock from 50 to 200 feet thick, varying in color from gray to red. I believe it to be an important horizon marker. The most northern exposures that I examined in Colorado were in Owl Canyon, which is a small branch of the Cache la Poudre drainage that is followed by the old main road from Denver to Laramie."

To avoid confusion, it will be noticed that he first refers to the Tensleep as a gray sandstone, but later explains that it varies in color from gray to red. Throughout most of the region under discussion this sandstone is a uniform red, though sometimes pink or gray, and is believed to be the exact equivalent of Fenneman's Lyons sandstone. The region from Owl Canyon to the Wyoming line, which was missed by Darton, has been covered with some care by the Colorado Geological Survey, and his statement that the Upper Carboniferous limestone "appears to merge into the Fountain red beds," and that it "rapidly gives place to coarse sandstones, mainly of red color, which extend for many miles south as the basal member of the sedimentary series," is certainly misleading. This series of limestones is everywhere underlaid by a considerable thickness of conglomerates and sandstones, so that the stratigraphic equivalent of the limestones in passing southward would be the top of the Fountain and the overlying Lyons sandstone, a matter more fully discussed under the Lyons formation.

The present survey, starting about two miles beyond the Wyoming line, found for a distance of eight miles southward into Colorado, uniformly within a few feet of the base of the conglomerates, chert nodules (28, pp. 491-492), varying from two inches to a foot in diameter, containing fossils assigned by Girty (MSS.) to the Mississippian stage (Lower Carboniferous)—"the same fauna which occurs on the east side of the Front Range at Canyon City and elsewhere"—and identified by him as *Spirifer centronatus, Cranaena subelliptica* var. *hardingensis* and *Spiriferina solidirostris.* The important facts connected with them are: (a) Their uniform occurrence at the same horizon for such a distance. (b) The approximate uniformity in thickness of the conglomerates, sandstones, and limestones overlying this horizon and underlying the Lyons sandstone. (c) The lack of a discovered break in the continuity of deposition of the conglomerates. (d) The nodules have the appearance of formation *in situ*, enclose coarse sand and gravel, and are in a matrix composed of granite debris, but could not themselves have been derived from the granite with recognizable fossils embedded in them. (e) We found nowhere underlying this horizon anything but conglomerate of the same character and the granite or gneiss base, except at one point just south of the Wyoming line, where we found a thin calcareous sandstone, which was either just above or just below the chert. (f) The failure of a thorough search along the line of contact of the granite and conglomerate to reveal any older formation from which they could possibly have been derived, the certainty that these nodules embedded in material much less coarse could not have been transported any great distance, the fact that they are not water-worn, and the probability that any older formations are deeply covered by overlap of the conglomerate.

The conclusion seems inevitable that the brachiopods, whose fossil remains are contained in the chert nodules, were living when the basal strata of the conglomerates in that vicinity were being deposited, and hence that the lower part of the Fountain there is either Mississippian or very early Pennsylvanian. The same is likely true of the more southerly locality from which the Wooster fossils came. At Perry Park we found a fauna in part the same in a cherty limestone about 50 or 60 feet above the granite, and overlaid apparently conformably, by coarse sandstones and conglomerates which appear to be equivalent to the Fountain, the relations being about the same as at Box Elder. The apparent conformity of these formations was noted also by Lee (34, p. 97; see, also, Girty 17, pp. 169, 170, 187, 209, 217), but other known facts raise a doubt as to its reality. As the whole conglomerate, sandstone, and limestone series of the region up to the Lyons formation is not thicker in the Box Elder Valley than the coarse sandstone and conglomerate usually are from Denver to the Cache la Poudre, and at Perry Park, it might be fairly, though not necessarily, inferred that the base of the Fountain from Denver northward is everywhere as old as the Mississippian stage, and that the base of the thicker portions may be even older.

On the other hand, however, Finlay (15, pp, 586-589) has reported a sandstone which he calls the Gleneyrie, of Pennsylvanian age, beneath the Fountain formation at Manitou, the following statements being extracted from his paper:

> "The Paleozoic section to the east of Pike's Peak, Colorado, in the Manitou region, is composed of four members, as follows: (1) A basal Cambrian sandstone; (2) a limestone series, the lower half of which is Ordovician (the age of the upper half is still in doubt); (3) a fossil-bearing sandstone of Pennsylvanian age; and (4) the Fountain formation, arkose sandstones, grits and conglomerates, the lower members of which are almost certainly of Pennsylvanian age, while the upper members may in the end be definitely correlated with the Permian and Triassic. The purpose of the writer is to describe the sandstone member (3) in the series as given above. It has not previously been described. It contains the only identifiable plant remains of Pennsylvanian age which have been found thus far in the Rocky Mountain region. These fossils make possible its safe correlation with the Upper Carboniferous of the East. The Fountain beds appearing in the section next above cannot, therefore, be older than the

Pennsylvanian, and the occurrence in them of brachiopods which have been recently found, points to their being of Pennsylvanian age. * * * The formation is below the unconformity at the base of the Fountain. * * * A collection of these fossils was made and forwarded to Dr. David White, of the United States Geological Survey. *Lepidodendron obovatum* and *Lepidodendron aculeatum* were identified by him. Dr. White has pointed out to the writer that these species indicate a horizon equivalent to the Pottsville of Pennsylvania. The Fountain formation next above in the series, resting on the Gleneyrie sandstone and separated from it by an unconformity with overlap, has a thickness of over a thousand feet. * * * Fossils from the Fountain are extremely rare, and only two genera, brachiopods, have been found in the Manitou region. * * * Dr. G. H. Girty has kindly examined the specimens and referred them tentatively to *Orbiculoidea manhattanensis*. With them a single productoid shell, resembling *Marginifera ingrata*, has been collected, but the specimen is not sufficiently good for identification. *Orbiculoidea manhattanensis* has a wider range than the Carboniferous, but its occurrence at this horizon points strongly to the Pennsylvanian age of the Fountain beds near Manitou."

The existence of an upper Pennsylvanian flora beneath the Fountain and 1,000 feet or more below the top of it at Gleneyrie, and the occurrence of a Mississippian fauna at the base of the Fountain and within 500 feet of the top of it in the Box Elder Valley, is an inconsistency to be cleared up by future work. Among the possibilities may be mentioned: (a) That the correlation of a fauna with a flora whose Rocky Mountain history is but little known may be misleading and dangerous, as the flora may have been accelerated in this region or the fauna retarded, though there is but little basis for this suggestion. (b) The possibility of an undiscovered period of erosion or non-deposition following the Mississippian stage at Box Elder, which would account for the Mississippian conglomerate in such close stratigraphic relation to the Pennsylvanian limestones. The fact that the base of the Fountain is mostly covered in the Box Elder region, with outcrops small and scattered, makes the question of conformity difficult to solve. With our present knowledge it is impossible to make an exact correlation of the thin stratum of Mississippian at the base of the sedimentaries in northern Larimer County with anything yet found between the Cache la Poudre

PLATE XVIII.

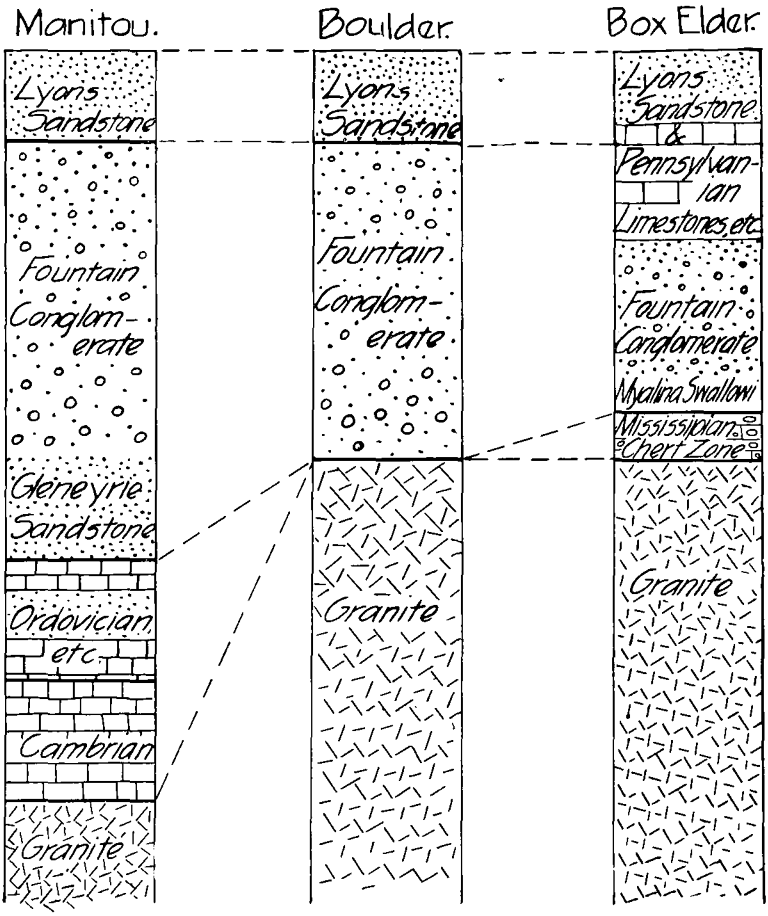


Fig. 27. Generalized geologic columns from granite to Lyons sandstone at Box Elder, Boulder and Manitou.

and the South Platte, though the material itself strongly suggests the Mississippian at Perry Park, a little south of the Platte.

When we come to the upper part of the conglomerate series the case is much more simple, for its upper limit is marked from Box Elder to Denver by the base of Fenneman's Lyons sandstone (=Darton's Tensleep and Eldridge's "Creamy sandstone"). Darton (10, pp. 10, 37) and Cross and Howe (5, p. 491) have recognized what is apparently the same sandstone as the upper limit of the Fountain at Manitou and Glencyrie, and I have found it at Perry Park, southwest of Denver. This sandstone has been traced from the Wyoming line to South Boulder Peak by the present Survey, and through the Denver Basin by Emmons and Eldridge, and forms a very definite horizon.

In and immediately below the Lyons in the Livermore Quadrangle is a series of limestone bands varying in thickness up to 25 feet or more, which pinch out in the Cache la Poudre Valley. They contain a fauna which we have submitted to Dr. G. H. Girty, of the United States Geological Survey, who says (MSS.) they are "Pennsylvanian, but I believe rather old Pennsylvanian, older at least than Knight's 'Permian' from the Red Beds of Wyoming. This is tentative, however." He identifies the species as follows: *Derbya* n. sp., *Productus cora*, *Productus nebraskensis*, *Spirifer rockymontanus*, *Squamularia perplexa*, *Ambocoelia* sp., *Nautilus* sp., *Phillipsia* aff. *major* and undetermined crinoid stems. The limestones in which these fossils were found contain numerous fragments of crinoid stems, and occur on the face of the escarpment. A little of the Fountain conglomerate is found in places overlying and between these limestone bands, clearly indicating that the lower beds belong with the upper Fountain rather than with the Lyons. The Fountain conglomerates in the Box Elder region are mostly calcareous. In a lower horizon, but a few feet above the Mississippian just north of Box Elder Creek, we found *Myalina swallowi*, which is also considered Pennsylvanian. The conclusion is safe that at least the greater part of the Fountain is Pennsylvanian.

On the whole the Fountain is quite variable. In many places, as at Owl Canyon, besides limestone bands, there are also thin-bedded, fine-grained sandstones, particularly in the upper half, much resembling the Lyons sandstones of that region, but farther south in passing upward to the Lyons the conglomerates finally cease so abruptly and so entirely, with a marked change of color when seen at a little distance, that it is usually not difficult to find the dividing line between the two formations. As would be expected in coarse material deposited in somewhat tumultuous water, these conglomerates in places show considerable cutting and filling. The rather abrupt change in the character of materials from Fountain to Lyons over such a long shore line is very interesting.

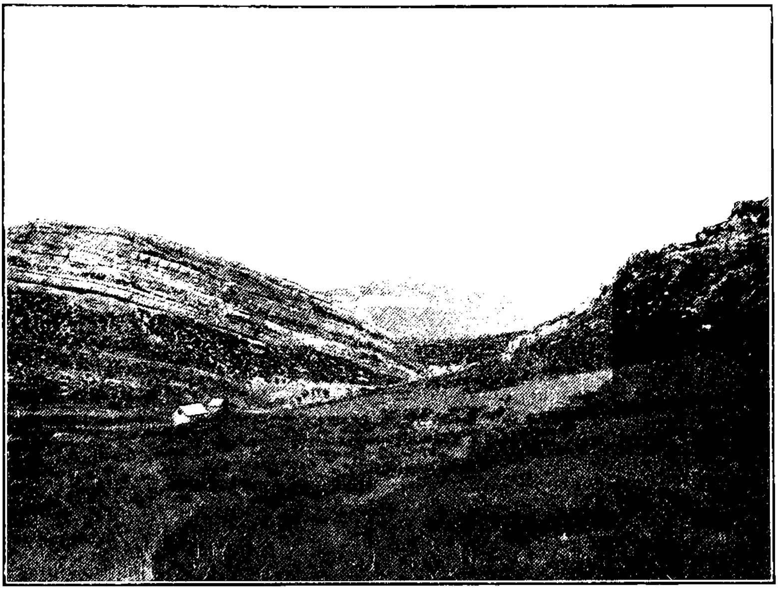
Lyons Formation.—Overlying the Fountain conglomerates and limestones and apparently conformable therewith, is a fine-grained, regularly bedded sandstone, varying in color, hardness, and thickness of bedding, but usually unmistakable in its demarcation from the underlying Fountain and overlying Lykins, so as to form an important horizon marker all along the foothills of the east side of the range. It was designated the Lyons formation by Fenneman (13, p. 23) in the Boulder District, the Creamy sandstone by Emmons (12, p. 19) in the Denver Basin, and the Tensleep sandstone by Darton (8, p. 81; 10, p. 10) in the Owl Canyon region. It has also been recognized in the Manitou-Gleneyrie region by Darton (10, p. 37) and Cross and Howe (5, p. 491) and by the present survey at Perry Park. As noted under the Fountain formation, the Lyons usually forms the crest of a west-facing escarpment, the Fountain exposed beneath it in the steep west slope, the Lykins covering the foot of the more gentle east slope or occasionally extending well up toward the crest. According to Darton (8, pp. 80, 82, 84) it is 50 feet thick at Owl Canyon, Larimer County, 80 feet thick at Lyons, Boulder County, and in general from 50 to 200 feet thick, but at Owl Canyon he included only the upper part. At Fourmile Canyon, north of Boulder, it is at least 300 feet thick, according to Fenneman.

At Boulder and at some other places this sandstone is very hard. At Stout, Larimer County, it is massive, yielding huge blocks of building stone. In many places the cross-bedding is remarkable, reaching a maximum angle of 35°. At Lefthand it is rather thin-bedded, the cross-bedding very regular and strong.

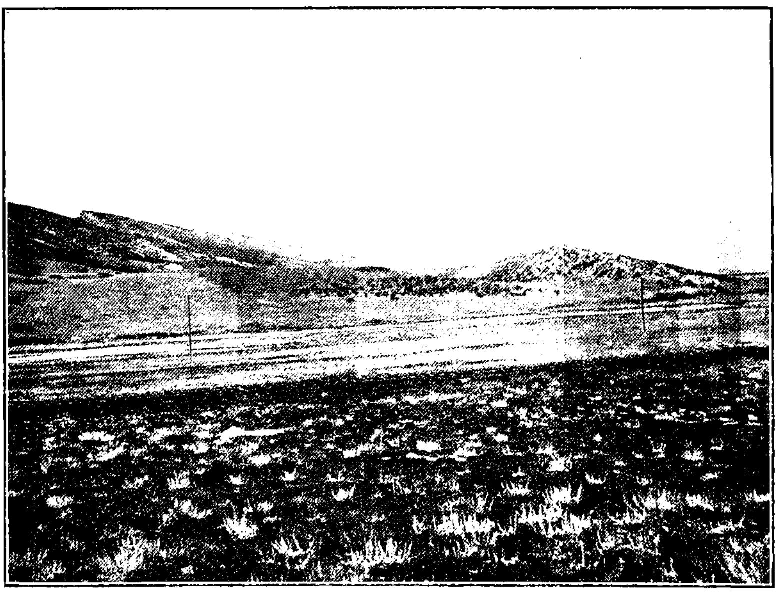
Lithologically thin local beds at some horizons in the Fountain closely resemble the Lyons, but they afford no difficulty, as the thickness, position, uniformity, and topographic importance of the Lyons, and the fact that it may be traced from Wyoming to Colorado Springs almost without losing sight of it, render its recognition easy.

As noted under the Fountain formation, Darton excludes the Pennsylvanian limestones from the Lyons formation at Owl Canyon, and says they pass into the Fountain. This is apparently erroneous. From Boulder to the Cache la Poudre these two formations are sharply differentiated, and neither contains any important limestones. At Owl Canyon, about seven miles north of the Cache la Poudre, strong limestones are found which are underlaid by Fountain and overlaid by Lyons, these limestones

PLATE XIX.



