COLORADO GEOLOGICAL SURVEY

BULLETINS 18, 19, 20, 21 and 22

Fluorspar Deposits, Cretaceous Rocks of Northeastern and Foothills of No. Central Colo, Ward Region and Mineral Deposits Western Slope

COLORADO GEOLOGICAL SURVEY
BOULDER
R. D. GEORGE, State Geologist

BULLETIN 18

FLUORSPAR DEPOSITS OF COLORADO

By
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GEOLOGICAL BOARD.

LETTER OF TRANSMITTAL.

State Geological Survey,

University of Colorado, April 29, 1920.

Governor Oliver H. Shoup, Chairman, and Members of the Advisory Board of the State Geological Survey.

Gentlemen: I have the honor to transmit herewith Bulletin 18 of the Colorado Geological Survey.

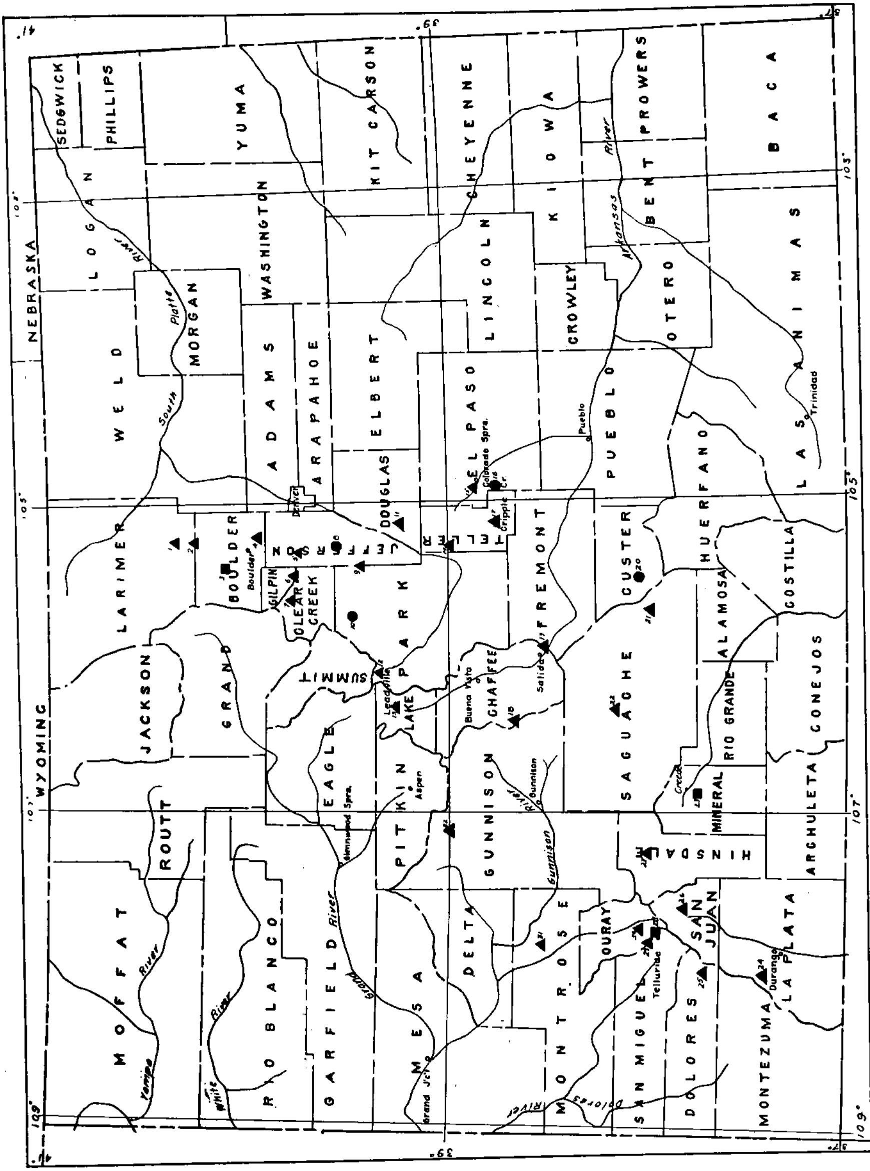
Very respectfully,

R. D. GEORGE,
State Geologist.

CONTENTS

LEGEND.

1—Big Thompson
2—Allen's Park—St. Vrain
3—Jamestown
4—Eldorado Springs
5—Bergen Park—Clear Creek
6—Idaho Springs—Central City
7—Georgetown—Silver Plume
8—Evergreen
9—Buffalo
10—Jefferson
11—Devil's Head
12—Alma
13—Leadville
14—Florissant
15—Pike's Peak—Cascade
16—St. Peter's Dome—Cather Springs
17—Cripple Creek
18—Mt. Antero
19—Badger Creek
20—Antelope Creek
21—Liberty
22—Bonanza
23—Wagon Wheel Gap
24—La Plata Mountains
25—Rico
26—Silverton
27—Lake City
28—Red Mountain
29—Telluride
30—Ouray
31—Montrose
32—Crystal
33—Powderhorn



MAP SHOWING DISTRIBUTION OF COLORADO FLUORSPAR

■ Commercial Deposits.

● Probable Commercial Deposits.

▲ Non-Commercial.

Fluorspar occurs as gangue mineral in ores or as individual crystals.

PREFATORY

During the spring and early summer of 1917 the State Geologist applied through the newspapers of the State, and by specially prepared notices, for information concerning workable deposits of certain minerals for which the war had caused an increased demand.

Persons knowing of such minerals were asked to send in samples together with a description of the deposit from which they were taken. If the sample and the description of the deposit seemed to warrant an investigation, a member of the Colorado Geological Survey was then sent to make an examination of the deposit. The data obtained from the investigation was filed in the office of the Colorado Geological Survey, and if a deposit proved promising a report was then presented to the proper United States official. Information concerning producing and workable deposits of these minerals was in this way made immediately available to the proper board in Washington.

MINERALS NEEDED BY THE U. S. GOVERNMENT

The Colorado Geological Survey is co-operating with the U. S. Government in an attempt to find workable deposits of certain minerals for which the war has caused an increased demand. Among these materials are: Ores of molybdenum (free from copper), ores of vanadium, uranium, nickel, manganese and platinum. Transparent, unfractured fluorspar in fairly large pieces, and as nearly colorless as possible is also needed. Pale green and very pale purple colors may not prevent its use if it is otherwise satisfactory.

Persons knowing of deposits of any of these ores should write to R. D. George, State Geologist, Boulder, Colo., sending an average sample of the ore if possible, and describing the deposit. If the sample and description appear to warrant further investigation the state geologist or someone appointed by him will examine the deposit without expense to the owner. If it should prove promising a report will be presented to the proper United States officials.

Prospectors and others not familiar with these ores will find descriptions of them in Bulletin 6 of the Colorado Geological Survey. This is now out of print, but Bulletin 12, covering much the same ground, will be sent to those who have not had Bulletin 6.

The Survey may be able to furnish small fragments of the commoner ores to a few prospectors. But unless they are really needed they should not be asked for as only a very small amount of the material can be spared.

(Signed) R. D. GEORGE,
State Geologist.

Deposits which were producing or had formerly produced any of the required minerals were investigated, and a careful analysis was made of the possibilities of each deposit as a source of immediate production.

As a result of these investigations a large amount of valuable information has been obtained, which should prove of real economic value even after the demands created by the war no longer exist. This bulletin presents the information gathered in the search for fluorspar.

Fluorspar Deposits of Colorado

CHAPTER I

INTRODUCTION

The greatly increased demands for Fluorspar since the beginning of the European War have caused a corresponding increase in the price of this non-metallic mineral which formerly had only a moderate value and for which there was only a limited demand. The demand has been stimulated on account of its extended use in metallurgical, chemical and ceramic industries; the greatest demand for it being made by the steel and chemical industries, where it is used principally in the manufacture of open hearth steel and hydrofluoric acid.

This demand with the resultant higher prices has stimulated a renewed interest in the fluorspar mining industry in Colorado. Mines which have been producing intermittently for years are now being worked with renewed energy, others which have been closed down for years are now being re-opened, and new mines and entirely new deposits are constantly being opened.

The milling of fluorspar is being tried for the first time in Colorado, and one company is successfully operating a commercial mill in Boulder. Other companies are contemplating the milling of their ores, and three of them have carried on experimental tests with a view to the installation of milling machinery.

LOCATION OF FLUORSPAR DEPOSITS

The fluorspar deposits of Colorado are found mainly in a belt roughly paralleling the eastern side of the Front Range. Several disconnected but equally productive areas occur in the southern and southwestern parts of the state, and other deposits of no economic value are found scattered throughout the mountainous portions of the state.

With the exception of those deposits in the San Juan district no deposits of economic value are found on the western slope.

Comparatively few specimens from that part of the state have come to the attention of the writer, and they gave no promise of commercial value.

Fluorspar is found exposed on a number of the streams forming the drainage on the eastern side of the Front Range. It is these deposits which form a belt roughly paralleling the Front Range, extending from the South St. Vrain in Boulder County south to St. Peters Dome and Cather Springs in El Paso County.

A second series of deposits, not so well defined and of much less extent, is to be found much closer to, but roughly paralleling the Front Range. These are shown by the presence of fluorspar in the ores of the Clear Creek, Cripple Creek and Alma districts, near Jefferson, Park County; Florissant, Teller County; and on Antelope Creek in Custer County.

A third district includes those deposits in the San Luis Valley where fluorspar is found on the west side of the Sangre de Cristo Range near Liberty, Saguache County; on the east side of the Continental Divide at Bonanza, Saguache County; and at Wagon Wheel Gap, Mineral County.

A fourth region includes the San Juan district where fluorspar is found both in commercial quantities and as a gangue mineral in the ores of the various camps throughout the district.

A small deposit of no commercial value is found on the south side of the Black Canyon of the Gunnison on Vernal Mesa near Montrose. Other scattered deposits of the mineral were noted, where it is found as a gangue mineral in the ores of the Crystal (Gunnison Co.,), and Leadville mining districts.

THE FLUORSPAR INDUSTRY IN COLORADO

In 1869, F. V. Hayden reported the presence of fluorspar in the ores of the Baker mine[1] located four miles above Georgetown in a canyon known as the West Argentine. Red and white varieties of fluorspar occurred largely as a gangue in the lode.

Again in 1878, F. V. Hayden reported the presence of fluorspar in the Terrible mine at Georgetown;[2] on Mt. McClellan and Gray's Peak; in the Sweet Home mine, Leadville; at Jamestown; and on Kendall Mountain near Howardsville, San Juan County.

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[1]Hayden, F. V., Geographical survey of the territories: U. S. Geol. Survey, 3rd Ann. Rept., p. 209, 1869.

[2]Hayden, F. V., Geographical survey of the territories: U. S. Geol. Survey, 10th Ann. Rept., pp. 142-143, 1876.

In his biennial report for 1880 the State Geologist of Colorado reports occurrences of fluorspar as follows: At Jamestown, Boulder County, massive deposits in which visible grains of free gold were occasionally found; in large metalliferous veins on Bear Creek, Jefferson County; and in the silver mines of Argentine and Georgetown.

The actual mining of fluorspar in Colorado appears to date back to the early "seventies," when fluorspar was mined from the deposit on Cub Creek, southwest of Evergreen, Jefferson County, and carted 28 miles to the Central City district[3] where it was used as a flux in the smelting of the gold and silver ores of that district. The mines produced about 600 tons of fluorspar[4] which was sold to the Boston and Colorado smelter at Black Hawk before it was removed to Argo.

H. N. Coffey is reported to have shipped fluorspar from the Poorman claim at Jamestown, Boulder County, as early as 1873 or 1874. This property had been opened for gold which did not occur in paying quantities, and as there was a limited demand for fluorspar, a small tonnage was hauled to the Boyd smelter at Boulder. After standing idle two or three years the shaft was repaired and other shipments were made to Boulder, where it was used as a flux in smelting the gold and silver ores of the Boulder district. The price was $5.00 per ton.

The fluorspar deposits on Cub Creek and at Jamestown were worked very irregularly. In 1905 it was estimated that Colorado had produced less than 6,000 tons. [5]The greater part of this production had come from the Jamestown district where development, although very slow, had progressed somewhat.

The inability of the miner to sort the material and make a high-grade product, the distance from the railroads, the high cost of haulage, and the low price made the mining of fluorspar unattractive. Metalliferous mining was much more inviting to the miner in those districts, and his chances for profit were far better.

Because of the high freight rates, the high cost of mining, and the low grade of the product, Colorado fluorspar could not compete on the eastern market with that from the Illinois-Kentucky fields, and that imported from Europe. The Colorado deposits had not been developed enough to show their possible production. Transportation to railroad was slow and costly, and no milling or sorting

[3]Burchard, Ernest F., Min. & Sci. Press, p. 258, Aug. 21, 1909.
[4]Williams, Albert, Jr., U. S. Geol. Survey, Min. Res., p. 587, 1882.
[5]Burchard, Ernest F., U. S. Geol. Survey, Min. Res., pp. 1099-1103, 1905.

facilities had been installed to guarantee a uniformly high grade product, such as was necessary to insure a good market. As a result, practically the only market for Colorado fluorspar was that furnished by the Colorado Fuel & Iron Company at Pueblo. As the available market for fluorspar was limited and the margin of profit exceedingly small no great progress was made in the industry. When there was little or no activity in metal mining, and an unusually promising deposit of fluorspar was found, the output of the State would increase.

These conditions prevailed up to 1915 when there was produced in the State a total of less than 1,000 tons of fluorspar. In 1916 greater demand and higher prices stimulated interest in the industry, and a corresponding increase in production followed. In 1917 there were one or more producing mines in six different districts. One mill was producing concentrates, and much experimenting in processes of milling was in progress. Mines were being opened in several entirely new districts. In the spring of 1918 practically all the mines which had produced in 1917 were again open, and in the Jamestown district many new mines were operating. Three mills were producing concentrates and preparations were being made for the operation of others.

ACKNOWLEDGMENTS

In presenting this report the writer desires to express his thanks and acknowledge his indebtedness to all who by their courteous treatment aided so materially in the gathering of much valuable data. He is especially indebted to John Evans of Jamestown, S. B. Collins of Creede, C. R. Wilfley of Ouray, and D. W. Phillips of Wagon Wheel Gap who gave much time and many valuable suggestions.

SCOPE OF THE FLUORSPAR INVESTIGATION

In the investigation of the various fluorspar deposits, special attention was paid to the location, size and character of the deposit, as well as to the production, or possible production under properly applied methods. Each deposit was examined carefully for the presence of optical fluorspar, and many smaller deposits, of no commercial value so far as production was concerned, were visited in the hope that optical material might be found.

GEOGRAPHY

Colorado fluorspar deposits are, with one exception, very poorly situated so far as transportation facilities are concerned. Those larger deposits along the Front Range at Jamestown, Boulder County; Bear Creek, Jefferson County; and Antelope Creek, Custer County are located four to sixteen miles from a railroad. The Barstow mine at Red Mountain while but one mile from the railroad, can depend on that road only five months out of the year. During the other seven months it must haul the ore fourteen miles to Ouray, over the most treacherous of roads. The Wagon Wheel Gap deposit can be worked the year round, is located one and a quarter miles from the railroad, and is connected with it by a tram. This is the only deposit of any size which is at all well situated so far as railroad transportation is concerned.

The building of good roads suitable for truck haulage will eventually solve the transportation problem in several localities where the construction of a railroad is not now justifiable.

The southwestern part of the State suffers through the lack of standard gauge railroads, the high cost of the present mode of transportation, the short period during which the deposits can be worked each year, and the difficulties experienced in shipping during the winter months.

CHAPTER II

THE FLUORSPAR INDUSTRY IN COLORADO

Up to the present time the Colorado producers of fluorspar have been unable to compete with eastern producers either in the eastern markets or in the local market furnished by the Colorado Fuel & Iron Company at Pueblo. This has been due to the following facts and conditions:

1. The meager development of the fluorspar deposits.
2. A lack of proper mining equipment.
3. Carelessness or indifference in the grading of ores. The silica content is so high that the value of the ores is greatly reduced. Markets for such a product are exceedingly scarce.
4. The cost of hauling to railroads and the high freight rate to eastern markets.

IMPROPER DEVELOPMENT

The fluorspar deposits in most districts have been worked irregularly and with one end in view—that of getting out the greatest tonnage possible in a short time. The ore has been obtained by gouging and gophering and no proper development has been done. Caving results, much valuable ore is rendered inaccessible, and the miner seeks a new deposit and starts again.

MINING EQUIPMENT

Very little machinery has been used under the prevailing method of mining, whereas, in many cases a small expenditure on equipment would have been repaid many times by the results obtained.

GRADING OF FLUORSPAR ORES

Until 1917 no attempt was made to grade the ore shipped from the various camps, other than to hand cob and sort it before shipping. Many foreign materials such as quartz, clay, fragments of the granite side walls and gouge would get into the ore, and the percentage of calcium fluoride was so low that, in some cases, there was no market for the product, or the shipment was penalized so heavily for the high content of impurities that it did not pay the shipping charges.

Illinois and Kentucky operators have always been able to deliver an 85 per cent spar, with a silica content of less than 5 per cent. This standard has been reached in only a comparatively few shipments from Colorado districts, the main cause being the poor methods of grading used, and the lack of effort to eliminate this fault.

In Illinois and Kentucky the principal gangue mineral is calcite, a carbonate of lime, and the vein walls are mainly limestone. Neither of these adds to the silica content of the ores, whereas in Colorado the vein walls are granite or some other highly siliceous rock, and the principal gangue mineral is usually quartz, or material high in silica content.

The usual method of paying for Colorado fluorspar has been to fix a certain price per ton for fluorspar containing 85 per cent calcium fluoride and to give a premium for each additional per cent of calcium fluoride contained. In like manner the product was penalized for each per cent of calcium fluoride below 85. Buyers did not like to accept ore carrying less than 80 per cent calcium fluoride, and it was extremely difficult to dispose of it. This method was at times looked upon as unjust by the Colorado miner, but when it is remembered that, in the steel industry, an average of about 2.5 per cent of calcium fluoride is needed to neutralize 1 per cent of silica, it will be clear that a high percentage of silica is very detrimental, and that a high calcium fluoride content must be required.

During the summer of 1917 several cars of fluorspar having a high silica content, consigned to eastern buyers, were rejected even though the need of fluorspar at that time was exceedingly great.

By such experiences the miner was gradually impressed with the fact that the fluorspar ores would have to be graded more carefully, if he expected to find a ready market for his product. The milling of fluorspar was then started with a view to getting rid of the excess silica, and raising the calcium fluoride content.

MILLING OF FLUORSPAR

The simpler washing processes in vogue in the Illinois-Kentucky fields are not well adapted to most of the Colorado ores, as there is only a very slight difference between the specific gravity of the fluorspar and that of the quartz and feldspar forming the gangue. (Quartz 2.65, feldspar 2.70, fluorspar 3.13.) These methods could be used, but they would entail the installing of an elaborate system of screens and jigs. This would without doubt prove too expensive for the indivdual property which is not only small, but is working on a very close margin of profit.

Well equipped mills are standing idle in the Boulder County, Custer County, and San Juan districts, and there is no reason why methods of jigging and concentration should not be tried in all these districts. A small mill operated by the Hoffnung Mine and Milling Company has been milling the dump of the Argo mine at Jamestown, making a lead concentrate, and at the same time demonstrating the ease with which fluorspar may be concentrated. Early in the spring of 1918 this company adapted their equipment to the milling of fluorspar, and expected to commence commercial operations in May.

During the latter part of 1917 a commercial mill was opened in Boulder for the milling of Boulder County fluorspar. Truck service was installed between Boulder and Jamestown. The miner was paid for his ore according to the percentage of calcium fluoride it contained. A deduction was made to meet the haulage and loading charges.

On a recent visit to the Jamestown district the writer was told that the Wano mill, which has been idle for some years, was about to be remodeled and opened for the milling of fluorspar.