Looking east through Owl Canyon. The ridge in the foreground is crowned by Pennsylvanian limestones, with Fountain conglomerates at the base.



Ridge making, cross-bedded sandstone in the lower part of the Lykins formation, south of Owl Canyon, looking north, with Carboniferous limestone ridge on the left, and Dakota-Morrison escarpment showing dimly on the extreme right.

continuing thence sixteen miles northward to the state line and far beyond. Intercalated with the lower limestones at Owl Canyon are beds indistinguishable from the Fountain, while with the upper limestones are sandstones like the Lyons. The next to the top limestone is the best horizon for brachiopods, other beds containing many crinoid fragments, which also extend well down into the Fountain. The species of brachiopods are mentioned under the Fountain formation, and as there noted are Pennsylvanian and tentatively considered rather early Pennsylvanian. Tracing the escarpment southward for six miles the limestones practically disappear, bringing the Lyons-like sandstones together in the upper part and the Fountain-like beds together in the lower part, the Fountain and Lyons becoming sharply differentiated and continuing thus in their extension southward. The upper limestones appear to pass very definitely into the Lyons. Hence the Lyons as well as all or nearly all of the Fountain must be considered Upper Carboniferous of the Pennsylvanian stage.

PERMO-TRIASSIC?

Lykins Formation.—Conformably overlying the Lyons is a series of variegated, mostly thin-bedded sandstones and shales, rather friable, chiefly deep red in color, with thin limestone bands, the upper part usually gypsiferous. In the Boulder District Fenneman (13, p. 24) named these beds the Lykins formation. It is the exact equivalent of the Upper Wyoming of Emmons (12, p. 20) in the Denver Basin and the Chugwater of Darton (8, pp. 84, 87) in Northern Colorado. In the Denver Basin monograph it is given a thickness of 485-585 feet, Fenneman makes it 800 feet in Four-mile Canyon, north of Boulder, and Darton gives it a thickness of 380 feet at Lyons and 520 feet at Owl Canyon. Though it varies greatly in thickness and in stratigraphic details, its general characters are constant throughout the region. As a whole the formation is non-resistant, the greater part being concealed by the debris in the lateral north-south valleys caused by its destruction.

From Owl Canyon to Little Thompson I have mapped as part of the Lykins a more resistant sandstone, strongly cross-bedded, which forms a ridge in the valley and which sometimes extends nearly to the top of the east slope of the Lyons escarpment. It is difficult to distinguish from the Lyons sandstone and should perhaps be assigned to that formation, but is uniformly separated from the latter everywhere north of the Little

Thompson by strata lithologically resembling the Lykins. In approaching Little Thompson Canyon these intervening beds rapidly play out, bringing the sandstone which is mapped as Lykins into contact with the Lyons and making the former the crest of the escarpment, almost covering the latter. (See Fig.

PLATE XX.

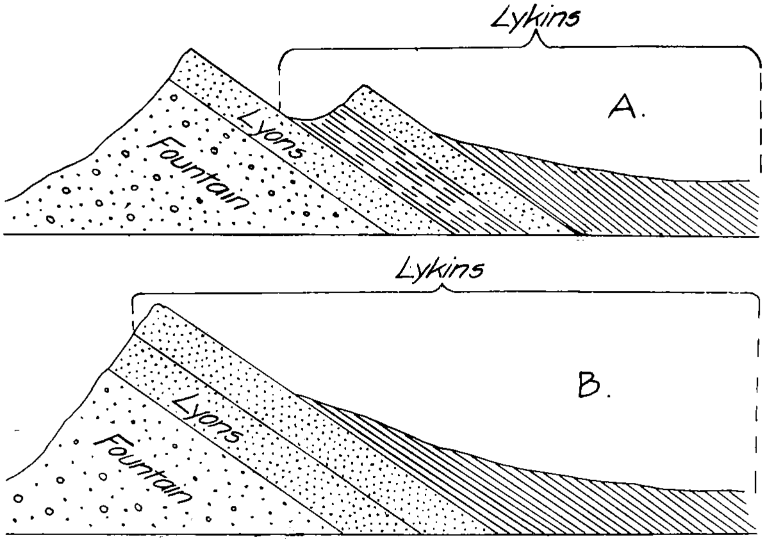


Fig. 28. A. East-West section, showing ridge of cross-bedded sandstone in the Lykins formation west of Fort Collins. B, showing apparently the same sandstone crowning the Lyons escarpment north of the Little Thompson.

28.) Thence southward it is doubtful if the two sandstones can be recognized as distinct formations, and nowhere have I found a noticeable unconformity. As the two sandstones after coalescing form an almost vertical escarpment, if they are distinct it is practically impossible to represent the Lyons on the map, yet northward they are quite distinct. The one which is mapped as Lykins in the northern region passes beneath the "Crinkled" sandstone of Fenneman's report, which is but a few feet above the Lyons just north of Boulder. This problem is worthy of further investigation.

In some places certain strata of the Lykins are very massive, though soft, and portions of the formation are locally calcareous, in addition to distinct thin limestone bands.

In the absence of paleontological evidence this formation has been usually assigned to Triassic-Jurassic age. It seems quite likely, however, that the base of the Lykins may represent

Permian time, as the immediately underlying Lyons is upper Carboniferous. The upper part of the Lykins is probably Triassic or Jurassic, as it is overlaid by known Jurassic in Northern Colorado, though it is possible that part of the Jurassic and Triassic is represented by the general unconformity between the Lykins and the Morrison. (8, p. 81.) At Chaquaqua Creek, Las Animas County, Darton collected from the upper layers of the Red Beds, beneath the Morrison, "a bone that has been identified as Belodon, indicating Triassic age" (36, p. 663; 5, p. 493). Williston (41, pp. 338-350; see, also, Hay 20, pp. 294-300) says *Hallopus victor*, from red sandstone near Canyon City, indicates upper Triassic. The beds from which these fossils were obtained are probably equivalent to upper Lykins. Girty (17, pp. 101-102) has shown that Darton's alleged Permian fossils from Morrison are too doubtful to be considered.

JURASSIC.

Sundance Marine Beds.—The problem of marine Jurassic in the Northern Colorado foothills is in a very unsatisfactory condition. Emmons (12, p. 21) says that the Jurassic sea was shut out from the Rocky Mountains of Colorado; yet Professor George and his party, in 1907, collected *Belemnites densus* and *Pseudomonotis curta*, marine Jurassic species, at Hahn's Peak, Routt County, from beds occupying a position similar to that of the North Central Colorado Jurassic with reference to the so-called "Dakota," and we have specimens also from near Meeker collected by Professor F. H. Hopkins. Darton (8, p. 96) says: "The Sundance formation extends only a few miles into Colorado from the northward, finally thinning out." Then in his Owl Canyon section, at page 82 of the same work, he places above the Chugwater a series of shale and sandstone "with Jurassic fossils." It is unfortunate that we are not informed more definitely about these fossils and the data upon which he bases his statement concerning the thinning out of the Sundance. On page 81 he indicates that he made no examination north of Owl Canyon, and in his next section, northwest of La Porte, he rests Morrison beds directly upon the Chugwater (= Lykins). Hayden (21, p. 119) found "*Ostrea* and fragments of *Pentacrinus asteriscus* on Box Elder Creek in yellow sandstones and clays." As the Jurassic cliffs follow Box Elder Valley for several miles, the exact locality of this discovery is unknown, and we have failed to find any fossils in the vicinity except a fresh-water gasteropod (*Valvata scabrida* M. & H.) found by Professor Crawford in the Morrison limestone. While the yellow sandstone does not appear south of the Cache la Poudre, so far as color is concerned, it is doubtful if the color is of importance, and the sandstone may be represented by a very similar sandstone which has not the yellowish tinge. A comparison of the entire Jurassic section at Box Elder Creek, where the marine and fresh-water formations are admittedly both represented, with that south of west from Loveland, thirty miles south of Box Elder Creek, impresses one with their similarity in thickness and more important general characters, though differing somewhat in minor details.

It seems to be the general opinion of geologists who have worked in the region that marine Jurassic does not exist in the Denver Basin and thence southward, but the question of the manner and place of its disappearance needs further investigation, in view of the fact that determinative fossils have been found in but few localities and not throughout the supposed Jurassic strata.

The northern marine beds are said by Darton to be separated from the Lykins by an unconformity, just as is the Morrison formation further south. (9, p. 82.)

Morrison Formation.—This formation in the Denver Basin has been described by Emmons and Eldridge (12, pp. 22, 60) as 200 feet of marls, sandstones, and thin limestones, more arenaceous above, essentially a formation of fresh-water marls, limited above by the "Dakota" sandstone and below by the brown or pink Lykins sandstone. The section at Lyons is given by Darton (8, p. 97) as 245 feet of greenish, gray, red, maroon, and buff shales and sandstone, while north of La Porte limestones are reported by the same author. At Boulder, as noted by Fenneman (13, p. 26), the formation as a whole is much lighter in color than the Lykins, and "a very much generalized section would present the beds in the following order, beginning at the base: Sandstones, clays, limestones, clays." The limestones in some places, as at South Boulder, are 30 to 40 feet thick. The present writer has found those compact limestones between the upper Morrison shales and the Lykins sandstones at all good exposures from the St. Vrain to Wyoming. The basal sandstone is almost pure white at some places near Boulder, as is the sandstone occupying a similar position just above the pink upper Lykins at Box Elder, which latter is supposed to be below the marine Jurassic.

Stanton (36, p. 657) says the Morrison in the foothills of the Front Range and similar beds in Wyoming, Montana and Western Colorado are all non-marine. Emmons (12, p. 21) also mentions the non-marine character of the Morrison in the Denver Basin. The *Inoceramus* which Darton (10, p. 22) says was found at Garden Park was not found in place, and was probably from Comanche strata, as Dr. Stanton says (MSS.) that he has found what appears to be the same species in the latter horizon within a quarter of a mile of where Hatcher's specimen was found. There is no basis for Darton's inference.

A widespread, gentle, uniform orographic movement seems to have occurred just prior to the deposition of these beds, resulting in an unconformity at their base which is usually difficult to detect and finds expression in difference in strike, rather than in dip (12, p. 22; 8, p. 82; 10, p. 21).

The Morrison has usually, though not always, been referred to Jurassic age because of the reptilian fauna, and has been called the "Atlantosaurus Beds." Recently Darton (8, pp. 34, 50, 58, 66; 10, p. 21; see, also, Hovey 31, pp. 216-223; 12, p. 23) announced that the Morrison is Cretaceous and the probable equivalent of the Comanche. Lee (33, pp. 343-352) suggested the same connection. Stanton (36, p. 667) has shown, however, that the Morrison passes beneath the Comanche. The latter writer, while leaving the age of the Morrison an open question, says that the "Dakota formation is more closely connected with the Comanche series than is the Morrison" (*Science*, XXII, p. 756), and that in the northern area the Morrison rests on the Sundance, which is not considered the latest Jurassic. (36, p. 669.) The most that can be definitely said is that the Morrison is either upper Jurassic or lower Cretaceous, and more likely the former than the latter.

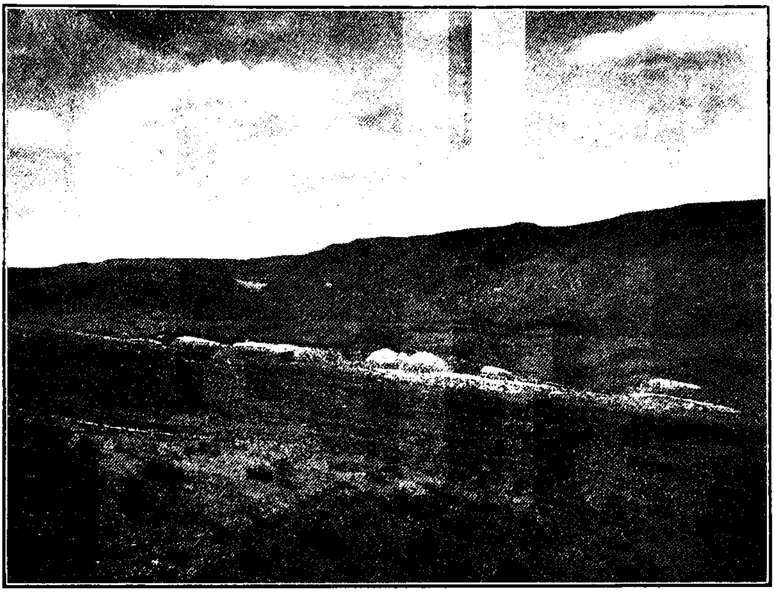
The Morrison is usually found in the west face of the "Dakota" escarpment, much of it being covered with talus, which renders it a hard formation to thoroughly study.

CRETACEOUS.

Comanche Formation.—This formation is discussed under the next.

"Dakota" Formation.—This formation rests upon the Morrison, in some places probably unconformably, according to Dar-

PLATE XXI.



Gypsum beds in the Lykins formation, southeast of Box Elder postoffice, looking northeast.

Valley in shales, between the upper and lower "Dakota" sandstone, at Owl Canyon, looking northeast. Fossils on the inner slope of the right hand ridge.

ton, who also reports (8, p. 99), that "north of Beulah for several miles the Dakota sandstone lies directly on the Fountain formation, but probably the Morrison beds formerly covered the region and were removed by pre-Dakota erosion." He recognized a general, though unimportant unconformity at the top of the Morrison throughout Eastern Colorado and Wyoming (36, p. 658). A fine exposure made by a canal excavation on the north side of the Cache la Poudre reveals the contact of this formation with the upper Morrison. The latter there consists of fine, structureless blue clay, passing abruptly into the basal "Dakota" conglomerate, which rests on an uneven bed of the clay. The abrupt change all along the foothills from fine clay to coarse conglomerate itself suggests an unconformity. An upper sandstone and lower sandstone separated by shales "strongly suggest the 'Dakota' sandstone, Fuson clay, and Lakota sandstone of the Black Hills," according to Darton, but this suggested correlation is doubtful. The upper sandstone member is often, though not always, a very hard, fine-grained sandstone, and the base of the lower member is usually a hard conglomerate. The formation, as a whole, generally makes a strong ridge or so-called first hogback in the region under discussion. This ridge is the most easterly line of foothills, forming a sharp line separating the Great Plains from the mountains. It often divides into two, or even three, minor ridges or benches.

Taken together, these three members, which are remarkably uniform throughout Eastern Colorado, have, until within a few years, been considered together as fresh-water strata under the name "Dakota," the supposition being that the time equivalent of the Comanche had not been discovered or was missing. Recently the discovery of marine fossils of Comanche age in the medial shale member near Two Buttes in Prowers County, and on Purgatory River, twenty miles south of La Junta, by Darton (9, p. 120) and Lee (33, p. 343) has modified the former views on that subject. They thought that these fossils occurred in the Morrison, but Stanton (36, p. 662) has shown that view to be incorrect. He reports that the Morrison dinosaurs are 200 feet below the Comanche fossils, and that the upper sandstone of the so-called "Dakota," where it passes under the Benton at the latter locality, contains a true "Dakota" flora and is separated from the underlying Comanche by an unconformity. The Comanche formation is also reported at Canon City by Stanton. Eldridge (12, p. 64) says that no marine fossils have been found in the Dakota of the Denver Basin. In the sense in which he used the term Dakota, that was also true for the region north of the Denver Basin until recently, but Dr. Stanton and this writer have now found *Inoceramus*, *Ostrea*, etc., at almost every good exposure of the medial shales from five miles north of Boulder to Owl Canyon in Northern Larimer County, though they are not determinative.

The uniformity of the tripartite character of the formation along the foothills of the Front Range and the discovery of Comanche fossils in the medial member at Canyon City and elsewhere southward, strongly suggest that at least part of the medial shales and the lower sandstone member in the Boulder District and northward may be the time equivalent of the Comanche. The fossils of the northern area are usually in very poor condition. At various places in the middle and upper portions of the shales are found large numbers of *Ostrea* of one or more species, apparently undescribed, with a smaller number of *Inoceramus* indistinguishable from *I. labiatus* Schl., a species which is very abundant in the middle and upper Benton overlying the "Dakota" throughout the region. At Owl Canyon and west of Berthoud I have found several specimens of *Avicula* closely related to *A. linguiformis* E. and S., a species said by Meek to range "through the Fort Pierre and Fox Hills Groups" in the upper Missouri region, credited to the upper Fox Hills in the Denver Basin Monograph, and not found lower than the Hygiene sandstone member of the Pierre in Northern Colorado, so that without perfect specimens one may well hesitate about considering our Owl Canyon and Berthoud specimens identical with *linguiformis*.