FLUORSPAR CONCENTRATES

It is reported that some users of fluorspar object to concentrates on the ground that, in use, there is great loss in the form of dust. With the increasing demands for fluorspar, there can be little doubt that methods will be adopted by which the concentrates may be used as effectively and economically as can lump and gravel fluorspar.

PRODUCING AND MARKETING

In order to overcome this handicap the Colorado deposits must not only be operated by the most economical methods, but the product must be constant in quality, and one on which the buyer can absolutely depend. The average miner or mine owner can not afford to operate a mill but must depend upon and cooperate with those who will mill and find a market for his ore. He must aid the shipper by having ready and actually furnishing his required tonnage at a specified time, as the buyer will likewise demand promptness of the shipper in his deliveries. The miner must be willing to accept a reasonable profit in the future, for while the war demands have created a high market value there will be a return to lower prices and more normal conditions.

GEOLOGY

The fluorspar deposits of Colorado are, with the exception of those at Rico, found entirely within areas of granite or other highly acidic rocks of igneous origin. The veins in Boulder County, Jefferson County, El Paso County, and Custer County are found in fissure veins, entirely within the granite. Their chief content is fluorspar, but at times the fluorspar content becomes negligible and the veins become mainly metalliferous. In some instances in Boulder County, fluorspar veins and metalliferous veins occur in the same district associated with porphyry dikes which have intruded the pre-Cambrian gneisses and granites.

In Mineral County and the San Juan district the veins occur within areas of highly acidic volcanic rocks of Tertiary age, mainly tuffs, rhyolite, latite and andesite.

Fluorspar occurs as a gangue mineral in some veins, but at Wagon Wheel Gap and in the Barstow mine at Red Mountain the vein filling is nearly pure fluorspar. Although the fluorspar vein in the Barstow mine lies in close proximity to metalliferous veins the material in the vein is very pure, and practically no fluorspar is found in the adjacent metalliferous veins. At Wagon Wheel Gap the vein filling is nearly pure fluorspar, though some barite is found locally near the surface. The wall rock, which is much more altered than in any of the other deposits mentioned, carries disseminated pyrite. The ores of most of the mining districts lying within igneous rock areas show the presence of fluorspar as a gangue mineral, while at Rico, fluorspar, although not of widespread occurrence, is abundant in the replacement deposits of the Black Hawk mine.

CHAPTER III

FLUORSPAR—FLUORITE

PHYSICAL PROPERTIES

Fluorite, or fluorspar as it is commonly called, is a non-metallic mineral, chemically a calcium fluoride, (CaF_2) consisting of calcium and fluorine in the proportions of 51.1 to 48.9. The mineral is oftentimes spoken of as "spar" but the term is very misleading as the average miner applies the same term to barite (heavy spar), calcite (calc spar, Iceland spar), fibrous gypsum (satin spar), ankerite (brown spar-pearl spar), dolomite, siderite, feldspar, quartz, etc.

Color.—Fluorspar may be almost any color from white, or colorless, and gray to deep red, deep green, and deep purple. In Colorado white, gray, brown, pale green, deep green, lavender, violet-blue, and deep purple fluorspar have been found.

Luster and Diaphaneity.—Its luster varies from vitreous in clear crystalline varieties, to dull and earthy in some of the granular varieties. Some deep purple varieties found near Evergreen had a sub-metallic luster. The mineral varies in its diaphaneity from transparent to almost opaque.

Crystal Form.—Fluorspar crystallizes in the isometric system and is often found in the form of cubical crystals, although the writer found numerous octahedrons encrusted with quartz in the Eagle mine near Bonanza, and in the Aspen mine at Silverton. Massive, crystalline and granular forms are common in Colorado.

Fracture and Cleavage.—The crystalline variety has a flat conchoidal fracture, the compact a splintery fracture, while optical fluorspar has a pronounced conchoidal fracture. It has a perfect octahedral cleavage shown by truncating the corners of a crystallized cube of fluorspar. The mineral is brittle and has a hardness of 4. This makes it slightly harder than calcite, but it cannot be scratched with a pin.

Streak.—When a mineral is drawn across a piece of unglazed porcelain producing a fine powder, the color of that powder is called its streak. Fluorspar gives a white streak.

Specific Gravity.—Fluorspar has a specific gravity of from 3.01 to 3.25, with an average of 3.13.

Occurrence.—The mineral occurs in beds or more commonly in veins or seams in granites, gneisses, volcanic rocks, arkose, slates, sandstones and limestones. In Colorado it is found mainly in granite rocks or volcanic rocks which are highly acidic.

Phosphorescence and Fluorescence.—One piece of fluorspar from St. Peters Dome exhibited phosphorescence under ordinary conditions, also a bluish fluorescence. This is undoubtedly due to the presence of yttrium and ytterbium which are known to exist in the associated minerals in the same vein.

Chemical Properties.—Fluorite may be readily distinguished by the following tests:

1. If heated in a closed tube it flies to pieces and glows.

2. Before the blowpipe, it fuses, coloring the flame red, and forms an enamel which gives an alkaline reaction when crushed and moistened on test paper.

3. It has a fusibility of 3 before the blowpipe, a small splintery fragment being readily fused.

4. It is slightly harder than calcite, since you can not scratch it with a common pin.

5. It does not effervesce with acids as do calcite and smithsonite. If fused in an open tube with salt of phosphorus it etches the glass.

6. By fusing a mixture of borax, acid sulphate of potassium, and fluorspar on a loop of platinum wire in the clear flame of the Bunsen gas lamp a green flash is seen which immediately changes to the yellow flame imparted by the sodium of the borax.

COLOR OF FLUORSPAR

The source of the color of fluorspar has not been definitely determined, although experiments tend to show that it is probably due to the presence of hydrocarbons rather than to metallic oxides.

Experiments by Wyroubloff[6] tend to show that the cause of the color and odor of fluorspar are the same, he having noted that in the violet-colored fluorspar from Welsendorf both color and odor were variable, and that the specimens with the strongest odor were also of the darkest color. In the course of his experiments he found that where there was no odor there were no hydrocarbons present, but that all specimens possessing an odor contained hydrocarbons. He also found that the quantities of metallic oxides present were totally inadequate to explain the color and were practically the same for several colors. As a result of his experiments on many different colors of fluorspar, he concluded that the coloring matters were various compounds of hydrogen and carbon, probably coming from bituminous limestone, and also that the phosphorescence on heating is due to the decomposition of the coloring matter.

W. S. Tangier Smith[7] suggests that the color may be due to the oxidation of the hydrocarbons, since they are found in colorless fluorspar, as well as in the colored varieties. He believes that the decrepitation of the fluorspar is closely connected with the amount of contained hydrocarbons, and noted that in the case of purple fluorspar occurring in vugs, the color where found was not uniformly distributed through the mineral, but was found in bands parallel to the surface of the vug. In some instances the bands completely encircled the cavity, passing from crystal to crystal and following all irregularities. These observations, he believes, strongly suggest, though they do not prove, that the purple fluorspar, at least in western Kentucky, is derived from fluorspar of other colors by the oxidation of the contained coloring matter.

Fohs[8] believes that the fluorspar occurred originally either colorless or brown, according to the amount and density of the contained hydrocarbons; that containing light hydrocarbons is white or colorless and that containing heavy ones is brown. He found that fluorite encased in unweathered barite is always colorless; that in softened barite and where calcite had been present and had been leached, is often purple. This he thinks is, in a manner, proof of the oxidation theory.

On account of the large number of localities visited and the limited time spent at each deposit, no special effort could be made

[6]Wyroubloff, M. G., Bull. Soc. Chem. de Paris, n. s., vol. 5, pp. 334-347, 1866.

[7]Smith, W. S. T., Lead, zinc, and fluorspar deposits of western Kentucky: U. S. Geol. Survey, Prof. Paper 36, p. 124.

[8]Fohs, F. J., Fluorspar deposits of Kentucky: Kentucky Geol. Survey, Bull. 9, p. 54, 1907.

to investigate the cause of the color of Colorado fluorspar. However, the following facts were noted during the investigations.

Nearly all fluorspar when struck or freshly broken gives off a peculiar odor characteristic of hydrocarbons. Contrary to the observations of W. S. Tangier Smith,[7] in the Kentucky fluorspar district, the purple fluorspar of Colorado seems to give off a stronger odor when broken than do the green, white, and colorless varieties. In the Jamestown districts the gray and white varieties, produced as a result of the weathering and bleaching of the violet-blue variety, undoubtedly give off a stronger odor than do the violet-blue fluorspars from which they are derived. The brown and purple variety, found in the Chancellor mine, seems to give off the strongest odor of all the fluorspars found in the state. This agrees somewhat with the findings of Smith, in that he believed that the brown fluorspar gave off the strongest odor.

With the exception of the lilac and purple-colored fluorspar, found in the replacement deposits of the Black Hawk mine at Rico, all the fluorspar deposits of Colorado are located within areas of pre-Cambrian granites and gneisses, or within areas of other highly acidic rocks of igneous origin.

The veins of the Jamestown district lie wholly within an area of pre-Cambrian granites and gneisses,—and although the greater part of the ores of the district are purple in color, there are two notable exceptions. The fluorspar found in the Emmett mine is deep purple in color, and the ore found in the veins on the hill above the Emmett is also purple. However, within a very few feet of these veins, another vein contains a considerable amount of colorless to pale green fluorspar, with no evidence of any purple fluorspar occurring in the vein. Some deep green fluorspar was noticed in a small opening, about 300 feet east of the Invincible mine. This occurrence was also peculiar, as all the fluorspar which has been found in that part of the district is purple in color.

In the deposit at Jefferson, the vein shows some deep purple fluorspar in the lower workings, whereas, in the upper workings on the same vein, the fluorspar occurs as a peculiar mixture of lilac and green-colored mineral.

The fluorspar vein in the Barstow mine at Red Mountain cuts an area of andesitic rocks, and where found at a depth of 1,040 feet is green. This point is below the zone of oxidization, but fluorspar found at or near the surface in other mines of the district is also green or colorless, as a result of bleaching. Large pieces of fluorspar from near the walls of the vein showed as high as 18 distinct color bands, varying from a light green to purple. These bands were parallel to the wall and did not appear to have any certain order of arrangement. Those bands occurring close to the wall were green, but were followed by violet bands which in turn were followed by bands of green, violet and blue.

The greatest variation in both color and method of deposition occurs in the Wagon Wheel Gap deposit. The various types of ore found in the deposit include, perhaps every color in which the mineral has been found. The fluorspar occurs in massive, crystalline, banded, and granular forms.

Not enough investigative work has been done on Colorado fluorspar deposits to determine either the cause or source of the coloring matter, but it can be seen from the facts noted that the source of the coloring matter can not be the same as that assumed for deposits in limestone regions, nor can the presence of purple ore be accounted for entirely by the theory of oxidation of contained hydrocarbons.

GENESIS OF FLUORSPAR DEPOSITS

Many different theories have been advanced in discussing the genesis of fluorspar deposits, but each deposit must be considered separately, as the derivation of the fluorine and the conditions affecting the deposition of the fluorspar were undoubtedly different in each deposit.

Clarke[9] discusses the origin of fluorspar as follows:

"Fluorite, although most abundant as a vein mineral and in sedimentary formations, is also found as a minor accessory in granite, gneiss, quartz porphyry, syenite, elaeolite syenite, and the crystalline schists. W. C. Brogger reports it both as an early separation in the augite syenites of Norway, and also as a contact mineral. It sometimes appears as a sublimation product or as the result of the action of fluoriferous gases upon other minerals, on volcanic lavas. It is also produced as a secondary mineral from the decomposition of various fluosilicates. It alters into calcite, being attacked by percolating waters containing calcium bicarbonate or alkaline carbonates. Crystallized calcium fluoride has been prepared by several processes, but they shed little light upon its presence in igneous rocks.

"Several other fluorides are found associated with granites or pegmatites—fluorine compounds, it must be observed, are rarely found in eruptive rocks. They are especially characteristic of the deep-seated or plutonic rocks, where the gaseous exhalations have been retained under pressure, and are commonly regarded as of pneumatolytic origin."

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[9] Clarke, F. W., The data of geochemistry: U. S. Geol. Survey. Bull. 330, p. 274.

Throughout Colorado the main source of the fluorine appears to be the deep seated rocks of igneous origin. From this source, hydrofluoric acid or other fluorine compounds in which silica formed a part, were transported, with other elements in solution, by means of ascending thermal solutions. These solutions in ascending through various fissures, faults, and dikes came into contact with lime or with other solutions, and fluorspar was deposited.

Bischof[10] has described two important reactions in the chemistry of fluorspar. (1) Under the influence of solutions containing alkaline carbonates fluorspar alters to calcite. This process is believed to be more or less active in the oxidized zone where the absence of pyrite permits the waters to be of alkaline character. (2) Sodium fluoride in solution at ordinary temperatures is decomposed by calcium silicate with the formation of fluorspar.

According to Mendeleef some hydrocarbon compounds result from the addition of a halogen acid to a carbonate of the metal. Thus the combination, in certain proportions, of calcium carbonate ($CaCO_3$) and hydrofluoric acid (HF) results in the formation of fluorspar (CaF_2) and the hydrocarbon compound (CH_2O_3).[11] This explains a possible source of the hydrocarbons in fluorspar, and it may be that they are, in part, the source of the coloring compounds in the fluorspar.

According to Emmons and Larsen,[12] who have described the geology and hot springs of the Wagon Wheel Gap district, the fluorspar vein being developed by the American Fluorspar Mining Company, would if projected, bisect a deposit of travertine, which surrounds one of the thermal springs in the Valley of Goose Creek. A partial analysis of the travertine from this deposit was made by George Steiger of the United States Geological Survey, with the following results.[13]

[10]Bischof, G., Chemische Geologie, vol. 1, 2nd ed., Bonn. pp. 48 and 54, 1863.

[11]Fohs, F. J., Fluorspar deposits of Kentucky: Kentucky Geol. Survey, Bull. 9, p. 62, 1907.

[12]Emmons, W. H., and Larson, E. S., The hot springs and mineral deposits of Wagon Wheel Gap, Colorado: Econ. Geol., vol. 8, pp. 235-246, 1913.

[13]Burchard, Ernest F., Fluorspar at Wagon Wheel Gap, Colorado: U. S. Geol. Survey, Min. Res., pt. II, pp. 380-381, 1913.

Partial analysis of the travertine from Wagon Wheel Gap, Colorado, hot spring.

	Per Cent
Lead (Pb)	None
Zinc oxide (ZnO)	0.007
Barium oxide (BaO)	0.045
Fluorine (F)	0.22
Copper (Cu)	None

If these percentages were recalculated to a mineral basis, they would show 0.45 per cent of fluorspar (CaF_2).

Emmons and Larsen show that the hot springs and the fissure vein are undoubtedly connected, since the strike of the vein passes through one spring and close to the second. This would indicate that the fluorspar has been deposited by the hot waters which probably had their source at some depth. Analyses of the mineral waters of the springs, made in 1904, by the Chemistry Department of Colorado College, however, do not show the presence of fluorine in the water.

Penrose[14] in discussing the origin of fluorine in the Cripple Creek ore bodies says:

"The fluorite characteristic of the Cripple Creek ore bodies has a somewhat uncertain source. It is a well-known fact that fluorine compounds are common in the vapors from many modern volcanic vents, and fluorine minerals are found in many of the districts of past eruptive activity in the Rocky Mountains, though as associates of gold they are rare. On the other hand numerous fluorine minerals, such as fluorite, cryolite, tourmaline, and topaz, occur in the granite of this part of Colorado; so that there are two possible sources for the fluorine found in the Cripple Creek veins: First, the volcanic materials; and second, the granite. It is, of course, not impossible that the volcanic materials may have derived their fluorine from the surrounding granite, thus making the granite the ultimate source of this material. It has been shown by Mr. Cross that hydrofluoric, hydrochloric, and sulphuric acids might readily be evolved from the phonolitic magma during solidification, and he also suggests the granite and the vapors of indefinite source evolved from the fumaroles which were once probably abundant in the district, as other possible sources of the fluorine.

"The fluorine which now occurs in the veins is, so far as known, all in the form of fluoride of calcium, fluorite. It is not at all improbable that the fluorine originally came into the fissure in a volatile or soluble form such as hydrofluoric acid, or, more probably, as some of the hydrofluosilicates, or as soluble fluorides, and there encountered solutions

[14]Penrose, R. A. F., Mining geology of the Cripple Creek district, Colorado: U. S. Geol. Survey, 16th Ann. Rept., pt. II, pp. 126, 157-159.

which carried carbonate of lime derived from the decay of the eruptive rocks or from other sources. The natural result would be the formation of fluoride of lime."

Lindgren and Ransome[15] have proposed three possible sources from which the fluorine of the Cripple Creek ores may have been derived, but consider as the most probable the theory that the fluorine, together with the other volatile constituents, may have been given off by the phonolitic magmas on their consolidation at higher levels in the earth's crust. It is also pointed out that a remarkable connection exists between the phonolitic rocks and deposits containing fluorspar and gold not only at Cripple Creek, but also in the Black Hills, Judith Mountains, and Little Rocky Mountains.[16]

According to Purington[17] the fluorspar of the Telluride district originated as follows:

"The well-known connection of fluorine with volcanic action, and its occurrence as fluoride of calcium in granite fumaroles, make it still more probable that the ore of this region was of deep origin. No fluorite has, so far as known, been found in connection with the rocks now visible in the district, yet it has been found in greater or less amount in well-marked occurrences in four of the veins which lie wholly within the igneous rocks and near the probable center of eruption. Hydrofluoric acid, or other fluorine compounds in which silica forms a part, may, as suggested by Mr. Penrose for the Cripple Creek occurrences, have accompanied the other elements in solution, and, uniting with the lime, have deposited in the veins the fluorine in the form of fluoride of calcium, fluorite."

Spurr, Garrey and Ball,[18] in describing the ores of the Georgetown district, discuss the derivation of the fluorspar in the gold and silver deposits separately. In discussing the origin of fluorspar in the silver and lead deposits the following facts are pointed out:

"The sericitization of the wall rocks of the silver-bearing veins argues the presence of a little fluorine in the mineralizing waters, although not necessarily so much that fluorite should have crystallized from these waters. Elsewhere the evidence suggests that if the mineral was originally deposited by the primary mineralizing solutions it has since been reworked and deposited in a concentrated form by surface waters.

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[15]Lindgren, W., and Ransome, F. L., Geology and gold deposits of the Cripple Creek district, Colorado: U. S. Geol. Survey, Prof. Paper 54, p. 219.

[16]Lindgren, W., Metasomatic processes in fissure-veins: Am. Inst. Min. Eng., Trans., vol. 30, p. 657, 1901.

[17]Purington, C. W., Preliminary report on the mining industries of the Telluride quadrangle, Colorado: U. S. Geol. Survey, 18th Ann. Rept., pt. III, p. 822.

[18]Spurr, J. E., Garrey, Geo. H., and Ball, S. H., Economic geology of the Georgetown quadrangle, Colorado: U. S. Geol. Survey Prof. Paper 63, p. 142. See also p. 153.

"The derivation of the fluorine in the original mineralizing solutions is also a matter open to doubt. The veins under discussion occur partly or wholly in granite. Granite is known to contain fluorine, which is present in mica, hornblende, and apatite, as well as in other minerals, and granitic rocks very commonly contain fluorite-bearing veins, in which the fluorite is either due to segregation from the granite or has been formed during the final process of consolidation."

In connection with the derivation of fluorspar in the auriferous deposits, it is pointed out that the fluorspar is evidently the product of the after action during the pneumatolytic period, when gases of magmatic origin rose along the channel followed by the intruded or extruded rock.

Fohs[19] in describing the genesis of the Kentucky-Illinois deposits says:

"Fluorspar consists of calcium and fluorine. The wall rocks form a ready source of calcium, but contained little or no fluorine. Igneous dikes of mica-peridotite, a dark green rock consisting of more than a dozen minerals, two of which, biotite and apatite, usually contain more or less fluorine, traverse the district. Upon analysis, this rock, none of which is very fresh, now shows very little fluorine content, yet it, together with the underlying mass from which it was given off, or the underlying mass alone, seems the most probable source of the fluorine. The compounds ultimately to form the deposits were transported by means of ascending thermal or heated solutions, coming as an aftermath of the eruption resulting in dikes."