A very fine exposure made by an irrigation canal a little south of west from Loveland, shows the usual sandstone at the base resting upon Morrison clays. The upper part of this sandstone includes layers of black and brown shales and all the upper part contains numerous fossil plant fragments, unidentifiable. Above the sandstone lies about 150 feet of shales and shaly sandstones. These shales are black below, but above the lower third thin beds of brownish sandstone begin to come in, becoming more abundant upward, until toward the top the shales disappear and the shaly sandstones pass gradually into the upper sandstone member, at the base of which again occur plant fragments. At about the middle of the shales occur the usual oysters and *Inoceramus*, with some fish bones. About a mile south of there two teeth, identified by Dr. J. W. Gidley, of the United States Geological Survey, as probably a species of plesiosaur, were found associated with similar fish vertebræ.

Colorado Group. { *Benton Formation* / *Niobrara Formation* }

Benton Formation.—This formation is remarkably constant throughout the region bordering the foothills of Eastern Colorado. It rests upon the upper "Dakota" sandstone, and throughout most of the region occurs at the very edge of the plains. The formation consists chiefly of black shales and thin-bedded black limestones, with a few hard bands of bluish or grayish limestone from a few inches to a foot in thickness, in the upper half. In the lower half are several strata an inch or two in thickness, composed mostly of the poorly preserved shells of an undescribed species of oyster. Large quantities have been broken out at several places in the effort to obtain specimens showing specific characters sufficiently well for description, without success. In the limestones of the upper half *Inoceramus labiatus* is found in abundance, associated with an undetermined oyster and several species of cephalopod. This formation is almost invariably capped by a sandstone or sandy shale reminding one of the Pugnellus sandstone to the southwest, but we have found in it no organic remains except casts of supposed worm borings and seaweeds. In a general way, the lower shales, the medial shales containing hard limestones, and the upper sandy shales with their immediately underlying black shales, seem to be the respective equivalents of the Graneros shale, Greenhorn limestone and Carlile shale and sandstone of the Pueblo Quadrangle (19, p. 564; 18; 29; 30). Good exposures occur five miles north of Boulder and west of Berthoud.

Niobrara Formation.—In the reports and maps of the Fortieth Parallel Survey, this name is also applied to the Tertiary formations of Northern Colorado. The Niobrara appears to rest conformably upon the Benton. At the base is a hard, massive, compact, fine-grained limestone, in appearance much resembling the *Inoceramus labiatus* bands in the upper Benton, but thicker-bedded, not separated by shales and containing great numbers of *Inoceramus deformis*, a large, very convex bivalve with prominent concentric undulations, quite unlike the smaller, flatter, less strongly undulating species of the Benton. This shell is often covered with *Ostrea congesta,* a small oyster which forms a flat base and then turns abruptly upward. Near the center of the formation is found a lime-shale zone composed of *Ostrea congesta* attached to large, flat *Inoceramus* whose specific identity can not be made out. This horizon is persistent from Boulder to Owl Canyon. The upper part of the formation consists of yellowish sandy shales, somewhat more resistant than the overlying Pierre shales and much lighter in color. Most of the way from Little Thompson to Owl Canyon this horizon forms a steep east-facing yellowish slope, the angle of the slope being approximately the same as the dip of the strata. In the Arkansas Valley the lower Niobrara has been called the Timpas and the upper part the Apishapa (18, pp. 566-7; 29; 30; 16). If the same divisions are to be applied in the northern field, the dividing line would probably be at the top of the *Ostrea congesta* horizon.

The Benton and Niobrara are often grouped together under the name "Colorado formation," but as they are entirely distinct in the region under discussion, it seems best to treat them separately. As with the foothills formations, their east-west horizontal limits are narrow, seldom occupying more than half a mile in width. The several members of the Niobrara have a tendency to form two or three low, north-south ridges, the more persistent and prominent of which is the basal limestone. The best exposures we have found in Northern Colorado are five miles north of Boulder, at Little Thompson, and at Owl Canyon. The basal limestone may be found almost anywhere along the foothill line, especially at the mouths of foothill gulches.

Montana Group.	*Pierre Formation*
	Fox Hills Formation

Pierre and Fox Hills formations, often considered together under the name of Montana Group, but more often separated as a matter of convenience, conformably overlie the Niobrara and consist of 7,000 or 8,000 feet of marine strata, chiefly clay shales, sandstones and irregular lenses of limestones, the limestones being confined to the Pierre. The Fox Hills formation, comprising a few hundred feet of the upper part, is mostly a series of rather soft sandstones, usually of a greenish yellow color in contrast with the slate-colored Pierre strata. The dividing line is rather uncertain, and the line of contact is seldom well exposed. The Fox Hills marks the beginning of the final retreat of the sea.

The Pierre consists mostly of clay shales, with a thick and persistent sandstone called the Hygiene at about the top of the lower third (13, p. 31; 26, p. 179). While many of the fossils are common to both groups, yet each has a characteristic fauna. *Baculites* spp., *Scaphites nodosus*, *Heteroceras* spp., *Ptychoceras* spp., *Placenticeras whitfieldi*, *Lucina occidentalis*, *Inoceramus* spp., *Nautilus dekayi*, *Anchura* spp., *Anisomyon* spp., *Anomia raetiformis*, *Ostrea inornata*, and others are somewhat common in the middle and lower Pierre, but seldom or never found in the Fox Hills of Northern Colorado, while *Cylichna* sp., *Dentalium gracile*, *Mactra warrenana*, *M. alta*, *Nucula* spp., and *Veniella humilis*, though common in the Fox Hills, are rare in or absent from the Pierre except the upper 100 feet or so (23, pp. 99-104; 24, pp. 149-152; 26, pp. 184-192).

*Laramie Formation.**—This formation, consisting of sand stones and shales and containing the coal beds of Northern Colorado, east of the mountains, marks the close of Cretaceous deposition and the final retreat of the sea from the region. The faunas of the Colorado and Montana Groups are strictly marine. The Laramie faunas, on the other hand, are of brackish-water and fresh-water types, and indicate a period of low-lying shores and marshes. Some of the lower sandstones are locally difficult to distinguish from the upper Fox Hills, but when seen in large masses at a little distance, they generally have a somewhat lighter color than the Fox Hills, and usually the Fox Hills yields marine fossils such as *Cardium*, *Mactra*, *Dentalium*, *Nucula*, etc., which will not be found in the Laramie. Although two Laramie species, *Ostrea glabra* and *Melania wyomingensis*, are frequently found in Fox Hills strata, they need mislead no one, as in such cases they are associated with marine species.

TERTIARY.

The Tertiary formations which once probably covered the region up to the foothill line, have been cut away throughout most of the area under discussion by the streams which have aided the South Platte in carving its broad valley (25, pp. 251-252), leaving portions, however, abutting on the foothills near the Wyoming line, and from Golden southward.

*As to the name, see Veatch, Journ. Geol., Vol. XV, pages 526-549; Cross, Science, Vol. XXVIII, 1908, page 128.

QUATERNARY.

Coarse, usually unconsolidated gravels, including boulders of considerable size, cover the mesas, which were formed by the streams cutting into the Cretaceous shales as they leave the mountain gulches. These gravels have been deposited by the wandering of the streams in their downward cutting. The only fossil I have seen from them is a single water-worn mammoth tooth found on Lover's Hill at Boulder. In places these deposits are consolidated by a calcareous cement.

ERUPTIVE ROCKS.

During the progress of the present work nothing has been done with the dikes and other intrusive bodies of eruptive rocks which are found in the foothills from Boulder to Lyons.

The Valmont dike has been the subject of study by Hayden, Cross, Diller and Fenneman, and the latter has also mapped and reported upon most of the intrusive bodies of the foothills.* The important body indicated southeast of Lyons on the map accompanying the present report does not appear to have been reported before, and limited time and adverse conditions of weather have prevented detailed examination. Superficially it appeared to be of the same general nature as the others along the foothills which have been studied by Dr. Fenneman. No intrusives were noted in the sedimentaries north of the St. Vrain Valley.

ECONOMIC GEOLOGY.

A brief summary of the economic products of the formations hereinbefore discussed may be useful.

Gypsum.—A thick bed of gypsum occurs in the Lykins formation in the Livermore Quadrangle. It is well exposed at Owl Canyon, and on Sand Creek east of Box Elder post-office. It occurs in the same way and at the same horizon at Perry Park, southwest of Denver.

Limestone.—The limestones of the Lykins, Morrison and Niobrara formations have been burned for lime for local use all along the foothills. The basal limestone of the Niobrara has been most used. The Pennsylvanian limestones are now being extensively quarried at Engleside, just south of Owl Canyon, for use in the sugar factories of Northern Colorado, to which the

*F. V. Hayden, 7th Ann. Rept. for 1873, p. 29. Whitman Cross, U. S. Geol. Sur., Mon. XXVII, pp. 297-302. J. S. Diller, U. S. Geol. Sur., Bull. No. 150, pp. 261-264. N. M. Fenneman, U. S. Geol. Sur., Bull. No. 265, pp. 36-40.

material is transported by a short branch railroad connecting with the Colorado and Southern at Ft. Collins.

Clay.—Fire clay is found in the "Dakota" and Laramie. The former has been used extensively at Golden. West of Ft. Collins clay from the lower Benton shales has been used for brick making, but the workings are now abandoned. Three large brick plants at Boulder are using middle Pierre clay and one at Trilby, south of Ft. Collins, gets its supply from the base of the Pierre, the kilns of the latter being located at the railroad some distance from the clay bank.

Building Stone.—At Boulder, and in a few other places, the "Dakota" sandstones have been used to a very limited extent locally, mostly for foundation purposes. At Boulder and Lyons very extensive quarries have been operated for many years in the Lyons sandstone, furnishing employment to a large number of men. The stone is very hard and does not weather easily. From Bellevue to Stout and at Arkins are large quarries in the Lykins sandstone, and at the former locality the Lyons is also quarried. Locally the Fox Hills, Laramie, and Hygiene sandstones have been used to some extent for ranch buildings. At Boulder and in some other places the water-worn boulders which occur all along the edge of the plains are rapidly coming into use for ornamental retaining walls, foundations and other purposes.

Artesian Water.—The "Dakota" sandstone, which is important for artesian water in the Arkansas Valley, is too deeply buried from Denver northward to be available. The Hygiene, Fox Hills and Laramie sandstones may furnish good water supplies in many places, but have not yet been much exploited. An understanding of their positions and characteristics is also important in order to avoid seepage in irrigation projects.

Petroleum.—The oils of the Boulder and Florence districts are found in the Pierre formation. There is no reason to doubt that systematic exploration will develop other important districts in the same formation along the edge of the plains from Florence to northern Larimer County.

Coal.—The coal of Northern Colorado east of the mountains is found in the Laramie formation.

Historical Geology.

Briefly stated, the geological history of the region, so far as it is disclosed by the evidence, is as follows:

In what is considered pre-Cambrian time, deposition of sandstones and conglomerates was in progress, but the distribution of land and water and direction of shore-lines were quite different from the conditions which prevailed from Carboniferous to the end of Cretaceous time. How long the pre-Cambrian conditions continued we can not ascertain, as the evidence is partly destroyed and partly covered by later deposits. Between pre-Cambrian and Carboniferous time the pre-Cambrian deposits were partly removed by erosion and partly metamorphosed into quartzite, quartz schist, etc., the remnants now exposed were elevated, tilted, complexly folded into the granite and the resulting mountains planed off. At or prior to the beginning of Carboniferous time, an approximately north-south shore-line was established corresponding in a general way to the present axis of the foothills, with the land area to the west of that line and the sea to the east, and a long period of subsidence began. The planing of the land area brought down and deposited along the shelving shore great quantities of coarse sand and gravel which built up the sea bottom about as rapidly as subsidence proceeded, thus preventing the existence of deep water for a long distance off shore. Meantime the subsidence caused the sea to constantly encroach upon the land, so that the newer strata kept overlapping the older.

At the beginning of Lyons time, the character of the materials depositing changed to fine sand. Subsidence and deposition continued through Lykins time, probably with deeper water. During Morrison and perhaps part of "Dakota" time the sea was apparently shut out from the region by some barrier, as indicated by fresh-water beds; but subsidence must have continued, as the medial "Dakota" shales contain marine fossils and overlie the Morrison in such a way as to show that the sea then reached a much higher level with reference to the adjacent land. During Benton, Niobrara, and Pierre time, the indications are that the sea in the region now represented by the edge of the plains reached a greater depth than theretofore. How far the shoreline had then retreated westward we have now no way of knowing, as the formations have been planed off the mountains, but it is inconceivable that it could be less than several miles.

There was probably a distinct shallowing of the sea toward middle Pierre time, and again in early Fox Hills time as the retreat of the sea began. Though we have direct evidence of the overlap of strata caused by the encroachment of the sea during

Carboniferous time, we have no such evidence of the reverse process toward the close of Cretaceous time, because these formations have been planed back a long ways from their original edge. During Laramie time brackish-water and fresh-water conditions prevailed, with low-lying shores and marshes.

This long and almost unbroken period of subsidence is quite remarkable, and at its close the earliest deposits, originally laid at about sea level, had doubtless sunk to the depth of 10,000 feet below sea level, for we find overlying those earliest deposits about 10,000 feet of strata, nearly all of which were deposited in the sea.

At the close of Laramie time occurred a period of general erosion, represented by an unconformity.

During Tertiary time, thick deposits were formed by streams and probably in small lakes, and the uplift of the entire region, accompanied by differential uplift of the mountain region, brought the mountain plateau into existence, tilted the foothills formations into their present attitude, and raised the edge of the plains to an altitude of about a mile above sea level. That this was the result of the tilting of the entire region and not merely the retreat of the sea into deepening basins, seems a necessary conclusion from the evidence. With the gradual uplift of the mountains began the cutting of the deep gorges which have transformed the original plateau into a series of approximately east-west canyons and corresponding divides or ridges. So strongly is the idea of sudden upheaval in the construction of our mountains entrenched in the public mind that it is difficult to get rid of, but it seems quite certain that they were brought into their present condition by being slowly elevated from sea level, and just as slowly carved into gulches and ridges by the very streams now at work. The streams have also cut away the Tertiary deposits from Golden nearly to Wyoming, and cut deeply into the edges of the Cretaceous formations, while at the same time denuding the mountains of the unmetamorphosed sedimentary rocks which at one time surely covered them for a distance of several miles back from the foothills line. This process is still going on, perhaps as rapidly as ever, and it is not at all certain that the process of tilting and uplift has yet ceased.

Summary.

This report is the result of a review of the literature bearing directly or indirectly upon the subject, and a prolonged study of

the formations in the field from the southern line of Boulder County to the northern boundary of the state.

There are no known sedimentary formations in the eastern foothills of Northern Colorado earlier than Carboniferous, except quartzites and quartz-schists southwest of Boulder and west of Berthoud and Loveland, which are tentatively assigned to the Algonkian. They extend irregularly back into the granite.

The basal conglomerates and sandstones of the Red Beds, until recently assigned to Triassic age, and by Fenneman correlated with the Fountain formation, have now been traced through to Northern Larimer County and found to be equivalent to beds containing Upper Carboniferous fossils in the upper part and Lower Carboniferous at the base. This formation rests upon granite and gneiss except where the quartzites and schists occur.

The overlying fine-grained sandstone, called the Lyons by Fenneman, has been traced almost continuously from Perry Park to Wyoming, and from its association with the Carboniferous limestones in the northern area it is believed to be also Upper Carboniferous.

No evidence has been found bearing upon the age of the Lykins formation (upper part of Red Beds) in Northern Colorado except its stratigraphic position between Upper Carboniferous and Jurassic strata, which, coupled with the fact that there is no known unconformity below, and the occurrence of Triassic fossils in the upper part of what appears to be its equivalent in Southern Colorado, suggest the probability that it is Permian below and Triassic above.

The Lykins is overlaid in the Denver Basin by the Morrison, a fresh-water formation of Jurassic age. To the north marine Jurassic strata, likely equivalent to the Sundance formation, intervenes, separating the Morrison from the Lykins.

The exact stratigraphic position of the so-called "Dakota" formation in this region is not satisfactorily ascertained. The three members, consisting of an upper and a lower sandstone and intervening shales, have hitherto always been considered Dakota, and declared to be of fresh-water origin. The discovery of marine fossils in the medial shales from Boulder to Northern Larimer County disproves the latter proposition, but they are not determinative of the age of the beds. In apparently equivalent beds of Southern Colorado, Comanche fossils have been found in the medial shales and Dakota plants in the upper sandstone, which suggests that the upper sandstone in Northern Colorado is likely Dakota, and the remaining beds Comanche.

We have no new information concerning the Benton and overlying Cretaceous and Tertiary formations, which are well known along the western edge of the Great Plains.

The pre-Carboniferous history of the region is obscure and little known. From early Carboniferous to the end of Cretaceous time there was an almost continual subsidence of the sea-bottom, its rate approximately coinciding with the rate of deposition, so that the sea never attained great depth in this region, although the total subsidence must have reached over 10,000 feet, as shown by the thickness of the deposits. The shore-line, at first approximately coincident with the present axis of the foothills, slowly encroached upon the land or present mountain area, the extent of which encroachment is unknown, but must have been at least ten or fifteen miles. Temporary interruptions in the subsidence are marked by slight unconformities and thin fresh-water deposits. At the end of Cretaceous time the sea retreated, and during Tertiary time the entire region was lifted over a mile above sea level, the great foothill monocline was steepened, the mountains reared far above the plains, and thick, fresh-water deposits were laid over the more or less upturned edges of the Cretaceous strata. More recently these Tertiary beds have been eroded from most of the region under discussion except along the northern boundary of the state.

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THE
HAHNS PEAK REGION

ROUTT COUNTY
COLORADO

AN OUTLINE SURVEY

R. D. GEORGE
and
R. D. CRAWFORD

CONTENTS.

INTRODUCTION.

The Hahns Peak region has for over forty years contributed to the mineral output of the state. Its remoteness from transportation facilities and from metallurgical plants, and the lack of reliable information in the shape of maps and reports have been regarded as drawbacks which have prevented it from developing into an important camp. The coming of the "Moffat Road" to Steamboat Springs, 30 miles distant, has improved the transportation facilities. To remove the last of these hindrances, the State Geological Survey undertook to prepare a general geological outline of the area. A party consisting of R. D. George, James Underhill, R. D. Crawford and B. H. Jackson, spent the month of July, 1907, mapping the geological formations and investigating the mineral possibilities. The result is the geological outline and map here presented. Many generalizations have been necessary, and many details have been omitted, especially in discussing the structural features. The lack of a topographic base map detracts seriously from the value of the results.

CHAPTER I.—GENERAL DESCRIPTION AND STRUCTURE.

FIELD WORK AND ACKNOWLEDGMENTS.

The work on which the present report is based was done in July, 1907, by Dr. James Underhill, Mr. B. H. Jackson, and the writers. The primary control was based on data prepared by the U. S. Geological Survey.* With Hahns Peak and Sand Mountain (Whitehead) as a base, secondary triangulation was carried over the district by means of a Johnson plane-table. Tertiary points were located by intersection and resection with a pocket sextant. Details were tied to the control points by means of pacing and compass readings with a Brunton pocket transit. Geographic positions in general may be considered reasonably accurate as they appear on the map. In the southeastern part of the district, however, the scarcity of points rising above the timber precluded adequate triangulation, and necessitated the taking of long sights with the Brunton transit.

The field party made constant use of the maps prepared by Mr. Hoyt S. Gale**, of the U. S. Geological Survey, to accompany his report of the district. Although Mr. Gale spent but a few days in the field, his topographic map was found to be both quantitatively and qualitatively accurate in a high degree. It needed only slight changes based on better control to make it of great service in mapping the geology. His geologic work was accurate along the lines of his traverses. Such changes as the present survey has made in his geological map are based on more detailed study than Mr. Gale could possibly make in his hasty examination of the region.

The State Survey wishes to acknowledge its indebtedness to Messrs. C. E. Blackburn, Pat Magill, A. C. Smith and others for courtesies in the field.

POSITION.

Hahns Peak village, at the south foot of Hahns Peak, is the county seat of Routt county. It is about thirty miles from Steamboat Springs, the present terminus of the Denver, Northwestern and Pacific Railway, the "Moffat Road." Columbine, the only other village in the district, is about four and a half miles

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*U. S. G. S. Bull. 201, pp. 92-93.
**U. S. G. S. Bull. 285, 28-34.

from the village of Hahns Peak. A daily stage runs from Steamboat Springs to both of these towns.

The region was mapped by the Fortieth Parallel Survey and the geology described by S. F. Emmons. In 1905 Hoyt S. Gale, of the U. S. Geological Survey, made an examination of the field and published a reconnaissance map with his report. A bibliography at the end of this paper, page 229, includes other articles and reports on the region.

PHYSIOGRAPHY.

Topography: The southern part of the district lies in the drainage basin of the Elk River, the northern part in the basin of the Little Snake. Hahns Peak, the most prominent point in the region, is at the eastern extremity of the Elkhead Mountains, a group formed by volcanic activity of late Tertiary or Quaternary times. The peak has an elevation of 10,862 feet,* and is between 2,600 and 2,700 feet higher than Hahns Peak village. It can be seen from long distances rising above the surrounding peaks. From the south it appears as a symmetrical cone, but from other positions of observation it is seen to be a somewhat ridge-like elevation, descending much less abruptly toward the north than toward the east, south and southwest. Farwell Mountain has nearly the same elevation. Many other peaks are from 200 to 1,500 feet higher than the surrounding country.

In Red Park, Little Red Park and the southwestern part of the area mapped the streams have a moderate to slight gradient. For some distance above the point at which Willow Creek enters the pre-Cambian area the stream meanders in its flood plain, which is several hundred feet wide. At this point a temporary base level has been established, because of the high resistance of the metamorphic rocks.

Landslide Topography: This feature, which is characteristic of the regions underlain by shale, finds expression in several places in the Hahns Peak district. One of the best examples is seen on the west limb of the syncline northeast of the peak. Here the thick beds of Mancos shales, having a considerable dip and overlain by conglomerate, have slid, in successive sections scores of feet across, down the slippery bedding planes toward the creek. The resulting relief, though not high, is very hummocky on a large scale.

*Gale, H. S., U. S. G. S. Bull. 285, p. 28, 1906.

Another good example may be seen in the Mancos area west of Willow Creek. The surface of the Mancos shales rises rather rapidly toward the west, and is in places covered by a considerable accumulation of disintegrated material and small patches of Wyoming gravels. A few springs issue from the shales, and in the vicinity of these landslide topography is very common. In a few instances the slides have formed basins, which enclose boggy areas of small size. These slides have in numerous instances left surfaces of the Mancos shales exposed. The landslide topography is observable from 1,000 to 2,000 feet back from Willow Creek.

Water Supply and Vegetation: Much snow falls during the long winters, and lies on the high peaks and many timbered slopes until late summer. The melting snow and the precipitation of the rainy season in July and early August furnish abundant moisture for the heavy growth of timber and other vegetation which is characteristic of this district. Spruce, pine and aspen flourish, and, together with the rank growth of grass in their shade, are doubtless responsible in large measure for the accumulation and retention of the black soil which is so common in numerous localities.

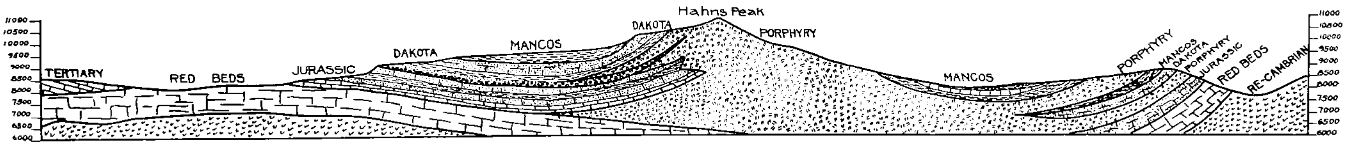
STRUCTURAL FEATURES.

The Hahns Peak region contains two rather distinct structural types: *a*. That characteristic of the meeting place of sedimentary formations with a recently uplifted complex of ancient metamorphic rocks, upon and against which they rest; *b*. That characteristic of sedimentary formations intruded by igneous rocks in bodies of various forms, such as dikes, sheets and laccoliths. The first structural type is well exemplified by the eastern half of the area, while the central and western half illustrate the second type.

FOOTHILLS TYPE.

In the eastern half are found sedimentary formations, ranging in age from Carboniferous to Tertiary, upturned against the ancient gneisses and granites. The strike and dip of the flanking formations vary widely from place to place. The dips range from a few degrees to verticality, and in one or two places actual overturns are found. The present attitude of the strata is doubtless the result of many factors, such as the extent of the upward movement in both the sedimentary and the metamorphic rocks, the regularity of the floor upon which the sedimentary rocks rested before the upheaval, faulting along the zone of contact,

PLATE XXII.



Section showing structure along a northwest-southeast line crossing Hahns Peak and Grouse Mountain. Vertical scale is double the horizontal.

both within and between the two types of rocks, the warping of the floor below the sedimentary rocks before, during and after the main movement, the regularity of the ancient shoreline, the character of the sedimentary rocks themselves, and subsequent erosion.

It is very evident that the upward movement was greater in some parts of the Park Range than in others, and it is quite possible that these differences were very local. The floor upon which the sedimentary formations were deposited was, for the most part, rather uniform and even, but exposed contacts show that irregularities existed, and that depressions were filled first, thus bringing formations of widely different age into contact with the ancient gneisses at points quite near to one another.

Faulting within the sedimentary rocks is evident in several places, and movement within the more yielding formations was very pronounced. Brecciation and shearing are common phenomena.

That warping of the ancient rock surface has occurred is evident from the isolation of certain areas of sediments and the dome and basin-like structures they now present. Erosion has undoubtedly played an important part. The best illustrations of the structural features of the first type are to be seen between Twin and Grouse Mountains and in the area east of Red Park.

In the eastern part of the southern Mancos area the rocks are on edge, and in one place show a slight overturn. The dip gradually decreases westward in a series of anticlines and synclines until the formation passes unconformably under the Tertiary sandstones.

LACCOLITHIC TYPE.

The central and western part of the area is a region of sedimentary formations intruded by igneous rocks of various kinds, in various forms of bodies, and of different ages. In the Tertiary area to the north a great series of basaltic dikes forms an amphitheatre opening to the northwest. The longest of these is over three miles in length and forms a great, irregular curve, from the western end of which numerous roughly parallel dikes trend northwestward. Most of the dikes are nearly vertical, and many show fine examples of columnar structure, the columns lying in different positions in different dikes. Contact metamorphism is nowhere pronounced, but is observable at a number of points.

The laccolithic form of intrusion consists of a more or less lens-shaped body of igneous rock having an arched cover, generally of sedimentary rocks, such as sandstone, limestone and shale. Molten rock, forced up through a vent in the earth's crust, arches the rocks covering the vent, and they remain as a cover over the mass of molten rock. The arching of the covering rocks allows the molten mass to spread laterally, so that a laccolith is frequently many times as wide as it is high. Of the laccolithic form of intrusion Hahns Peak and Grouse Mountain are the best examples.

There is no certainty that the formations which now flank them ever completely covered the igneous masses. But many facts make it highly probable that Hahns Peak was once a true laccolith, covered by the Cretaceous formations. On the northwestern shoulder a mass of almost horizontal Dakota lies within a few hundred feet of the summit, and a little farther to the east a narrow band of Dakota, dipping with the slope of the mountain, almost connects with it both above and below. Still higher up on the northwestern side, probably within 200 feet of the summit, Dakota quartzite and baked shale are found, but their attitude could not be determined. On the western side, while the Dakota rocks were arched up into an almost vertical position, they were covered by the porphyry. In one place a tongue or sheet of porphyry seems to have followed the shales of the Dakota, leaving one of the sandstone members on one side and one on the other. On the south side again, a sandstone, probably the Dakota, is penetrated by a tunnel, at an elevation of nearly 10,000 feet. On the southeastern slope, at a point along one of the ditches, there is an exposure of Dakota, with porphyry above and below it. The tunnels of the Hahns Peak Gold Mining and Milling Company show that dikes radiate from the central porphyry core. It seems probable that the Dakota formed the immediate cover over the porphyry on the north, northeast and a part of the northwest, and that the porphyry broke through to a higher horizon on other parts of the mountain, but it probably remained covered by the later Cretaceous rocks until erosion exposed it.

The evidence in the case of Grouse Mountain is not so convincing, but there are still facts which point unmistakably to the laccolithic structure. This is also true of Peak and Iron mountains.

CHAPTER II.—HISTORICAL GEOLOGY.

PRE-CAMBRIAN.

The Hahns Peak region is along the much disturbed area between the pre-Cambrian mass of the Park Range on the east, the Tertiary volcanic group known as the Elkhead Mountains to the northwest, and the great sedimentary plateau which stretches far to the west. A large part of the eastern half of the map is within the pre-Cambrian area. The rocks, like those of similar areas in the Rocky Mountain region, are a vast complex of schist, gneiss, gneissoid granite and granite, with isolated areas of quartzite.

No attempt was made to differentiate on the map the various members of the series. In parts of the area the changes from one rock type to another are so numerous, and the mingling of the various members of the series is so intricate, that separate representation of the lithological units would be impossible on a map of one inch to the mile.

In general it may be said that the schists are the oldest member of the complex, but there are areas of schist which do not belong to the fundamental formation of the region. These are the result of intense local metamorphism, and, from them as centers, the alteration decreases outward until, without any evidence of an actual change of formation, the rock becomes gneissoid granite. The more ancient schists rarely show marked differences of structure, though variations in composition are frequent. In places the directional structure is regular and constant for considerable areas, but for the region as a whole it was impossible to discover any prevailing dip or strike suggestive of a sedimentary origin. This is not strange, since over large areas the schists are far exceeded in volume by the intruded granites and gneissoid granites. These vast intrusions, belonging to widely different ages and cutting not only the schists, but all rocks of greater age than themselves, have profoundly changed the structure of the earliest rocks, and, age by age, have added greater complexity to the pre-Cambrian series.

In composition they range from quartz-mica- to quartz-feldspar-hornblende-schists. The quartz-mica-schist varies widely in the proportion of the two minerals, resembling in this respect the great quartzite-mica-schist series of the Big Thompson region east of the range, where the rocks are undoubtedly of sedimentary origin. Muscovite is often abundant, and chlorite is a very common alteration product from both hornblende and biotite. Considerable areas are found in which both composition and texture suggest a sedimentary origin, but near these may be others in which not the slightest hint of a sedimentary ancestry appears. The amphibole-schists are not so prominent as are the mica-schists. These also vary widely in the relative importance of the constituents. Quartz is always present, and mica is rarely absent, though it may be very poorly represented. The amphibole is commonly black or dark greenish black, and is often quite fresh looking. The schists rich in amphibole resist weathering much better than do those in which mica predominates. Garnets of both pink and cinnamon color are very common in certain areas, and occur both disseminated and in bands. In size they range from one-sixteenth of an inch to two inches in diameter. Bands of massive garnet a foot wide occur toward the divide farther south. Feldspar seems to form a connecting link between the schists and the gneisses, and the feldspathic schists are commonly closely related to the latter. In many places the same rock mass may show bands of highly micaceous quartz-mica schist in contact with bands showing at best but a poor gneissoid structure.

Intrusive granites of varying age have suffered varying degrees of metamorphism, but the extent of the change is by no means directly proportional to the age. The location with respect to certain lines and zones of weakness has had an important bearing upon the structure. Those farthest away from the lines of movement show only a slight degree of change, while those along the line are profoundly altered. The gneisses including those carrying biotite as their principal dark mineral with subordinate hornblende are the most abundant, while others having hornblende in excess of the biotite also occur. Alteration prior to the development of the present structures seems to have determined in some instances the relative importance and the distribution of the minerals now present. But in other cases the distribution seems to have been determined entirely by the origin of the rock and subsequent segregation resulting from dynamic metamorphism.

The gneissoid granites are structurally intermediate between the gneisses and the granites, and gradations from one to the other are common. The granites and gneissoid granites include many variations in texture and composition. Porphyritic forms are common in both. The phenocrysts are mainly orthoclase. Very coarse and very fine textures may be seen in contact near the borders of the diorite on Farwell mountain. In color the granites range from gray to rather dark red.

Dikes and small intruded bodies are very common, especially toward the divide and on the head waters of the Elk River to the south of the map. These dikes include aplitic granite, granite, pegmatite, porphyritic granite, diorite, quartz-porphyry and occasionally diabase or basalt. In size they range from mere stringers and veinlets to dike-like bodies which can hardly be classed as dikes. Pegmatite dikes or veins are everywhere, and locally are very abundant. As usual, they present a very wide variation in the proportion of the constitutent minerals.

In the walls of deep, narrow valleys, gulches and canyons the intruded bodies are shown in every position from horizontal to vertical. This is notably true of the headwaters of the Elk River.

Quartzite occurs in the southwestern part of the pre-Cambrian area, near the southern border of the map. The commonest form is a dense bluish-gray rock, breaking with a chonchoidal fracture. But in places lamination is prominent, and is generally parallel to the bedding. Mica is present in varying quantity, and is responsible for the parallel, platy, almost schistose, structure sometimes observed. While this area is the only one in which the rock was observed in place, debris was found at other points, especially to the southwest and northeast of the outcrop, and at much greater elevation.

RED BEDS.

Under this general name are included rocks which may range in age anywhere from Carboniferous to Jurassic resting upon the eroded surface of the pre-Cambrian formations, and presenting a smoothly irregular surface to the overlying marine Jurassic—the Sundance. Lithologically, the series includes sandstones, shales and limestones, but the sandstones greatly predominate. In color the rocks range from deep brick red to pink and gray. The bedding is generally distinct, but quite variable.