USES OF FLUORSPAR

The uses of fluorspar depend on its chemical composition, fluxing properties, phosphorescence when heated, its optical properties, structure and color. By far the greatest part of the fluorspar used in the industries is utilized in the metallurgy of iron, steel, aluminum, manganese, gold, copper, lead, tin, nickel, and alloys of these metals. Next in importance is its use in the manufacture of various kinds of glass, sanitary and enamel ware, glazes and fireproof ware, and third its use in the chemical manufacturing industry.

OPTICAL FLUORSPAR

During the early spring of 1917 the search for optical fluorspar was encouraged by an appeal from the Director of the United States Geological Survey, to all fluorspar producers, asking that particular attention be given in their work of production to the finding of a transparent, colorless, or faintly-colored fluorspar,

[19]Fohs, F. Julius, Fluorspar deposits of Kentucky: Kentucky Geol. Survey, Bull. 9, p. 61, 1907.

suitable for the manufacture of lenses and prisms used in optical instruments.

At present the United States is dependent upon Japan and Switzerland for its supply of optical fluorspar, but since the war has cut off most of the foreign supply the United States must depend on its own deposits for the mineral. It has recently been reported that some absolutely clear fluorspar has been imported from Japan and has been valued at about $30.00 an ounce. This material has been used mainly in the manufacture of apochromatic lenses. Such lenses give a field of vision practically free from the color rings due to the breaking up of light rays.

A diligent effort was made during the examination of the Colorado fluorspar deposits to locate material that would be suitable for this purpose. Fluorspar from the Geo. Walker claims at Jamestown, from the Kentucky Belle, Rainbow and Rhodochrosite mines at Alma, and from the Barstow mine at Red Mountain was carefully examined but proved either too deeply colored or too badly fractured for optical purposes. The Barstow mine at Ouray appears to give the best promise of producing optical fluorspar, and with proper care, material well away from the metalliferous veins, and mined with the use of very little or no explosive might prove of optical quality.

The following description of the properties, uses and value of optical fluorite has been published by the Illinois State Geological Survey.[20]

"Properties, Uses, and Value of Optical Fluorite."

"Each transparent mineral not only bends or refracts rays of light in a definite and characteristic manner, but bends the colored components of the individual rays at slightly different angles—a property called dispersion. In addition to this, most minerals break light into two rays, each of which is both refracted and dispersed; only minerals that crystallize in very symmetrical forms, such as cubes or octahedrons, do not show this double refraction. Fluorite bends light very slightly (has a low index of refraction); disperses light faintly (that is, its refraction of red rays differs only a little from its refraction of yellow rays and so on); and normally displays no double refraction. These three properties place fluorite in a unique position among minerals and fit it for a highly specialized optical use which no other mineral or artificial substance can meet equally well. Only three or four other minerals have lower refraction than fluorite; but these are either colored or are not sufficiently transparent, and moreover show marked double refraction as a result of their crystallization. Hence fluorite stands alone.

[20]Pogue, Joseph E., Optical fluorite in southern Illinois: Bull. 38 (extract) pp. 1-7, 1918.

"Glass. of a special kind, is the dominant material used in all optical apparatus. By varying the chemical composition of the glass and the shape of the lenses and prisms made from it, the various optical effects desired are obtained. Owing to the reflection of light from surfaces and a breaking up or dispersion of light in passing through a substance, errors are introduced, and to neutralize or minimize these errors calls for the best efforts of technical art and scientific knowledge. It is here that optical fluorite finds its chief use. Due to its low refractive power and very weak color dispersion, this mineral is especially suitable for correcting the spherical and chromatic errors of lens-systems. The so-called apochromatic objective used with microscopes consists of a lens of fluorite placed between lenses of glass and represents the finest type of objective that optical art produces. There are two other classes of objectives, less fine and less costly, the achromat and the semiapochromat; fluorspar is used only in the second of these, which is a sort of compromise between the cruder achromat and the more nearly perfect apochromat. The less expensive semiapochromat could replace the apochromat in many instances, were optical fluorite more available; but at present the manufacturer is forced to conserve his meager supplies of fluorite for use in making the finer and more expensive apochromats. It therefore appears that a plentiful supply of optical fluorite would be of great benefit to the microscope industry, as thus far the output of optical systems containing fluorite has been limited simply by an insufficient supply of this material. The development of adequate sources of optical fluorite therefore becomes a matter of considerable importance, affecting ultimately through cheaper and more efficient microscopes the progress of scientific and medical research.

"Optical fluorite is also used in making prisms for spectrographs employed in ultra-violet work and for use in other optical apparatus in cases where great transparency to the ultra-violet and infra-red parts of the spectrum is required. It is likewise employed as part of the lens-system in telescopes to correct certain color effects. Specimens suitable for such highly specialized uses as those mentioned in this paragraph are difficult to obtain, because of the comparatively large size of pieces required; but the demand for such material is rather limited in an economic sense, though very insistent and important for the furtherance of investigational activities. While practically all fluorite possesses the optical qualifications noted above, the vast preponderance of material is too strongly colored or else too clouded with internal fissures and inclusions to transmit light unaffected by these undesirable influences. Moreover, some clear and colorless specimens otherwise suitable for optical use are found to show an anomalous double refraction, due probably to abnormal conditions during crystallization, which renders them unfit. These incidental, rather than inherent properties, therefore, become the controlling factors in determining the availability of material, and consequently determine the practical specifications which prospective material must meet.

"For optical use a specimen of fluorite must contain a portion at least one-fourth of an inch in diameter, free from flaws, and colorless or nearly so. Crystals, or pieces bounded more or less completely by plane surfaces, are more likely to qualify than irregular masses. As the surfaces of most crystals are dull, a corner of such a specimen should be broken off with a sharp blow so as to expose the interior. In doing this, it is desirable to rest the specimen on a wooden base and break off the corner along an incipient cleavage plane by means of a knife blade or chisel; such planes are usually present and may be located by moistening the specimen with kerosene. If the specimen looks promising, it is better to proceed no further, as fluorite is fragile and a misdirected blow will fill a clear piece with a net work of fractures. A peculiarity of fluorite of optical quality is its conchoidal (irregularly curved) fracture and the absence of a strong tendency to break into pieces bounded by smooth planes in the fashion of the ordinary mineral.

"As to color, material that is absolutely water-clear is of course the most desirable, and in fact is essential for highly specialized uses; but faint tints of green, yellow and purple do not in themselves render material altogether unsuited for optical use. Flaws must be lacking from the portion to be used, but flaws are present in the bulk of fluorite, due both to cracks (incipient cleavages) and to inclusions of bubbles or of visible impurities; accordingly the most detailed search is necessary to find pieces free from these objections. Moreover, careless handling, even jolts resulting from shipping, may develop flaws in clear material; hence the utmost care must be exercised in separating material of optical promise from its crude associations and in suitably packing such material.

"The anomalous double refraction shown by some specimens, particularly by symmetrical crystal groups known technically as 'twin crystals,' bars such material from optical use; but this property can be determined only by a microscope or other optical instrument at the eye of a trained observer. A clue to this condition is given in some cases by fine, parallel striations or rulings, marking a twinned condition of crystallization. In general, however, the clear specimens of southern Illinois fluorite already examined have been largely free from double refraction; hence for all practical purposes this test may be ignored in the field and left to the optical dealer to apply at his discretion.

"The value of optical fluorite and the demand for it cannot be expressed in definite figures, for the material is a specialized thing instead of a staple product. On the one hand, the demand will increase if optical fluorite can be produced at a figure sufficiently reasonable to warrant an enlarged utilization; whereas, on the other, an inflated price will destroy the opportunity for an increased demand. It must be remarked also that only a small portion, say 4 to 8 per cent on the average, of material classed as optical fluorite actually passes into the make-up of a lens-system, so much of the mass must be destroyed or discarded during manufacture. In other words, 25 pounds of good-looking, clear fluorite may produce no more than a single pound of finished lenses. Hence the value of the finished product comes only in part from the value of the raw fluorite entering into it; much of its value is introduced by the skillful work essential to its manufacture. These statements are to obviate the assumption that crude optical fluorite is of gem-value. In order to make the matter more specific, fluorite qualifying as optical in quality is worth a dollar or more a pound, while particularly large and fine specimens have an individual value of $10 and more apiece. These figures are rough approximations only, designed to give prospective producers a general idea of what their product may be expected to yield but not to be taken as quotations of market prices."

For the information of those who believe they might become producers of optical fluorspar the following names may serve as a list of possible purchasers:

Bausch and Lomb, Optical Co., Rochester, N. Y.

Spencer Lens Co., Buffalo, New York.

Bureau of Standards, Washington, D. C.

Wards National Science Establishment, Rochester, N. Y.

METALLURGY

In metallurgy, fluorspar has a wide application based mainly on its quality of rendering slags fusible at low heats. Other cheaper fluxes are used in the iron and smelter industry, but the superiority of fluorspar renders it almost indispensible in many operations.

As a result of experimentation it is seen that while the results obtained from using fluorspar are good, there is a limit beyond which the results do not increase as the quantity of fluorspar is increased. This is shown by an article in "The Foundry" for January, 1905, by N. W. Shed, and while it applies particularly to its use with foundry pig, it has also been found to be true in the manufacture of open hearth and Bessemer steel.

IRON AND STEEL

Since 80 per cent of the fluorspar output of the United States and all the imported fluorspar, is used as a flux in the manufacture of open hearth and Bessemer steel, it will be seen how important is its use in this industry alone. In the metallurgy of iron and steel it carries the silica, phosphorus and sulphur, three very detrimental elements, into the slag and effects a saving in fuel by permitting the charge to melt at a low temperature through its fluxing power. In the open hearth steel furnace fluorspar gives a more fluid slag in the basic process, allows of the use of a greater amount of cheap scrap, and eliminates part of the silica by volatilization, increasing the basic properties of the slag. The phosphorus content is lowered, partly through slagging and partly by volatilization.