Outcrops showing both the lower and upper contacts were not seen, but several exposures of the basal beds and several showing the upper strata were examined. On King Solomon Creek the basal beds consist of friable, brick-red sandstones and sandy shales, well bedded, but crumbling readily to a loose, blocky talus. On Beaver Creek, east of Grouse Mountain, the rocks are of the same general type, but are more massive and more feldspathic.

An excellent exposure (not mapped) on the slopes of Iron mountain presents very heavy-bedded, coarse-grained arkose in places approaching a pebbly conglomerate in texture. Southeast of Farwell Mountain, what appear to be the basal strata are coarse, pinkish to reddish sandstones, massively bedded, and weathering, by gradual disintegration of the surface, into rounded outlines. Feldspathic sandstone debris was found in the creek, but no strictly arkose strata were seen in place. The formation was overlain by a strong limestone carrying marine Jurassic fossils, and did not appear to exceed seventy-five feet in thickness.

The upper strata are exposed in contact with the porphyry of Grouse Mountain at certain points along the Jurassic contact east of Beaver Creek. They resemble the exposures of Red Park and King Solomon Creek. On Iron Mountain the uppermost beds below the porphyry are yellowish gray sandstones of coarse texture, followed by irregularly bedded, mottled, reddish-brown and white sandstones.

In structural features the rocks included in the Red Beds resemble the Fountain and Lykins of the Boulder area, east of the range. Cross-bedding, flow-and-plunge structures, heavy, pebbly strata and alternations of sandstone, shale and shaly sandstone are common. In general the basal members are coarser and more massive than the upper, and bear a resemblance to the Fountain. The upper strata are more friable, shaly, and of deeper color, and resemble the Lykins.

The Fountain has yielded Carboniferous fossils, but the Lykins has afforded no organic evidence of its age. It may, therefore, stand anywhere between Upper Carboniferous and Jurassic.

The relations of the series to the underlying pre-Cambrian suggest a progressive advance of the sea over an eroded surface. The depressions were first filled by coarse, in places pebbly, granite debris—arkose. Before the higher elevations were covered the character of the sediments changed, and they were overlain by finer, more clayey material. This accounts for the variable character of the basal strata from place to place.

The rocks of the upper contact are also variable, and there again is evidence of an erosinal interval between the Red Beds and the Sundance.

JURASSIC.

Wherever the Jurassic overlies the Red Beds in the Hahns Peak district there is a gradation from one to the other, such that it is impossible to determine the base of the younger system within a stratigraphic range of many feet in most parts of the field. Consequently, where the two appear in a horizontal or nearly horizontal position in areas of low relief, the boundaries between them, as shown on the map, should be considered as only approximate. The zone between the undoubted Red Beds and the undoubted Jurassic is remarkably variable in character. In at least three places strong limestone bands were seen in contact with the Red Beds, while elsewhere sandstones and sandy shales form the greater part of the transition zone.

These variations in the lithological character of the transition zone suggest an unconformity between the two systems, and the Jurassic would seem to have been deposited on an irregularly eroded surface of Red Beds.

An entire section of the Jurassic is not known to outcrop in the district. Hence the maximum thickness is unknown, and the stratigraphic relations of the several beds seen in the various exposures were imperfectly correlated.

Limestones, clays, sandstones and sandy shales are present, and, in outcrops removed some distance from the Red Beds and from porphyry masses, range from dark to light gray. The principal limestone occurs near the base, and is dark gray, compact, and breaks with a conchoidal fracture. The basal part weathers into thin, platy blocks, ranging from one to three inches in thickness, and is followed upward by more compact beds, ranging from ten inches to two feet in thickness. It is irregularly jointed at right angles to the bedding. Brachiopods were found within a few feet of the contact with the massive red sandstone. The limestones of the Jurassic are not likely to be confused with rocks of other periods, and are perhaps the most persistent of the system in the several exposures. There are several strata of this rock intercalated with beds of clays and sandy shales. The only limestone observed outside the Jurassic is in the Mancos formation, which carries characteristic fossils, and is in most places separated from the Jurassic by outcrops of the Dakota.

The clays and shales are, as a rule, friable, but are in some exposures considerably indurated.

The sandstones occur in several horizons, and in at least one instance, east of the area mapped, the highest beds exposed have a very considerable thickness. In some cases the Dakota overlies the limestone or shale, with little or no sandstone intervening. These facts strongly suggest the presence of an unconformity. The sandstone is gray to pink, thick to thin bedded, and shows a wide range in hardness. Near some porphyry intrusions, notably west of Columbine, the rock is decidedly quartzitic through silification. This bedded sandstone is especially abundant in the east part of the district, where the rock, in color, texture, structure and composition, strongly resembles the Lyons sandstone of the foothills east of the front range, but is not so hard as the latter.

In the west part of the district all the members of the Jurassic weather to a pink soil, which is very easily confused with the weathered soil of the Red Beds and the recent surficial deposits. A good example of this can be seen on the Columbine road, about midway between Columbine and Hahns Peak village. West of this point, and also on the slopes of Iron Mountain, the sandstone passes from a light gray to a deep red as the porphyry contact is approached. Many detached flagstones strongly resemble those of the Red Beds; others show a fine line of demarkation between red and white at right angles to the bedding. Close to the contact the sandstone is freakishly mottled, as well as hardened. It is inferred that the coloring and the sharp contrasts in color, while they may have been produced in part by contact metamorphism, have largely been brought about by solutions circulating through the contact zone. These solutions may have had unusual efficiency, because of their high temperature.

The Jurassic limestone on the southeast slopes of Farwell mountain is of a bluish-gray color on fresh surfaces, but weathers to gray and dove colors. It shows indistinct stratification, except in the much-weathered portions, where the strata range from a few inches to two feet or more in thickness. Simple tests indicate that it is a rather pure limestone.

Professor Junius Henderson, paleontologist of the Survey, has identified the following characteristic fossils of the marine Jurassic, Sundance, from this locality:

Belemnites densus.

Pseudomonotis curta.

No fresh water Jurassic fossils were found in this region.

CRETACEOUS.

It is probable that, prior to the deposition of the Dakota formation, the region was exposed to erosion for a period of unknown, but possibly brief, duration. The best evidence of an unconformity at this horizon is found in the basal conglomerate characteristic of a rapidly encroaching sea and in its relations to the underlying Jurassic, which are similar to those in other parts of the state from which an unconformity has been reported.

Dakota Formation: This formation is the most prominent of the sedimentary series, because of its wide distribution and resistance to weathering. It possesses an economic interest, in that both conglomerate and quartzite have been prospected for the precious metals, with some degree of success.

Whenever the base of the formation is exposed a bed of conglomerate is present. Water-worn pebbles of flint and chert, with some quartz, predominate, and are firmly cemented by a very hard siliceous matrix. The conglomerate grades upward into a quartzite and fine-grained sandstone, almost white in color. Toward the top of the formation quartzites and quartzitic sandstones alternate with shales in beds several feet thick. The top of the uppermost bed of sandstone and quartzite is here taken as the contact between the Dakota and the overlying Mancos formation. The Dakota shales are black to bluish-black, considerably indurated in some exposures, and thick to thin bedded. In a number of instances the thin bedding seems to have been brought into prominence by folding, since the same beds, traced to places where the disturbance has been less intense, appear to be thick bedded. Examples of this may be seen along the Dakota ridge, extending from Grouse Mountain northward to the point where it is cut off by the porphyry of Twin Mountain. Cubical jointing is common in the thick-bedded shales and in the quartzite, and surfaces of the joint blocks are often stained with iron oxide. The maximum thickness of the Dakota formation is probably not less than 175 feet.

Both the sandstone and conglomerate are in most places hard and flinty, due to a high degree of silicification, which has produced true quartzite and quartzite-conglomerate. This extreme alteration may have been brought about by the deposition of silica in the interstices of the rocks from waters whose solvent power had been greatly increased by heat from the porphyry intrusions. The conglomerate does not show evidence of shearing stresses, which produce a lenticular form in the pebbles of quartzite-conglomerates developed through dynamo-metamorphism. Both the quartzite and the conglomerate are much jointed, and in many places are badly fractured.

The effects of the very thorough shaking up to which the region has been subjected are more apparent in these beds than in the formations which readily yield to stress. East of the Front Range the basal part of the "Dakota," particularly in the southern part of the state, contains Lower Cretaceous (Comanchean) fossils. But, so far as the writers are aware, this is not true of the Dakota west of the front range. No fossils were found in this formation in the Hahns Peak field, and its assignment to the Dakota is based on its stratigraphic position and its lithologic characters, which are unmistakably the same as those of the "Dakota" east of the range.

Mancos Formation: The Mancos formation conformably overlies the Dakota, and is composed chiefly of thick-bedded carbonaceous and calcareous shales, with a few thin strata of limestone and thin-bedded shales. Ironstone concretions, such as characterize the Pierre formation, are present in some outcrops. Nothing is known of the original thickness of the Mancos in this district, since it has long been exposed to erosion in recent times, and, as noted elsewhere in this report, suffered erosion before the deposition of the Tertiary sediments.

Fossils are plentiful in the more calcareous beds, which in places emit a marked bituminous odor when struck with a hammer. At one point in the syncline, northeast of Hahns Peak, spring waters issuing from the shales are strongly charged with hydrogen sulphide. Professor Henderson has identified the following fossils from this formation in the Hahns Peak district:

Baculites gracilis,
Inoceramus dimidus,
Ostrea congesta,
Prionocyclus wyomingensis,
Scaphites warreni.

He states that they are characteristic of the Colorado group, and are usually considered as being restricted to the Benton, except the Ostrea congesta, which was found at a higher horizon than at the eastern base of the Rocky Mountains in Colorado, where it is confined to the Niobrara.

Many fish scales were found, but were too poorly preserved for identification.

Laramie Formation: This formation will be treated with Tertiary, for reasons stated below.

POST-MANCOS CONGLOMERATE.

In several places a bed of very coarse conglomerate rests unconformably on the Mancos formation, and reaches a thickness of twenty feet or more. One of the best exposures is about a mile northwest of Hahns Peak. A smaller one occurs near the top of the mountain on the west slope. Other occurrences were observed on the south slope of Hahns Peak, and within the syncline northeast of the peak. Loose boulders from the disintegrated conglomerate are numerous on some of the slopes, as well as in the stream terraces in the southwest part of the district.

The conglomerate contains sub-angular pebbles and boulders from the older sedimentaries and pre-Cambrian metamorphics, firmly cemented. There is little doubt that the material came comparatively short distances, and it is very probable that it was deposited by streams. In fact, if the material of some of the present stream beds were to be consolidated, a similar conglomerate would result, in which later eruptives would find a place among the pebbles.

Gale* noticed coarse conglomerates in several places in the district, but was in doubt as to their stratigraphic position. He also describes similar boulders and pebbles in the placer** deposits near Lay, west-southwest of Hahns Peak about fifty miles. While admitting the possibility that the material in the Lay placers may have been derived from the Uinta Mountains, Gale suggests the Park Range as the more probable source. He also describes a bed of conglomerate overlying the uppermost Cretaceous strata nonconformably, south of the placer field and extending westward, where it passes beneath the Browns Park beds. This bed of conglomerate, he states, may be traced continuously eastward to Fortification creek, north of Craig. This point is about fifteen miles from the outcrop at Lay creek. Gale states that this bed might be expected to carry values, and suggests the same origin for the conglomerates and the boulders of the placer deposit, and that both the pebbles and gold of the Lay placers were derived from it.

A similar conglomerate, of great thickness in places, is found in the extreme northwestern part of Colorado and in adjoining territory, where it has been described by Powell.*** The formation was originally widely spread, but is now exposed only in isolated patches, which unconformably overlie various formations of the Tertiary period, in different exposures, and in other places overlie Jura-Trias and Carboniferous beds. Powell attributes the deposition of these conglomerates to "sub-areal agencies, chiefly the

*U. S. G. S. Bull. 285, p. 30.

**Gale, Hoyt S., Gold Placer Deposits Near Lay, Routt County, Colo. U. S. G. S. Bull. 340, pp. 84-95.

***Powell, J. W. Bishop Mountain Conglomerate, Geology of the Eastern Portion of the Uinta Mountains and a Region of Country Adjacent Thereto. U. S. Geol. Survey of the Terr. 1876, pp. 169-171.

action of rains and streams." Emmons* thinks they are in a measure a littoral or beach deposits, but there are evidences which seem to show that they extend to distances of twenty and thirty miles from the shore line.

LARAMIE AND TERTIARY.

After Mancos times, and beginning at an unknown date, the region was exposed to active erosion for a period long enough, apparently, for the entire removal of the Mancos formation from the northwestern part of the field. It is also probable that at this time a drainage system altogether different from the present drainage became established, and perhaps reached maturity. This is mentioned below in connection with the Wyoming conglomerate.

Laramie (?) and Tertiary Formations: It is impossible to differentiate the Laramie formation and succeeding Tertiary sediments throughout the greater part of the field. However, in the southwest and northwest parts of the district, and beyond the limits of the map in the directions mentioned, there is a very considerable deposit of sandstone, which is lithologically similar to the Laramie and is in a similar stratigraphic position. The sandstone is nearly white, and composed chiefly of poorly cemented quartz sand. Cross bedding is general. In the northwest part of the field this formation is cut into terraces 200 to 300 feet high. Here the Laramie (?) apparently rests unconformably on the Jurassic, but in the southwest part of the district it overlies the Mancos shales.

The interruption of deposition, and an apparent erosion period prior to Laramie (?) times, and the continuous sedimentation through at least a part of the Tertiary period, make the logical grouping of this sandstone with the Tertiary rather than the Cretaceous. No fossils were found above the Mancos. One section of these formations, just beyond the western border of the map, showed approximately 1,200 feet of sandstones. The lower members of the series were somewhat more consolidated, and on exposed surfaces showed a peculiar dull, whitish, earthy speckling, suggesting the kaolinization of minute feldspar sand grains. Turtle-back jointing was also quite common. Above this series were hundreds of feet of a very soft, friable sandstone, more decidedly Tertiary in character.

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*Emmons, S. F. Wyoming Conglomerate on Muddy Mountain, Southwestern Wyoming. Geol. Survey of the Fortieth Parallel, Vol. 2, p. 189. See, also, same volume, p. 205, on a Conglomerate in the Green River Basin.

Lake Beds: The best outcrops of the Lake Beds are along the banks of Willow creek and its tributaries. Clays and friable sandstone make up most of the formation. The beds are white, gray, yellow, pink, and in occasional outcrops are almost red. Gray and yellow, perhaps, are the prevailing colors. The pink and reddish varieties are easily confused with the weathered Jurassic rocks and with recent surficial deposits along stream courses and on the slopes in the vicinity of porphyry. West of Hahns Peak village, near the border of the map, there is a bed of dark-brown limonitic sandstone, which is very resistant to weathering. Elsewhere the Lake Beds are poorly consolidated, and are easily removed by erosion. In weathering on the banks of streams they scale off in slabs parallel to the weathered surfaces.

PLEISTOCENE AND RECENT.

Glaciation: In the eastern part of the district, particularly on the north and east slopes of Farwell Mountain, are moraines and morainal materials more or less reworked by water. Toward the summit the moraines are very recent in appearance, and the striae and grooving of the surface of the rocks are still very clearly defined. Two or three small lakes owe their existence to morainal damming by glaciers moving from the peak. Farther down the slopes the evidences of glaciation decrease greatly, and there is a very rapid change from the freshly planed surfaces to those on which the striae and grooving are found only in protected places, and further, to those which were never glaciated or which have lost all evidence of glacial erosion. But far beyond these limits are to be found glacial boulders and smaller detritus. On the headwaters of Elk river, in the Slavonia area, to the east and southeast of the map limits, moraines are numerous, and glaciated surfaces show by their delicate striae that they were ice-covered at no distant period.

The Wyoming Conglomerate is composed largely of pre-Cambrian materials from the east. In some of its characteristics it closely resembles glacial detritus reworked and deposited by water.

Alluvium: A very large alluvial area occupies the broad angle between Beaver and Willow creeks. It is safe to say that the Mancos underlies a large area north and east of Willow Creek, and that the pre-Cambrian formations extend considerably farther west of Beaver Creek than the map shows, but the absence of outcrops of these rocks and the thickness of the alluvium made it desirable to map the whole area as alluvium.

The deposit is of the usual character, and includes, throughout most of the area, a rather heavy covering of dark soil underlain by heavy clays, sands, silts and gravels. Old placer pits show that in places the surface soil and loam or silt reach a depth of several feet. Below this gravel, sand and angular rock debris occur in alternating layers. Most of the gravel is fairly well rounded, but the porphyry and other debris is angular or subangular. In a few places large deposits of subangular gravel suggest the breaking up and redeposition of a conglomerate similar to the Post-Mancos Conglomerate. In other places deposits resembling worked-over morainal material occur, and here and there thick beds of a pink or reddish sand of rather angular habit. The placer deposit, being worked by the dredge, included all these varieties of material, but the larger sand deposits lay west of the placer ground.