In the Bessemer furnace the fluorspar fluxes the lime present making the slag effectively basic, while any phosphorus present tends to form calcium phosphate and later phosphorus fluoride, which passes off as a gas.

L. Goldmerstein[21] in the Iron Age describes a method of injecting small cartridges of manganese sesquifluoride into the molten metal. With the vaporizing of the fluorine of the compound and its union with the sulphur and phosphorus, for which it has a great affinity, the resultant compounds pass off as vapors. This should take place after the silica has been burned out, then on the injection of the cartridges the fluorine will unite with the impurities and the temperature of the mass will be raised.

Other artificial fluorides of both iron and manganese have been used in the Bessemer process with the same end in view, the creating of a more fluid slag, together with the removal of any sulphur, silicon, or phosphorus which might be present.

In the production of pig iron the use of fluorspar is limited by its high price. It is a very valuable flux, and when blown as a powder into the blast furnace through the nozzles, carries phosphorus into the slag and greatly reduces the fuel cost through its fluxing qualities. In cupola furnace work, if added to the limestone flux, it will carry part of the silica and phosphorus into the slag, and will form an alloy with the iron, producing a soft gray iron of greater malleability.[22] The slag is thin and the metal flows better and consequently sharper castings will result.

Fohs[23] states that in the electric furnace the addition of calcium fluoride forms volatile fluorides of silicon, sulphur, and phosphorus, and that the calcium forms a silicate slag.

OTHER METALLURGICAL USES

The presence of zinc sulphide with fluorspar is usually considered very detrimental in the smelting industry as it attacks the distilling vessels. However, the ordinary glazed distilling vessels are said to be greatly improved by a glaze baking consisting of sulphate of zinc and fluorspar in equal quantities.[24]

Fluorspar is used in minor quantities in the extraction of aluminum from bauxite.[25] In this process it is fused with bauxite and soda ash into a product resembling an artificial cryolite (sodium

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[21] Goldmerstein, L., Prolonging the life of the bessemer process: Iron Age, Jan. 22, vol. 93, p. 250, 1914.

[22] Hill, R. C., The Foundry, May, 1915.

[23] Fohs, F. Julius, Kentucky fluorspar and its value to the iron and steel industries: Am. Inst. Min. Eng., Trans., vol. 40, p. 261, 1909.

[24] Fohs, F. Julius, Fluorine in lead and copper blast furnace slags: Kentucky Geol. Survey, Bull. 9, p. 174, 1907.

[25] Burchard, Ernest F., Our mineral supplies. Fluorspar: U. S. Geol. Survey, Bull. 666, p. 4, 1918.

aluminum fluoride) to which more bauxite is added; and from this mixture aluminum is extracted in the electric furnace. A process, as described by Hall,[26] consists in providing a bath of fused fluorides to which the aluminum is added and reduced by an electric current. The specific gravity of aluminum being greater than that of the bath, the metal sinks to the bottom and can be drawn off. Alloys of aluminum are made by placing a metal and alumina in a bath of fluorides, and the metal on melting will form a cathode, with which the aluminum unites as it is reduced.

Fluorspar is also used in the metallurgical treatment of ores of manganese, gold, copper, lead, silver, tin and nickel and in the production of alundum, a patented artificial corundum, used in making abrasive wheels, etc. This process is essentially one of fusing bauxite at extremely high temperatures, in an electric furnace.

In the smelting industry where limestone is usually used in the smelting of refractory ores, the use of fluorspar produces highly satisfactory results.

USE OF FLUORIDES IN WOOD PRESERVATION[27]

The use of sodium fluoride as a wood preservative was suggested by the use of certain fluorides, known to have antiseptic properties, in the prevention of wild yeast growths in mash. About 1906, tests on the impregnation of wood with solutions of sodium fluoride and zinc chloride were carried on for the first time; later tests with sodium fluoride were tried with apparently good results. The experiments show that the salt penetrates the wood very satisfactorily, that it is practically non-corrosive of iron or steel, and that the wood can be painted as usual. Tests show that the treatment has no apparent effect on the strength of the wood.

The cost of sodium fluoride for wood preservation should not be excessive. Enough tests have been made and enough data have been gathered by the Forest Products Laboratory to show its worth.

A report on impregnated panel tests and fire retardant paints[28] shows that panels treated with sodium fluoride, painted and exposed to the weather for 18 months stood the test remarkably well. The impregnation made them resistant to decay.

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[26] Packard, R. L., Mineral resources of the United States. Aluminum: U. S. Geol. Survey, 16th Ann. Rept., pt. III, p. 540.

[27] Teesdale, C. H., Use of fluorides in wood preservation: vol. III, No. 4 and vol. 4, No. 1. Reprinted from Wood-Preserving.

[28] Gardner, Henry A., Report on impregnated panel tests and fire retardant paints: Paint Mfg. Assn. of the U. S., Bull. 51, Feb., 1916.

PLATING

Antimony fluoride is readily soluble in water, does not hydrolize and being entirely inorganic, does not decompose prejudicially or become altered during electrolysis. No other antimony salt possesses these properties which are so essential in making a plating bath.[29]

GLASS, ENAMELS, GLAZES

A considerable amount of fluorspar is now being used in the manufacture of common, plate, opaque and opalescent glass. In the manufacture of the last two, cryolite, a phosphate of lime, fluorspar, and feldspar have been used. But owing to the harmful effect of the high fluorine content of the cryolite, and the presence of phosphorus, the use of fluorspar and feldspar has increased. The ores of the Wagon Wheel Gap, Ouray, and Antelope Creek districts should be ideal for this purpose as they show few impurities and have no appreciable color. The color of the ores of the Jamestown district should not prevent their use in this industry since, on heating, they fuse and become white. The coloring matter evidently is not permanent and is of such small amount that it should not be injurious in the manufacture of glass.

Ground fluorspar mixed with a refractory substance is used as a flux in enamels. These enamels are used in the manufacture of bath tubs and sanitary ware, enamel ware, cooking utensils, clock and watch dials, and in the glazing of tile, brick, and terra-cotta.

HYDROFLUORIC ACID

Hydrofluoric acid is made in large cast iron vessels by decomposing the purest grades of fluorspar with sulphuric acid. The acid is used in chemical and metallurgical work, and as a cleaning agent for castings. The common formula used is one part of acid to 10 parts of water. This, if properly mixed, will remove the sand quickly and perfectly, the time required depending upon the amount of sand to be removed and the condition of the "pickle." An average of 10 to 15 minutes is required for the operation.

CONCRETE OR FLOOR HARDENER

Magnesium fluosilicate is used with zinc oxide, iron oxide, lithophone, silica and other pigments in the manufacture of con-

[29] Mathers, F. C., Means, K. S., Richard, B. F., Am. Electro-Chemical Soc., Trans., vol. 31, p. 293, May 5, 1917.

crete or floor hardeners, which are really paints. The magnesium fluosilicate seems to have the power of uniting with some element or elements in the concrete, producing a very hard, dense, and non-porous surface.

ORNAMENTAL FLUORSPAR

Fluorspar being but slightly more than half as hard as quartz is not ordinarily suitable for wear as jewelry. It takes a high polish closely resembling that of quartz, but it is easily scratched and is quite brittle. It readily splits along cleavage planes when being mounted. Through cutting and polishing the color is accentuated and many beautiful effects may be had which, if the stone were otherwise suitable, would make it a valuable gem.

The fact that the average Colorado Fluorspar fades on continuous exposure to light detracts from its gem value, whereas fluorspar from Derbyshire, England, is made into many ornaments. Vases are cut from particularly fine pieces. The color of this fluorspar does not fade on exposure.

A variety of fluorspar found at Amelia, Virginia, is both phosphorescent and fluorescent and is known as Chlorophane.[30]

The clear varieties of colored, transparent fluorspar are known as fake ruby, emerald, sapphire, and amethyst.

MISCELLANEOUS USES

Many other uses have been reported for the mineral. Among these may be mentioned its use in the making of cement, in the manufacture of carbon electrodes to increase their lighting efficiency and decrease cost, in the electrolytic refining of antimony, lead and copper and as a bond for the constituents of abrasive wheels.

The flue dust of cement works is calcined with fluorspar, and a second flue dust thus formed is collected and treated with water and lime or calcium sulphate to recover the fluorine and potassium compounds which it contains. This process has been patented and is now in use.

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[30]Day, D. T., U. S. Geol. Survey, Min. Res., p. 960, 1904.

SUMMARY

Fluorspar for iron and steel manufacture should contain 85 per cent calcium fluoride, should not contain over 5 per cent of silica, and be free from sulphides and sulphates. Fluorspar used in the chemical industry should contain from 95 per cent to 98 per cent calcium fluoride.

During 1917 some fluorspar was shipped from Colorado for use in the chemical industry, but by far the greater amount produced was used in the manufacture of iron and steel.

CHAPTER IV

FLUORSPAR DEPOSITS OF COLORADO

BOULDER COUNTY

Fluorspar has been reported as occurring in the Allens Park district, in Antelope Park, and near Lyons, but as no definite information could be obtained regarding the exact location of the deposits they were not examined.