Debris: Certain areas of considerable size are mapped as debris. In a number of instances it would have been a rather safe guess to extend the boundaries of the older formations so as to cover much of these areas, but the deposits were of such thickness and extent that it seemed wise to give them recognition.

The debris differs from place to place, according to the source from which it comes. That near the porphyry areas is composed very largely of fragments of porphyry, decayed porphyry, with clay and soil. It is rarely of the character of stream-deposited material, and frequently shows no evidence of having been stream moved. The higher parts consist of angular talus. Farther down the slope more and more fine material, the product of disintegration, is mingled with the coarse, and still farther down it is covered by a soil supporting vegetation.

Near the quartzite areas, and in places at considerable distance from them, the debris contains a large amount of quartzite. In places the character and arrangement of the material suggest flood deposition, but such areas are not large, and are so situated with reference to present drainage lines that such an origin is easily possible.

THE IGNEOUS ROCKS.

PORPHYRIES.

While there are several varieties of porphyry in the district, they may, in the main, be considered closely related phases of a series rather than distinct types. They include rhyolite, dacite, latite, andesite and quartz-basalt. Although quartz is seldom absent, it is never predominant. Texturally the rocks range from essentially felsite, with few and small phenocrysts, to porphyry with feldspar phenocrysts two inches in diameter.

It is practicable to discuss the porphyries in only a general way, since really fresh rock does not occur in the exposures, and the few tunnels and shafts of the district do not pass through the weathered zone. Distinct contacts between different varieties are probably few, and in any case are so difficult to trace that no attempt has been made to represent them on the map which accompanies this report.

Field relations show that there were at least two eruptions, separated by a considerable interval of erosion, and it is possible that each of these eruptions is one of a series in a period of vulcanism. One of the best exposures observed occurs on the slope of Little Mountain, in what are considered Tertiary sediments. Just above the Tertiary beds is a mass of debris ten to twelve feet thick, containing pre-Cambrian and porphyry boulders. Above the debris is a stream-laid bed of sandy clay, gravel and boulders. The weathered porphyry of the edge of the Little Mountain body overlies the stream-laid deposit. There has evidently been a radical change in surface drainage, apparently brought about by the latest eruption. That the drainage was changed by crustal movement long after the porphyry had been exposed to erosion, and that the decaying porphyry which overlies the stream-laid deposit is slide-rock, seems very improbable. Other evidences of more than one eruption are mentioned in the description of the rhyolites of Hahns Peak.

RHYOLITE AND RHYOLITE PORPHYRY.

On and near the top of Hahns Peak are two varieties, which we shall consider as the "earlier rhyolite" and "later rhyolite," respectively. While the two may differ widely or but little in age, the presence of an eruptive contact is certain, and the relative age of the two porphyrys is reasonably evident.

Earlier Rhyolite: This is the "white porphyry" of the highest point, which shades from almost white to light pinkish gray, with but little trace of dark mineral apparent to the naked eye. It varies from a rhyolite-porphyry, in which phenocrysts and ground mass are about equal in amount, to a felsitic phase, with only a few small phenocrysts. Feldspar phenocrysts far outnumber the quartz. But few reach their maximum diameter of 1 cm. They are usually more or less kaolinized, but a few retain a glassy luster. Quartz phenocrysts are sparingly present in some specimens; in others they occur in considerable numbers, and are generally 1 to 3 mm. in diameter. Regular crystal outline is absent. Specimens taken from prospects at the contact carry numerous small cubes of pyrite.

The microscope shows orthoclase to be the principal phenocrystic feldspar in some cases, but frequently plagioclase exceeds the orthoclase in numbers. The quartz phenocrysts are corroded and embayed, and many enclose portions of the ground mass. Many orthoclase crystals have suffered resorption similar to the quartz. The biotite has been largely replaced by kaolin. The ground mass appears to have been originally very glassy, but is now more or less devitrified.

At the contact with the later rhyolite there is a narrow zone of breccia, in which fragments of the white porphyry are cemented by the later intrusion. Here, also, are numerous small fissures, in which chalcedony, quartz and metallic minerals in small quantity have been deposited.

Later Rhyolite: This rock, which is medium gray, with a bluish tinge, contains phenocrysts of feldspar, quartz and biotite in a dense ground mass. The feldspars range in diameter from 6 mm. to 1 mm. or less, and are much kaolinized. The average size of the quartz phenocrysts is somewhat less than that of the feldspars, and while some show a hexagonal bipyramidal outline, the great majority of them have been rounded by resorption. Quartz varies greatly in amount from place to place, and is absent from a few specimens. In some cases the small biotite crystals retain their luster, but in most of the rock exposed they have been greatly altered, and even completely replaced or weathered out.

In addition to the minerals recognized by the eye alone, the microscope shows apatite and magnetite. The groundmass has become partially crystallized. The rock is so badly weathered that comparatively few feldspar phenocrysts can be determined. However, plagioclase seems to exceed orthoclase in amount, and in one quartz-free specimen all the determinable feldspars are plagioclase. It is possible that the rock grades from mica-andesite to plagioclase-bearing rhyolite.

Rhyolites of Unknown Relative Age: In composition the several varieties of rhyolite differ, as a rule, in the relative proportions of the constituent minerals rather than in the minerals themselves. Although the texture varies, the phenocrysts are usually large, and equal or exceed the groundmass in volume when the rock becomes a rhyolite porphyry. The groundmass weathers so much more readily than the feldspars that on certain slopes well-preserved and perfectly formed crystals of orthoclase up to two inches long can be found in numbers. Many specimens with much-weathered greenish groundmass carry glassy orthoclase phenocrysts half an inch or more in diameter. Quartz phenocrysts with a diameter of half an inch are rare. The quartzes are almost invariably rounded by re-solution, although a few have a well-preserved hexagonal bipyramidal form. This mineral is generally present, and in some cases exceeds feldspar in amount, but as a rule it is subordinate to feldspar, and in places almost disappears. Some specimens carry biotite in greater or less amount, but it is generally much weathered.

Microscopic examination proves plagioclase phenocrysts to be nearly universally present. Where the rock approaches dacite in composition, phenocrysts of orthoclase are rare or absent. Extinction angles of the plagioclase are usually low. Nearly everywhere the groundmass is more or less devitrified. The rhyolite porphyry on the timbered hill about three-fourths of a mile southwest of Hahns Peak village contains augite in considerable amount.

Specimens of rhyolite porphyry from a dike at Slavonia are reddish-gray, and show a great number of pink feldspar phenocrysts, 1 to 5 mm. in diameter. About an equal number of rounded quartz phenocrysts 1 to 2 mm. in diameter are present. Small biotite crystals are numerous, replaced in some instances by epidote or muscovite. Both feldspars are somewhat kaolinized, and the orthoclase is usually flecked by small muscovite crystals. The groundmass is made up of quartz, feldspar, biotite and epidote.

A quartz-poor tuffaceous rhyolite occurs in a dike on the east slope of Hahns Peak. It contains numerous small biotite flakes, occasionally glassy orthoclase phenocrysts and a few small phenocrysts of quartz. Thin sections show much secondary quartz. The groundmass was probably originally a glass, but is now in part crystallized.

DACITE PORPHYRY.

Dacite porphyry occurs on Iron Mountain, Grouse Mountain, the northeast slope of Hahns Peak, and at other points in the field. Probably in some of these places it is merely a modification of the rhyolite. In texture it is similar to the rhyolite. Quartz varies from a minor constituent to the predominating phenocrystic mineral. Plagioclase crystals are abundant and mostly under 6 or 8 mm. in diameter. Some show striae on cleavage faces. Small biotite crystals are very plentiful.

All the feldspar phenocrysts observed in thin sections are plagioclase, with low extinction angles. The quartzes are invariably rounded by resorption, and often enclose portions of the groundmass. In some slides the groundmass is felty, with numerous lath-shaped feldspar microlites in a base which is largely anisotropic. In others, small xenomorphic crystals of what appears to be feldspar compose most of the groundmass.

LATITE AND LATITE PORPHYRY.

Latite of varying texture is exposed on the peaks, near the western border of the area mapped. One variety is almost white, speckled by a moderate number of small, shiny biotite flakes. About an equal number of small, lusterless feldspar phenocrysts are present. Quartz is all but absent. Under the microscope the feldspars prove to be largely plagioclase, some of which are intergrown with orthoclase. The groundmass is composed mostly of feldspar in microscopic form.

Latite porphyry in the same general locality contains numerous feldspars 5 to 15 mm. long, and small biotite crystals in a dense gray groundmass. The largest feldspars are orthoclase, with a glassy luster, but of the smaller most are plagioclase, determinable only under the microscope. Besides lath-shaped feldspar microlites with fluxional arrangement, the groundmass contains considerable interstitial material, which cannot be resolved under the microscope.

A specimen of latite porphyry from a point about three-fourths of a mile southeast of Hahns Peak contains numerous sanidine phenocrysts nearly 2 cm. long, and many smaller feldspars in a green groundmass. Some of the smaller phenocrysts show twinning striae in the hand specimen. Small quartz phenocrysts are sparingly present. The microscope shows nearly all the smaller feldspars to be plagioclase, with low extinction angles. The larger orthoclase crystals enclose plagioclase. What appears to have been biotite was originally present in considerable amount. Much secondary calcite and less quartz is scattered through the partly devitrified groundmass.

There is a small exposure of reddish-gray latite on the south slope of Farwell mountain, near the border of the diorite. Numerous very small phenocrysts of pink feldspar and patches of epidote are the only constitutents identifiable with the unaided eye. Microscopic examination shows that the original dark constituent, which was probably biotite, has been completely replaced by epidote, with chlorite and magnetite. Orthoclase and plagioclase are present in nearly equal amount. The groundmass is an aggregate of feldspar, secondary quartz, epidote and magnetite.

ANDESITE.

A much-weathered andesite, with pronounced flow structure, is found on a dump about half a mile northeast of Columbine. It carries numerous hornblende phenocrysts, fewer biotites and many feldspars, all of which are in an advanced stage of alteration. Some of the feldspar phenocrysts are completely replaced by calcite and kaolin, but many retain the albite twinning, seen only under the microscope. The groundmass is partly devitrified.

QUARTZ BASALT.

Quartz basalt is found in several dikes near the western border of the area mapped—on Peak Mountain (colored as porphyry on the map), and in greater quantity on Whitehead or Sand Mountain, southwest of the area under consideration. Except the Peak Mountain basalt, all carry both olivine and quartz, and are dense and very dark in color. The dike cutting the porphyry near the Columbine road shows megascopic phenocrysts of pyroxene, biotite and quartz. Of these the pyroxenes are fewest in number, and rarely over 3 mm. long. The amount of biotite varies greatly in different parts of the dike. The quartz phenocrysts are also irregularly distributed, and are appreciably rounded by re-solution. In addition to the phenocrysts, small patches of serpentine are numerous.

In thin section most of the serpentine is seen to be pseudomorphous after olivine and possibly pyroxene, but one section shows that it has been deposited in cavities. A few small automorphic crystals of olivine are still present. The freshest biotite is deep brown, but much of the mineral is badly altered. The groundmass is that characteristic of basalts, and ranges from microcrystalline to glassy.

In the dike southwestward from the village the olivine has been largely replaced by carbonates of iron, calcium and magnesium, with a colorless isotropic substance, which is probably opal. Olivine was originally present in great amount. Augite is present in the form of phenocrysts, in aggregates, and as minute crystals and anhedrons throughout the groundmass. Biotite is absent. The groundmass is similar to that of ordinary basalts, but contains considerable isotropic material and much carbonate. The basalts of Sand Mountain differ from those described chiefly by the presence of feldspar phenocrysts.

Peak Mountain Type. Quartz-basalt forms the core of Peak Mountain, which rises conspicuously above the surrounding Tertiary sandstone. It is light gray in color and of low specific gravity. The latter is largely due to the vesicular character which is very apparent under a hand lens. Phenocrysts of biotite 1 to 4mm. in diameter, and smaller augites are numerous. From one to ten quartz phenocrysts may appear on one face of the hand specimen (3x4 inches). Their maximum diameter is 1 cm., but most of them are smaller.

As seen in thin sections the biotite encloses portions of the groundmass and apatite crystals. Augite occurs as phenocrysts and aggregates, some of which are intergrown with biotite. It is also abundant in the groundmass. The quartz is corroded, and some phenocrysts are surrounded by bands of serpentine. The groundmass is composed of feldspar, augite, biotite, magnetite, apatite and possibly a small amount of residual glass.

OLIVINE BASALT.

The basalt of the dikes west of Little Red Park is the most basic rock in the district. It is microcrystalline except for a few minute olivine crystals which can be detected with the naked eye. Though brittle, it breaks with a very uneven fracture, and weathered surfaces in joint plains have a peculiar pitted apppearance. Much of the basalt is compact, but amygdaloidal structure is common. The amygdules are small; few have a diameter of 1cm. Apophylite occurs in most of the cavities.

The microscope shows that olivine and pyroxene make up about half the rock. Polysynthetically twinned lath-shaped feldspar microlites, small crystals and grains of magnetite, apatite microlites and a variable quantity of glass, with a little serpentine make up the remainder. The other half is composed of feldspar, magnetite, apatite, serpentine and glass.

DIORITE.

The area mapped as diorite includes several widely differing forms of dioritic rock and in one or two places gradations to a rock of the granodiorite type. The boundaries as shown on the map are only approximations. The northeastern part of the area, with the exception of a few points, was deeply snow covered, and much of the southwestern part is loaded with talus. In addition to these obstacles, the compass proved very unreliable.

The textural varieties of the rock range from those so fine that the grains are not easily distinguished without a lens to others in which the hornblendes reach a diameter of an inch, and the feldspars one-half inch. Transitions from one texture to another are generally gradual, but in a few places the change is so abrupt as to suggest an intrusion of the coarse grained rock by a finer. Luster mottling, due to the exposure of the large, brilliant cleavage faces of hornblende gives some areas of the rock a striking beauty.

In structure there are also wide differences. The great volume of the rock is massive, but gneissoid and even schistose phases are common. A platy structure is also developed over considerable areas. Abrupt changes of structure may be observed in a number of places. Spheroidal sundering occurs even in the fresh rock of massive structure.

The mineral composition varies almost as widely as does the texture. The coarse, gneissoid forms are richest in feldspar, while the luster-mottled rock is richest in hornblende. The rock is remarkably fresh in appearance. Even small flat blocks show but a thin, weathered crust.

The feldspars of the coarsest rock, where fresh, are blue and show a fine play of colors on both basal and pinacoidal cleavage faces. Twinning striæ are common in this phase. Dark minerals vary in quantity from about a third to three-fourths of the rock mass. Hornblende, more or less chloritized, is the chief dark mineral, but a few small crystals of dark mica and irregular grains of black iron ore can be seen in the coarser variety.

Dike-like bodies of aplitic granite are somewhat numerous in certain parts of the area, and toward the eastern extremity of the area it is very much cut up by stringers, dikes and veins of various types of granite—aplitic, gneissoid, porphyritic and pegmatitic. In places the diorite forms merely boulders and blocks in a granitic network. Along its eastern border the diorite holds blocks of included schist, gneiss and fine granite.

In thin sections the feldspars are lath-shaped and often show Carlsbad or pericline twinning combined with the universal albite twins. Extinction angles are those of labradorite. Inclusions of apatite are common. The hornblende, which is green and strongly pleochroic, is usually in aggregates of small anhedrons.

Brown, pleochroic biotite is very subordinate in amount to the hornblende, with which it is frequently intergrown. It is not present in all the specimens examined. Black iron ore in skeleton crystals and formless grains is fairly common.

In all probability the rock was originally a gabbro or diabase with ophitic or diabasic texture. Both the hornblende and mica show evidences of their secondary origin and many have been derived from more than one variety of pyroxene.

GABBRO.

The wall rock of the Snowbird mine, which is nearly due north of Columbine, four and a quarter miles distant, is a gabbro, closely related to the diorite of Farwell Mountain. The gabbro is exposed over a considerable area, but the contact with the older rock was not traced. It is a fine-grained, dark colored rock in which the unaided eye can detect the twinning striæ of the feldspars and recognize brownish-black mica as one of the dark minerals. The greater part of the dark constituents is augite, determinable only under the microscope. It is hypautomorphic, having crystallized later than the feldspars, and in many cases is intergrown with the biotite. Green hornblende is not infrequently seen around the borders of the augite crystals as an alteration product. Black iron ore is associated with the ferromagnesian constituents. Slightly more than half the rock is plagioclase, which is similar to that of the diorite but with less regular outlines.