ELDORADO SPRINGS DISTRICT

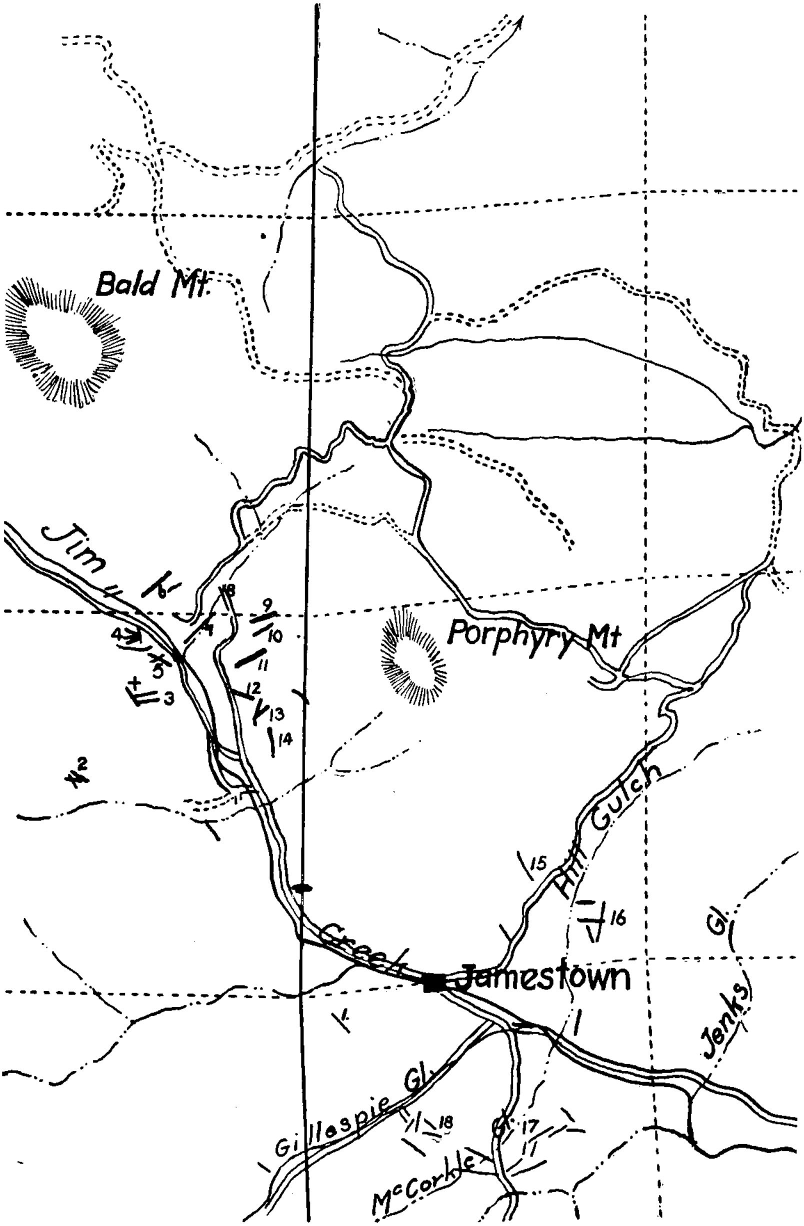
Some fluorspar was mined in 1917 about three miles west of Eldorado Springs. Samples of the ore containing 69 per cent of calcium fluoride were given the writer, but no examination was made of the property.

JAMESTOWN DISTRICT

The Jamestown mining district is located about 16 miles northwest of Boulder on Jim Creek, a branch of Lefthand Creek entering that stream from the north. It is reached by auto stage from Boulder over a splendid road following the base of the foothills and turning abruptly to the west as it continues up Lefthand and Jim creeks.

The town of Jamestown, commonly called Jimtown, is located on Jim Creek at an elevation of about 7,000 feet and is surrounded by mountains which reach an elevation of from 8,000 to 8,500 feet. The town was at one time scattered along the narrow valley for a distance of two miles, but had dwindled until in 1917 it had a population not exceeding 150 or 200 people, and only remnants remained to show the former size of the camp. Gold and silver mining had stopped, at least temporarily, through the closing of the Alice mine, at the extreme north end of the district. However, the increased demand for fluorspar was causing the opening of many old properties, and undeveloped deposits were being brought into production.

FLUORSPAR VEINS OF JAMESTOWN DISTRICT.
Topography by United States Geological Survey.
Contour interval—100 Feet. Scale—2 Inches = 1 Mile.



MINES.

1—Poorman
2—Silver Ledge
3—L. R. Evans
4—Geo. Walker
5—Emmett
6—Argo
7—Warren
8—Alice
9—Markt and Atkinson
10—Buchannan
11—Terry
12—Chancelor
13—Brown Spar
14—Invincible
15—L. Evans Lease
16—Buffalo Creek
17—Blue Jay Hill
18—Indian Point

The district is mainly one of granites and gneisses of pre-Cambrian age, intruded by numerous dikes of quartz, porphyry, and cut by many fluorspar and metalliferous veins. The main district extends northwest and southwest along Jim Creek for about two miles and although very irregular in shape reaches a maximum width of about one-half mile in both the northern and southern parts of the district. Jim Creek and its tributaries cut directly through the area, and have exposed numerous veins and dikes.

A large dike of quartz porphyry having a northeast-southwest trend cuts across Little Jim Creek, forming falls just north of the junction of Jim Creek and Little Jim Creek. On the east side of the district a mass of quartz porphyry forms the greater part of Porphyry Mountain and so far has proven barren of fluorspar veins. Other dikes of porphyry occur in the Emmett mine and on Indian Point where one dike with a northwest-southeast trend is exposed for a distance of 1,000 feet and is paralleled by a second dike which is exposed for about 400 feet. The district is divided by the porphyry dike crossing little Jim Creek, leaving a broad barren zone, with a mineralized area to the north and south.

FLUORSPAR VEINS

The granite of the northern half of the field is weathered to a less degree than that in the southern half. Both however are cut by many veins carrying fluorspar. These veins may be classed under one of the following heads:

1. Veins containing nothing but fluorspar.

2. Veins having fluorspar as the predominant mineral, and having quartz, decomposed granite, or clay formed by the decomposition of feldspar as gangue material.

3. Veins in which the principal mineral is fluorspar, but having galena, pyrite, chalcopyrite, chalcocite, bornite or some telluride mineral in addition.

4. Those formerly worked as metalliferous veins. Fluorspar was considered a gangue mineral in these veins, but they are now being worked for the fluorspar. These include the Argo, Alice, Chancelor, and Invincible mines, formerly working in either sulphide or telluride ores, but now operated for fluorspar.

The veins of the district occupy fissures in which movement has caused a greater or less amount of brecciation and mixing of the wall rock with the fluorspar of the veins. This is especially noticeable in the northern half of the district, where in the Warren, Argo, and Alice mines, angular pieces of wall rock are found enclosed in the vein matter. As to their direction the veins fall into two groups, those that have a strike northeast-southwest and those that have a northwest-southeast strike. Of forty veins examined twenty-five took the former direction and only fifteen the latter. Prominent veins are found in each group, but the larger number occur in the group having a northeast-southwest strike.

In width the veins vary from a few inches to a maximum of 17 feet, as shown in the Warren mine. This variation in width occurs both laterally and in depth, but an average width is from 2.5 to 5 feet. The Argo mine contains a great mass of ore in which width and direction are extremely hard to determine. This deposit can hardly be spoken of as a vein where it is opened, although, as a whole, it undoubtedly does take a definite course or direction.

COLOR OF ORE

In general, the fluorspar of the district is blue-violet in color, but almost colorless, and light green to deep purple ores are found. One characteristic of the ore is that on exposure to the light the purple color fades in a few months to pale purple, lavender and white. This fact makes prospecting rather difficult to the inexperienced, since the surface vein material becomes the same color as the country rock, and it is only through testing the hardness and looking for an occasional color that the ore can be distinguished. This bleaching often extends to considerable depth, and the fluorspar, which has the appearance of granules of quartz, is often mistaken for that mineral.

Some pale green to almost colorless, glassy-appearing fluorspar, was found on the hill above the Emmett mine and in an opening east of the Invincible mine on claims owned by George Walker of Jamestown. Material from both of these claims was examined with care but proved to be badly fractured. These veins contain the only known occurrence of nearly colorless fluorspar in the district, and appear to be the only ones which might yield optical fluorspar.

MARKET AND MINING

The ore is cobbed and all large pieces of wall rock are removed. The "gravel" ore is hauled 16 miles to Boulder, where it is either loaded on cars for the market, or concentrated prior to shipment. During the spring of 1918 only concentrates were shipped from

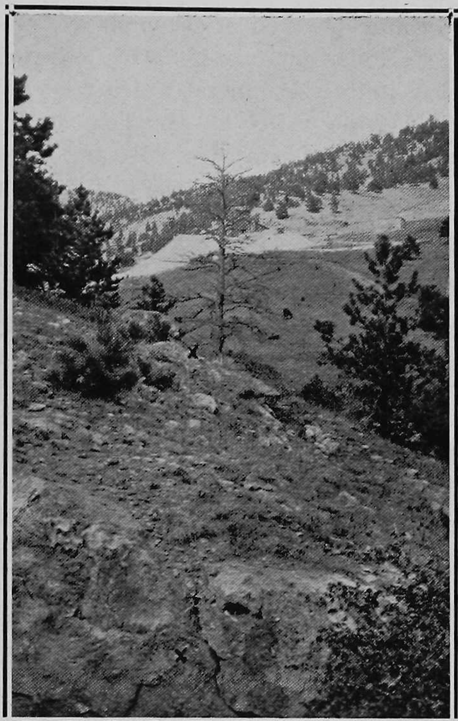
Boulder, as the Chesbro Company bought crude ore at the mines, hauled it to Boulder, concentrated it, and shipped it to available eastern markets. The opening of the Hoffnung or Lehman mill at Jamestown for the treatment of commercial ores, and the possible opening of the Wano mill for the same purpose should stimulate production. The crude ore can then be milled in the district and the concentrates hauled to the railroad at Boulder more cheaply than concentrates can be loaded on the car by the present method.

Fluorspar in the Jamestown district was being bought at the mine at prices averaging $7.00 per ton for 80 per cent ore. A premium of 20 cents per unit was paid for each per cent above that standard and a like penalty was imposed for each per cent below it. The minimum percentage of calcium fluoride was fixed at 70. A haulage charge of $3.00 per ton was deducted from this amount on settlement at the mill in Boulder.

Very little systematic fluorspar mining has been carried on in the district. Most of the work has been done for the purpose of getting out as large a tonnage as possible with the least expense to the operator, or has been done as assessment work. Most of the development consists of surface workings or short drifts usually not exceeding 200 feet in length. In these drifts the ore has, in many cases, been stoped so close to the surface that the property would soon cave. The workings are all shallow, the greatest depth reported having been reached in the sinking of a shaft to a depth of 112 feet, on Blue Jay Hill. A crosscut tunnel 300 feet long cuts this vein at a depth of over 100 feet, but the surface workings and shaft have caved. Most of the workings in the district cave when they stand idle, since the rock forming the walls is badly weathered and very little timbering is ever done.