CONTACT METAMORPHISM.

In addition to the very general metamorphism of the Dakota sandstone and conglomerate and less general metamorphism of the Jurassic sandstones noted in the descriptions of those formations, a thorough change has been effected in the sedimentaries at the contact with the porphyry masses. Fracturing of the country rock for short distances almost invariably accompanied the intrusion of porphyry. By the ingress of the molten rock into the fissures formed, extreme metamorphism was produced in many cases. The Mancos and Dakota shales are indurated and in some instances altered to pocellainite. Perhaps brecciation is more pronounced in these shales than in any other rock except the Dakota quartzite.

Good exposures at the eruptive contact are uncommon and the effects of metamorphism are not easily observed. One of the best places for studying the phenomenon is near the top of

Iron Mountain on the southeast slope. Here the prophyry in its passage upward has dragged with it the edge of the sandstone beds, giving them a strong dip away from the porphyry mass. In addition to the coloring mentioned in the description of the Jurassic sediments the sandstone has been transformed to a structureless quartzite, which breaks with a conchoidal fracture and shows little or no evidence of the original sand grains.

Similar intense metamorphism may be seen at the contact of the Mancos shales with the porphyry of Twin Mountain, a mile northeast of Hahns Peak, where the shales are baked to a very hard porcellainite which rings under the hammer and breaks with a smooth conchoidal fracture. This marked change extends in places with but slight decrease in intensity for a distance of 15 to 20 feet from the contact beyond which the effects gradually decrease until at 40 feet from the contact the shales have their normal appearance. In other places the intense metamorphism is confined to a band not more than 8 or 10 feet wide. Similar phenomena are observed at the contact of the Hahns Peak porphyry and Mancos shales directly east of the peak.

CHAPTER III.—ECONOMIC GEOLOGY.

THE PLACERS.

The Hahns Peak placers were discovered by Joseph Hahn in 1865, and active work was begun on them in 1866. While the activity with which the placers have been worked has varied, probably not a year has passed in which there has not been some gold taken out. The total production of the region is a matter of uncertainty and will never be known. The "estimates" are the merest guesswork, as is shown by the fact that they range from $200,000 to $15,000,000. The more conservative estimates place the amount at from $200,000 to $500,000.

The attempts to locate the lode from which the placer gold came have resulted in a reasonably thorough examination of the region by prospectors and others. But, up to the present, no mines of large promise have been opened, and the source of the gold is yet a matter of doubt. The mines which have yielded the most—the Tom Thumb and the Minnie D.—have, strangely enough, given absolutely no aid to the solution of the problem, since they have yielded mainly silver and lead, and practically no gold in a form which could satisfactorily account for the rather coarse placer gold of the area south of the peak.

A number of theories have been advanced to account for the gold, but none of them is backed by convincing field evidence. The most popular theory is that the gold came from the porphyries of Hahns Peak. In support of this view are the following facts: (a) A very large percentage of the debris of the placers is porphyry. (b) The drainage from the porphyry area is toward the placers. (c) The contact between the sedimentaries and the porphyry is everywhere more or less mineralized. (d) And free gold has been found in the porphyry near the contact. (This last statement has been made by reliable men in the district, but has not been confirmed by the writers.) (e) The porphyry is said to assay regularly from a trace to 60 cents per ton in gold, while occasional assays reach $1.50 per ton. Another theory is that the gold came from the Dakota formation, and particularly from the basal conglomeratic member. In support of this view are: (a) The fact that, locally, the conglomerate pans gold. (b) Some of the branches of Beaver Creek, Ways

Gulch and other tributaries of Willow Creek drain an area from which Dakota has been removed by erosion. (c) Placers have been worked along the streams flowing through Little Red Park, which also drain an area from which Dakota has been eroded, (but in which porphyry still remains). A third possibility is that the gold was derived primarily from the metamorphic rocks of the pre-Cambrian area. The drainage from the west slope of the Park Range would bring the products of erosion from the granites, gneisses and schists and deposit them along the gentler slopes of the range, and on the plains to the west. The facts bearing on this view may be stated as follows: (a) Grains of placer gold are found attached to and partially surrounded by vein quartz. (b) Pebbles of vein quartz, schist, granite and gneiss are found in the placer gravels. (c) The metamorphic rocks contain many small quartz veins while the porphyries show few or none. The Wyoming conglomerate which occurs in isolated patches is composed largely of Archean material. There is evidence that at no very remote time this conglomerate, which is certainly post-Mancos in age, and possibly late Tertiary, once covered a very large area in the vicinity of Hahn's Peak. Two or three panning tests of the conglomerate yielded colors and it is reported that a small body of the disintegrated rock, near Columbine, gave good results when worked as a placer.

The structural features of the conglomerate suggest deposition from running water rather than deposition in lakes. It was never very firmly consolidated, and consequently would be completely broken down in the process of erosion, and the gold would be concentrated at no great distance from its secondary source in the conglomerate. In several parts of the area mapped, especially in the southern and southwestern, there are deposits of gravel more or less cemented. The materials of these are very similar to those of the conglomerate. In a few places the relations are such as to suggest that they may be remnants of the same conglomerate which was less firmly cemented at a distance from the igneous intrusions around the peak. In other areas they are evidently of more recent deposition and may be the product of the erosion of the conglomerate. Panning tests of these gravels along Willow Creek yielded a few very fine dust-like colors.

A serious obstacle to the working of the placers by sluicing and hydraulicking is the absence of sufficient gradient to dispose readily of the tailings.

A small amount of mining is done almost every year, but the volume of gravel moved is small. The general character of the deposit is such that dredges should encounter no serious obstacles in that regard. But the supply of water is limited and the ground can be worked only from excavations filled with water to float the dredges. The Iowa Hahns Peak Gold Mining Co. holds 500 acres of patented ground, on which it has placed an 80-horsepower bucket-ladder dredge having a capacity of 500 yards per day. The operation of the dredge has not proved profitable, and it is now idle. The failure is probably due to the faulty construction of the dredge rather than to the lack of gold, since reliable tests have shown that the gravel in that vicinity should pay well under proper dredging conditions. The gravel at the point where the dredge was at work in the summer of 1907 had a depth of about eight feet.

Messrs. C. E. Blackburn and Thos. A. Brown have put in a hydraulic plant, which is now in operation. A clean up in July, 1909, yielded 150 ounces (Troy) of gold.

LODE MINING.

Lode mining has not yet proved successful or remunerative. Two mines—the Tom Thumb on the west side of the peak, and the Minnie D., near Columbine—have taken out ore of excellent grade, but the absence of good transportation facilities and the distance to the smelters made the cost of mining and treatment so high as to leave no profit for the operators. The Tom Thumb produced a limited amount of ore on which the returns showed values of $60 to $70 per ton in silver and lead. The last work was done about 1897, under lease, by Mr. Pat Magill, who reports that he took out a small shipment which ran over $90 per ton, but that the profits were nothing.

The workings consist of two tunnels, each about 200 feet long, a shaft 50 feet deep and a winze 50 feet. Considerable stoping was done from the lower tunnel which follows the brecciated contact of a pale pinkish gray rhyolitic porphyry with the whiter porphyry so abundant on the peak. This contact is near the face of the mountain. A purplish porphyry also occurs, but is not abundant in the lower tunnel, which is about 50 feet below the upper. Slipping and minor faulting are common, and have proved favorable for ore deposition. Blocks of the white porphyry were found coated with ore—mainly a silver-bearing galena. In places weathering has changed part of the galena to cerusite (lead carbonate). The ore carries a small amount of gold. Shipments are said to have amounted to 200 tons of ore, part of which went to Denver and part to Leadville. The only available assay of a shipment was that of nine tons which ran 2 ounces of gold, 52 ounces of silver and 51.8 per cent of lead. But this was probably higher in gold than the average. From what can now be seen in the mine the ore filled narrow seams and formed crusts over blocks of porphyry in the breccia zone. Too little work has been done to prove the mine either a possible success or a failure.

The full workings of the Minnie D. were not accessible. They consist of a vertical shaft 325 feet deep, an adit of about 300 feet and some exploratory work from the shaft.

The following log of the shaft was furnished by Mr. D. Stukey, of Steamboat Springs:

	FEET.
Black shale	25
Quartzite, white to gray	42
Shale, mostly black	80
Quartzite and fine conglomerate	35
Limestone and dolomite	140
	322

The strata are nearly horizontal and represent Cretaceous and Jurassic time—the limestone and dolomite belonging to the latter. The vein is rather well defined and varies in width, reaching a maximum of about four feet. The distribution of ore in the vein is said to be irregular. Various assays are reported, but probably the returns of a small shipment to Leadville may be regarded as representative so far as gold and silver are concerned. This is reported to have given 0.42 ounces gold and 8.32 ounces silver per ton. An assay from the vein, given by Mr. E. L. White in the report of the Bureau of Mines for 1905-6, page 132, gives 0.16 ounces gold and 82.52 ounces silver per ton.

The tunnels of the Hahns Peak Gold Mining and Milling Company are on the northwest slope of the peak, at elevations of 9,200 and 9,600 feet. The longer one is 950 feet in length and follows a course N. 80° E. From this tunnel a winze was sunk 60 feet, following a seam of ore. From the bottom of the winze a drift was driven 100 feet northward. The tunnel starts in

Dakota quartzite, passes through Jurassic sandstone and limestone and into sandstone again. At 25 feet from the breast a quartzite dips 30 degrees in a northwesterly direction. Shale bands occur at two points. Dikes of porphyry and rhyolite cross the tunnel at several points. Pyrite is found in considerable quantity throughout the tunnel. It occurs in two forms: Well-defined crystals of small size, and in bunches ranging from one-half inch to two inches in diameter. The bunches are soft, finely granular and resemble marcasite. The ore is in gouge-like or talcose seams and consists of dark ruby silver and galena, associated with pyrite. Thirty-five tons of ore were taken from the winze and drift, and it is reported that the ore became richer with depth. Assays of selected samples range as high as $300 and $400, mainly in silver. High gold values are reported from the winze.

The lower tunnel is in 480 feet and is intended to reach the lead followed by the winze. It is reported that a shipment of 150 tons from the Silent Friend gave returns of over $80 per ton.

The Southern Cross Tunnel is owned by Robert McIntosh and Richard Paulson. It is driven 800 feet into the south side of the peak, at an elevation of about 9,800 feet, and is in porphyry practically all the way. At about 400 feet from the portal a shaft was sunk 90 feet in porphyry, but part of the way it is said to have followed a quartzite (Dakota) contact. At 125 feet from the portal the tunnel passes into a highly kaolinized, decayed porphyry, parts of which are distinctly plastic. This is about 120 feet through, and is followed by a fault breccia and a black shaly band. The remainder of the tunnel is in hard white porphyry similar to that already described, page 212. The fault zone crossing the tunnel resembles the contact between the Cretaceous rocks and the porphyry along the ditch on the southeast slope of the peak. Considerable mineralization has occurred along the fault zone and thin seams of galena and silver minerals, mainly ruby silver, were formed. While good assays may be had from selected material, the quantity is not promising.

The Oro-Cache Tunnel, on the east side of the peak, was driven by T. R. Miller, Mike Conlon, E. C. Stimpson, C. E. Blackburn and B. Farris. It could not be examined, but the dump shows much disintegrated white porphyry with distinct pyritic mineralization. The tunnel is 600 feet long. No ore was found. Many other tunnels, varying from a few feet to four hundred, have been driven into the peak in the hope of finding the source of the placer gold. Some of the men interested in these are D. Morgan, E. Bernette, F. Sandhoffer and E. D. Young. Some of the work has yielded just enough promise to encourage further search, but much of it has been entirely barren. Most of these tunnels have been abandoned, but on some of them work is still being done.

Little pits, shafts, and tunnels are very numerous in the vicinity of the peak. The absence of any mineral indications in their neighborhood leads one to the conclusion that most of the work was done where digging was easiest, with no serious thought of mining, but merely to hold the claims.

The principal company operating in the district is the Hahns Peak Gold Mining and Milling Co. The principal properties developed by the company are the Royal Flush and the Silent Friend. They have recently purchased the Minnie D. and have taken an option on the Tom Thumb. They have put in an air compressor and are using air drills. As soon as the developments demand it a mill will be built.

On Farwell Mountain between forty and fifty claims have been located. Only a few of these have been developed farther than the assessments required. The country rock, as may be seen from the map, belongs mainly to the metamorphic series. This is cut by dikes of aplite, granite, diorite and basalt. Small stringers of quartz are very numerous in the gneisses and schists. Copper carbonates, azurite and malachite, in very small quantity (frequently only stains), accompany the quartz in many cases. These copper indications have led to the location of most of the claims.

All those claims on which work has been done were examined. Messrs. James and Henry Campbell have sunk a shaft over 100 feet deep and have taken out a small amount of copper carbonates and a little chalcopyrite. The ore carries an average of $5 to $6 in gold. Mr. E. F. Carr has a shaft about 75 feet deep. Messrs. Michael Conlon and Frank Sandhoffer have struck ore which runs $5 in gold. The Buckle brothers have had assays which ran as high as $57 per ton in gold and copper. The ores are usually in lenses and stringers of very irregular width and value. Some locations are near, or along the contact with intruded rocks.

Bornite and chalcocite were seen at two or three places. No commercial ore bodies had been reached when the prospects were visited.

The Snowbird mine is north of Columbine, beyond the limits of the map. The development, in September, 1908, included a shaft 25 feet deep, a tunnel about 200 feet long, a tunnel 512 feet long and a drift of 60 feet. The country rock is a fine grained gneissoid gabbro. The vein matter in the shaft is mainly quartz stained with copper. Specimens showing native copper and native silver were found in the progress of the work. The vein is several inches wide and strikes about N. 8 degrees W. The 200-foot tunnel was driven on the lead, but at the time of visit was in bad condition. The gabbro is disintegrated. A small pile of ore showed some native copper. Specimens obtained in 1907 showed chalcopyrite, bornite and chalcocite. The longer tunnel is 385 feet below the shaft. This also follows the lead, but the amount of quartz has decreased. For the last 150 or 200 feet the tunnel follows a vein of siderite. Little or no copper occurs, but assays have shown as high as $14.00 in silver.

The Slavonia camp is on the head waters of the Elk river, outside the map limits to the southeast. The district is well within the metamorphic area. The prevailing rock is a gneiss which, on the one hand, grades into a gneissoid granite, and on the other into schists of various compositions. Cutting the main country rock are dikes of quartz porphyry, granite porphyry, granite and diorite. The vein formation is that characteristic of the metamorphic rocks. Zones of movement and shearing have developed quartz lenses and stringers—sometimes grouped, sometimes singly. In places these form what might be called a vein system. The ores include those of copper, lead, zinc, silver and gold. Nickel has been reported, but tests by the writers failed to show its presence in the samples taken.

It is reported that about forty locations are recorded, but only a few of these have been developed beyond the assessment stage. The Ethel claim, owned by C. E. Blackburn and T. A. Brown, shows a vein zone of considerable width. The ore is galena and sphalerite carrying silver in important amount. The Martha Vranesich claim, on the east side of the creek, is owned by M. Malich, P. Smilanich and N. Rayakovich—showed a rather promising development. There was an open cut on the bluff face and a tunnel 145 feet long at a lower level. The open cut showed a mineralized zone over seven feet wide in which the sheared gneiss was impregnated with chalcopyrite, bornite, sphalerite and galena. While the whole face was mineralized there were richer stringers following the gneissoid structure which was almost vertical. The tunnel follows the course of the vein. Timbering prevented a detailed examination of the walls, but the breast was in ore similar to that exposed in the open cut. A picked sample from the face of the tunnel assayed $62.00 in copper, lead, zinc and silver.

The Slavonia No. 4 is another claim on which considerable work has been done. The character of the vein is similar to that of the Vranesich. On the divide beyond Slavonia proper a number of claims have been located, and some work has been done. One, on a spur of the range, carries much copper-bearing pyrite and a little chalcopyrite. The deep snow prevented the examination of most of these higher claims, but some exposures near the claims showed much pyritic mineralization and heavy gossan. No ore bodies of commercial size have been opened in the Slavonia camp.

The Hahns Peak region in general may be called, even yet, an unproved area. It is true that much work has been done, and that comparatively little of value has been discovered outside the placer ground. But so far as much of the work is concerned, it has been done in an unscientific, unminerlike fashion. Sites for tunnels and shafts have been taken haphazard, in many instances probably because the assessment work could be done at these points more easily than elsewhere. Work once begun was continued in the ill-chosen places to "avoid the loss" of the money already spent.

While it seems to the writers doubtful whether the district will develop into a mining camp of importance, they believe that it is still worthy of a certain amount of well-directed effort. A number of the prospects mentioned in this report deserve further investigation. But the random expenditure of money and effort is unwise.

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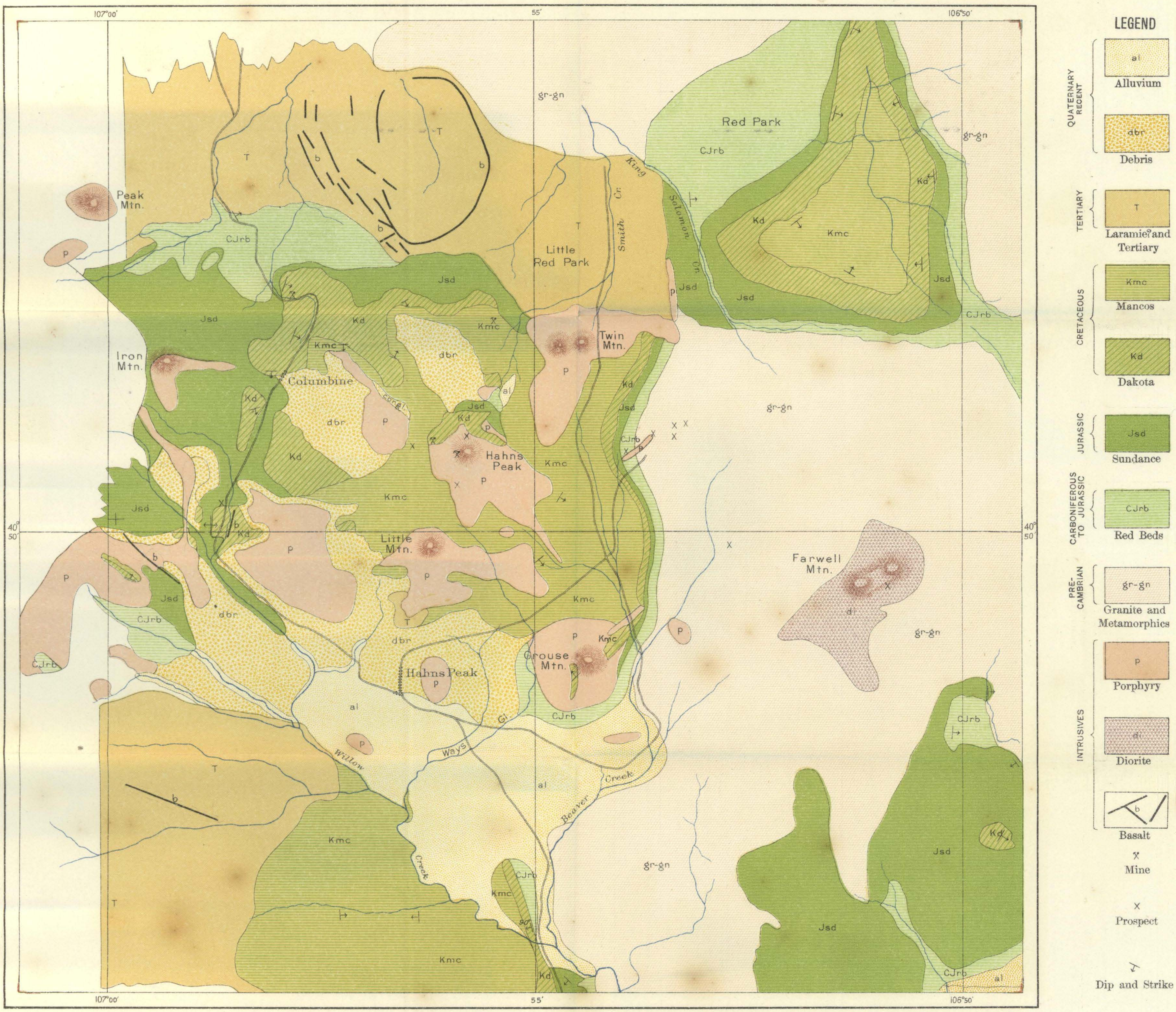
COLORADO STATE GEOLOGICAL SURVEY,
R. D. GEORGE, DIRECTOR

FIRST REPORT, 1908



Topography from various U. S. Surveys, Original Surveys, and other sources.

GEOLOGIC MAP OF THE HAHNS PEAK DISTRICT
ROUTT COUNTY, COLORADO

Scale $\frac{1}{62500}$

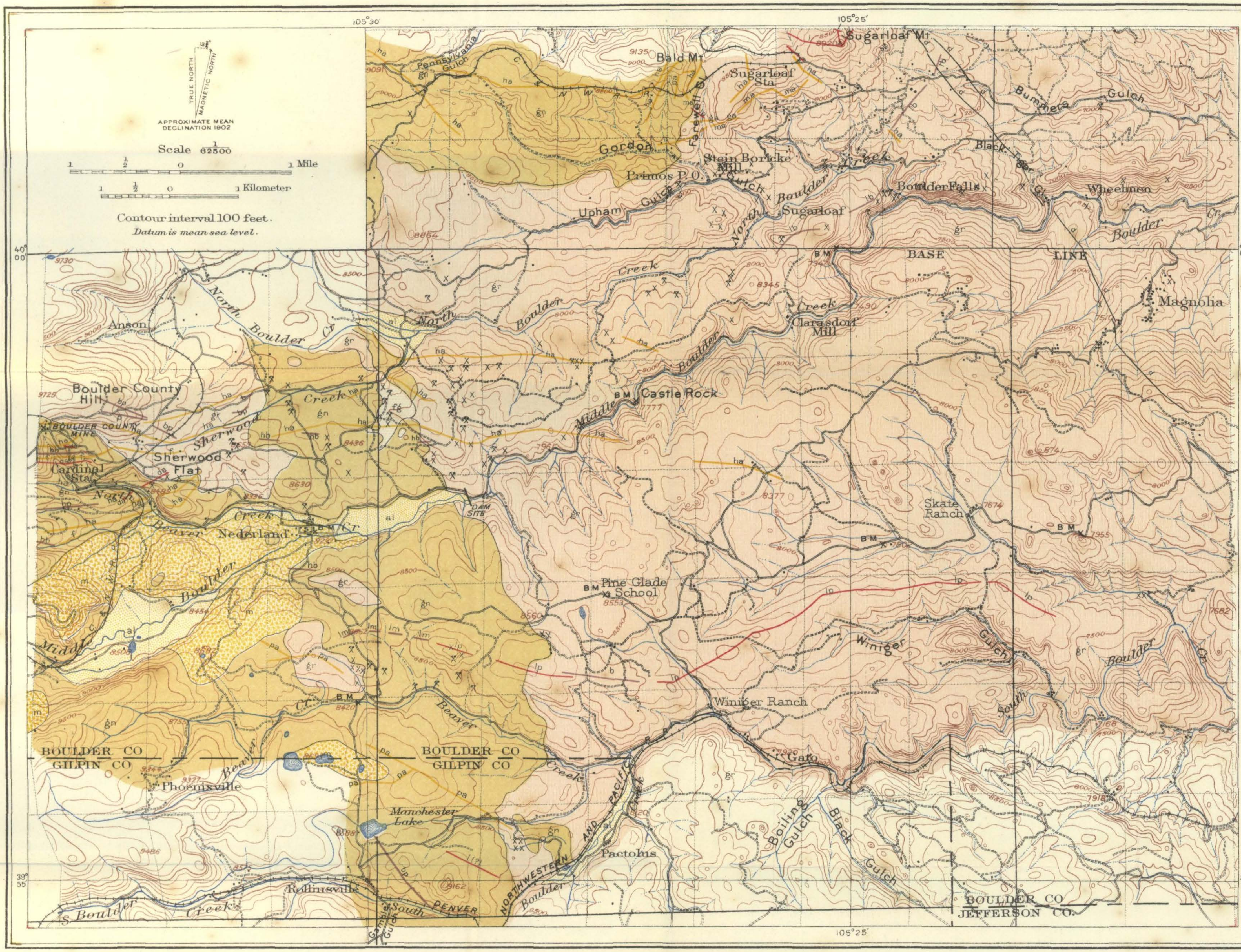
1 ½ 0 1 2 Miles

Geology by R. D. George, James Underhill, R. D. Crawford and B. H. Jackson.

A. HOEN & CO. BALTIMORE, MD.

COLORADO STATE GEOLOGICAL SURVEY,
R. D. GEORGE, DIRECTOR

FIRST REPORT, 1908



Topography by U. S. Geological Survey
Culture modified by
State Geological Survey

GEOLOGIC MAP OF THE MAIN TUNGSTEN AREA
BOULDER COUNTY, COLORADO

A. HOEN & CO. BALTIMORE

Geology by R. D. George and
R. D. Crawford

LEGEND

QUATERNARY

RECENT
- al — Alluvium

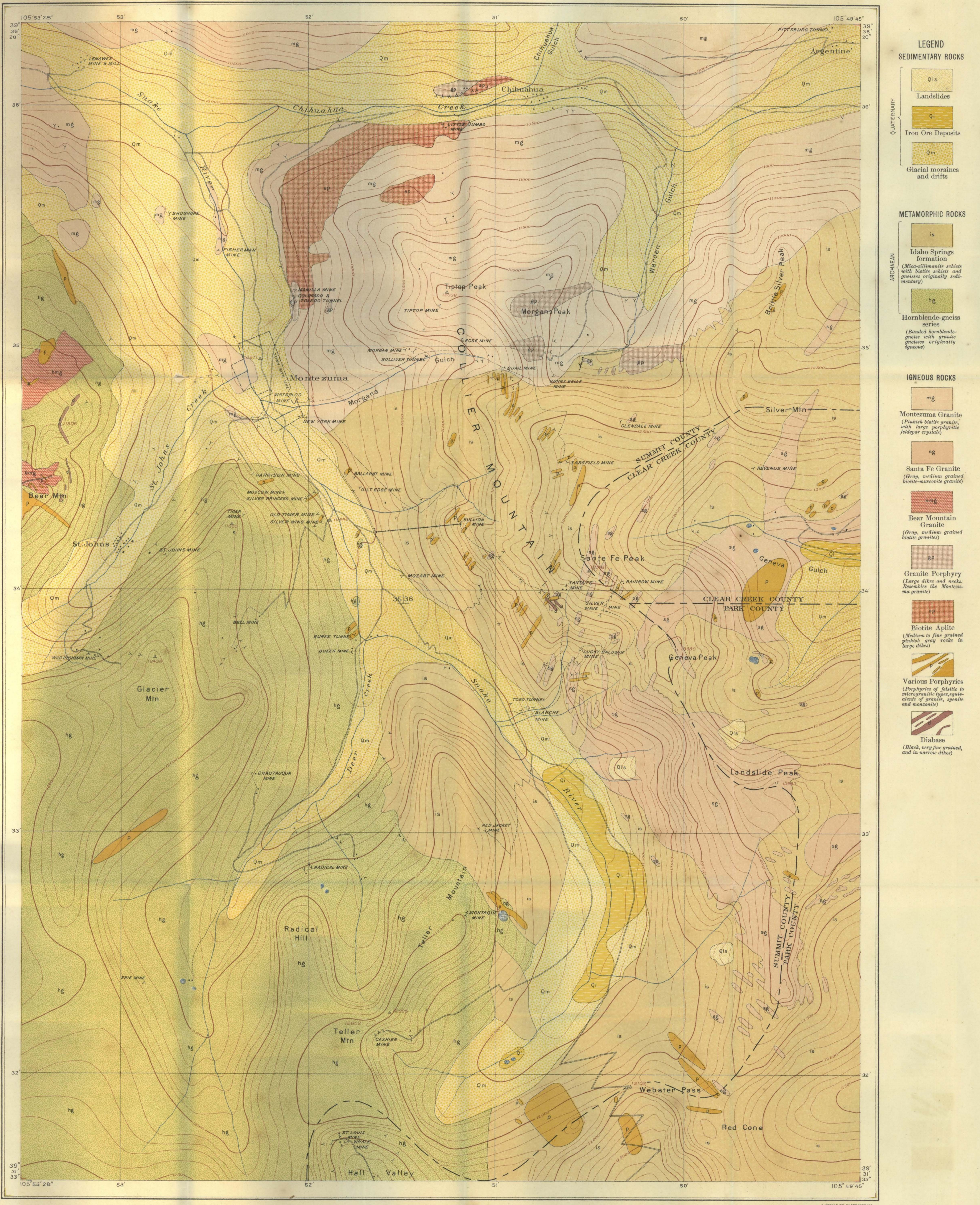
RECENT AND PLEISTOCENE
- m — Moraines

PROBABLY PRE-CAMBRIAN

METAMORPHIC
- gn — Gneiss and Schist (*Probably derived from sediments*)
- gr — Granite, gneissoid, coarse-grained (*of igneous origin*)
- fg — Granite, gneissoid, fine-grained (*of igneous origin*)

INTRUSIVES

DIKES
- da — Dacite
- l — Latite
- lp — Latite Porphyry
- f — Felsite
- ma — Mica Andesite
- ha — Hornblende Andesite
- ga — Glassy Hornblende Andesite
- pa — Pyroxene Andesite
- d — Diabase
- lm — Lamprophyre
- b — Basalt
- bp — Basalt Porphyry
- hb — Hornblende Basalt
- p — Pyroxenite
- lb — Limburgite
- Mine
- x Prospect



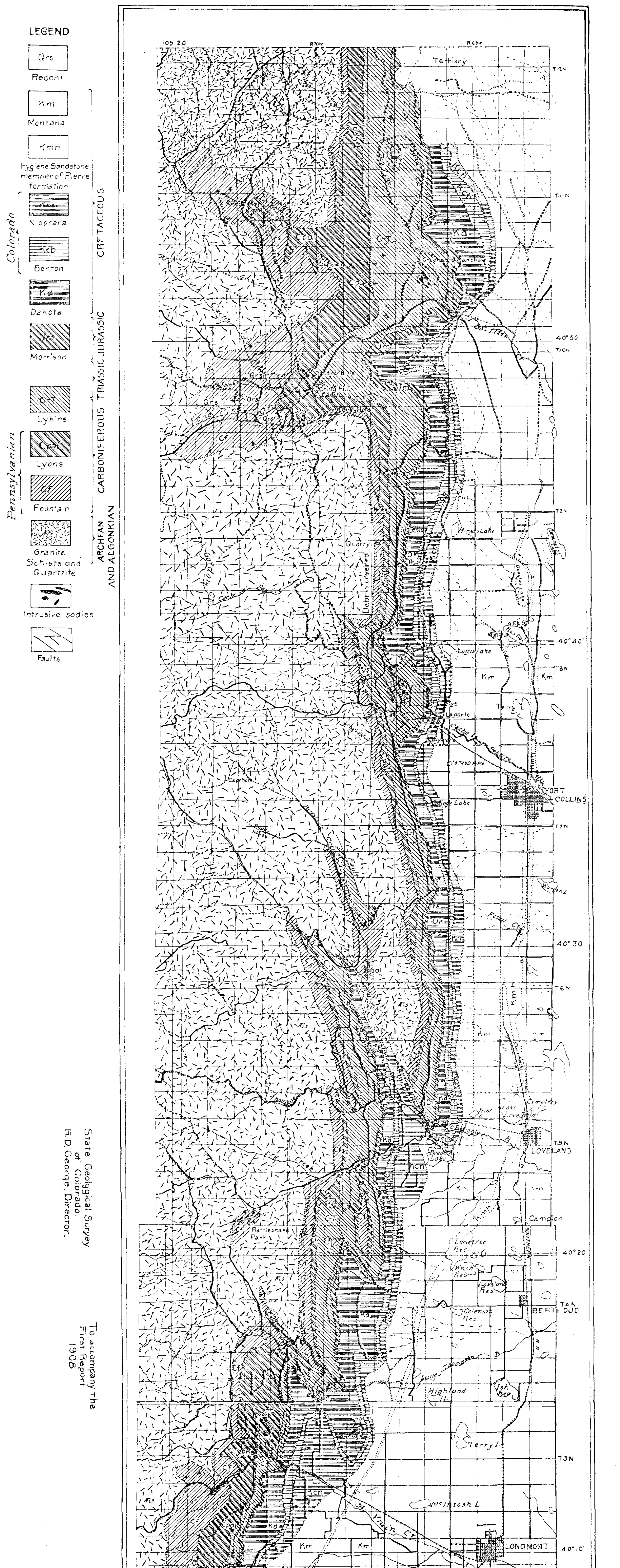
Topography by T. Dyer Benjovsky, and William M. Lewis, under the direction of Horace B. Patton and Charles E. Smith.

GEOLOGIC MAP OF MONTEZUMA, SUMMIT COUNTY, COLORADO

Scale 1/18000
or 1500 feet to the inch

Contour interval 100 feet.
Datum is mean sea level.
1908

Geology by Horace B. Patton, assisted by Charles E. Smith.



Topography reproduced from maps of the U.S. Geological Survey

GEOLOGIC MAP OF THE FOOTHILLS OF NORTH CENTRAL COLORADO

0 1 2 3 4 5 6 Miles

Geology by Junius Henderson Jas. Underhill R.D. Crawford