The Alice mine, working at a depth of 400 feet, has a vein of fluorspar from four to five feet wide. This property and the Argo were previously worked as metalliferous mines but in the spring of 1918 the production of fluorspar was undertaken. The camp is now chiefly engaged in the production of fluorspar, and the output should increase rapidly as the demand increases.

Alice Mine.—The Alice mine had, up to the summer of 1917, been shipping a complex ore of galena, pyrite, chalcopyrite, chalcocite, tetrahedrite, tellurium and fluorspar, which ran well in gold, silver and copper. It is developed by a 400 foot shaft located 75 feet northeast of the main ore body. On four levels, crosscuts have been driven from the shaft to the ore body, which is developed by drifts, extending N. 20° W. and S. 20° E., ranging in length from 30 to 150 feet. A crosscut tunnel has been driven from the west, striking the vein at a depth of 40 feet, but is not connected with the shaft.



Vein Along Warren Vein Showing Outcrop of Fluorspar (xx), Alice Mine in Distance.

The fluorspar shows at the surface, is found in all levels, and lies to the west of the mineralized part of the vein. On the fourth level the fluorspar forms a vein from four to five feet wide in which there were a few pieces of granite wall rock and a small amount of finely disseminated pyrite. The wall rock is a coarse-grained granite or pegmatite, in which the feldspar minerals are somewhat weathered, but which stands well with very little timbering.

The property had shipped some little metalliferous ore in 1917, but in the spring of 1918 only a little fluorspar was being mined and shipped from the main vein, near the breast of the crosscut from the surface.

Mr. Mohr, one of the leasers, informed the writer that the property would undoubtedly ship some fluorspar that summer, and that a six-ton unsorted sample from the second level, ran 71.2 per cent calcium fluoride, but had a high silica content.

A particularly fine specimen of clear, glassy, uncolored fluorspar enclosing long slender crystals of native tellurium, and small rounded pieces of a dull black mineral which reacted for uranium and copper, was given the writer by Mr. Tom Mohr, who said it was found in one of the pockets of high grade metalliferous ore found in the mine. The fluorspar was too badly fractured and too small for use in the optical industry.

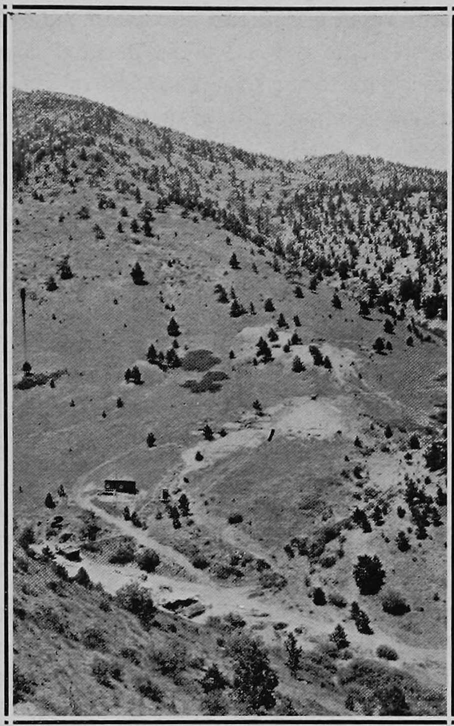
The ore is of a violet-blue color and undoubtedly extends below the 400 foot level. Although it is of no commercial value at present, because of its low fluorspar and high silica content, it could be brought up to market grade by concentration. The deposit is large and is properly equipped to handle a large tonnage, such as could be mined by stoping in the various drifts.

Argo Mine.—This property lies at the extreme northern end of the district. It was formerly worked as a metalliferous mine producing a large tonnage of galena, and cupriferous pyrite containing gold and silver. In the early days some carbonate of lead was found near the surface, and quite recently several hundred pounds of carbonate were found while prospecting for fluorspar in the large "glory hole," above the main tunnel.

The property is located in an area of porphyritic granite. The vein is branched and very irregular in width. The walls are poorly defined and the only way the strike of the vein can be determined is from the position of openings along its course. It is developed by a tunnel and two shafts, beside numerous drifts, upraises, and levels. The drifts have no uniform direction, but follow the fluorspar courses.

The fluorspar is a violet-blue mineral, in places stained a brownish color by iron oxide. When placed in the bins and allowed to stand, it bleaches rapidly to a light lavender color. The ore is soft and granular, the greater part appearing like "mill dirt" when placed in the bins. In places, the ore is high grade; in others, fragments and large pieces of wall rock lower the percentage of calcium fluoride and increase the silica content. It can be easily milled, and that appears to be the only means of getting rid of the fine pieces of wall rock scattered through the ore.

During April, 1918, the property was being operated under a leasing system and a considerable tonnage of fluorspar was being produced, but not enough work had been done to show the value or extent of the fluorspar deposits.



ARGO MINE.
1—Glory Hole. 2—Tunnel Portal

The opening of a vein to the west of the Argo had exposed some high grade ore. Work was being done in the gulch to the east on a vein running N. 47° E. Several sets of leasers were producing ore in the main workings of the Argo, and others had applied for leases.

Atkinson and Markt.—This vein running N. 81° E. is located 400 feet east of the Alice mine. Good ore is exposed for about 500 feet on the surface and the property is developed by a tunnel 60 feet long, entirely within the ore. The vein is about 40 feet wide, but very irregular, pinching and swelling through the length exposed. The ore is light violet-blue and is found in irregular-shaped masses throughout the vein. A shipping platform had been built and ore was being shipped to the mill in Boulder.

Blue Jay Hill.—On Blue Jay Hill at the south end of the district there is a series of fissure veins cutting the badly weathered granite. The main veins lie on the northwest side of the hill and parallel McCorkle Gulch. Several veins parallel Slaughter House Gulch, and others occur toward the east end of the hill. The ore found in the various veins on Blue Jay Hill is deep purple, hard, and quite solid.

The Blue Jay vein has been developed by open cuts, a shaft and a crosscut tunnel which cuts the vein at a depth of slightly over 100 feet. The shaft and surface workings are badly caved at present, but with a little cleaning up work, a good tonnage can be produced.

A large tonnage has been produced from the veins on Blue Jay Hill, and in the spring of 1918 ore was being shipped from four different openings.

Brown Spar.—The Brown Spar mine is located at the bottom of a small gulch several hundred feet to the northwest of the Invincible mine.

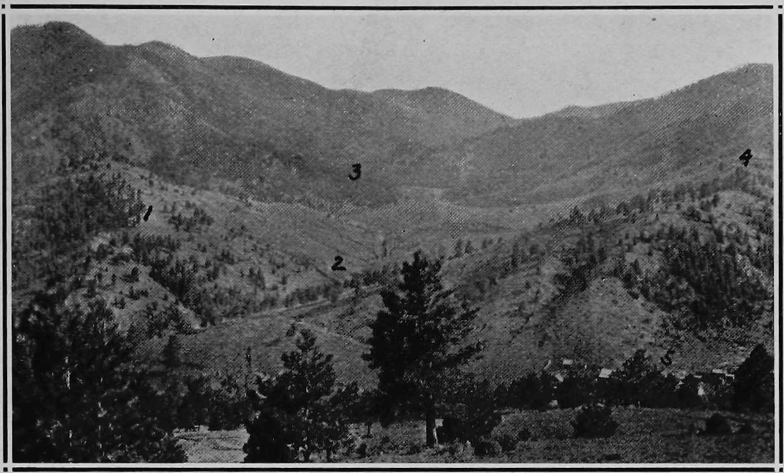
A tunnel cuts the vein at a depth of 25 feet, at which point a large, irregular body of ore 16 feet in width was taken out. There appears to be a branching of the veins at this point, one having a strike N. 68° E. and the other S. 53° E. The veins are vertical, and have side walls of granite. A shaft had formerly been sunk on the property, and an engine installed for hoisting the ore.

One set of leasers took out 2,000 tons of very good ore from this property in a short time. The property was under lease and was shipping ore to the mill in Boulder.

Buchannan.—The Buchannan is located about 500 feet southeast of the Alice mine. The vein has a strike N. 35° W., is nearly vertical, and is about 10 feet wide. The ore is violet-blue where it is not bleached, but where it is bleached it varies from gray to a light lavender. The ore does not fill the whole vein but forms irregular-shaped masses in the vein.

The property is developed by a crosscut tunnel to the vein, and by a small drift on the vein. An ore platform was built and other preparations for shipment had been made.

Buster.—The Buster Claim extends across the upper part of McCorkle Gulch, and the vein has been exposed for about 300 feet. It is nearly vertical and has a strike S. 64° E. and a dip of 83° SW.



McCORKLE GULCH.

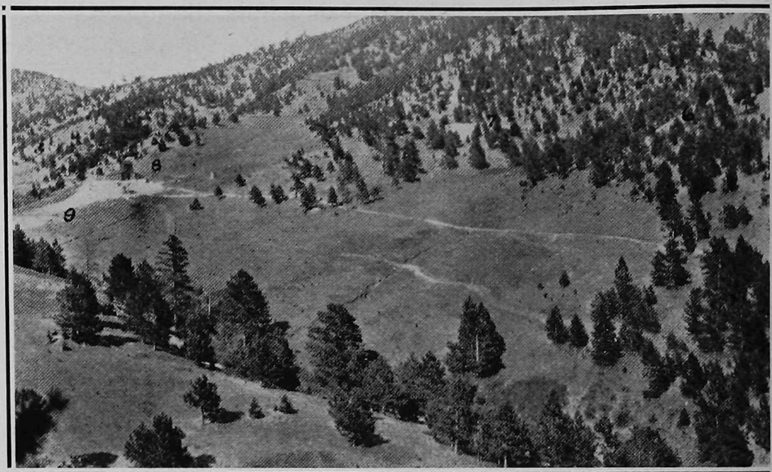
1—Blue Jay Hill
2—McCorkle Gulch
3—Slaughter House Gulch
4—Indian Point
5—Southern Part of Jamestown

It was opened in 1911 by drifting on a 4-foot vein, but later a crosscut was driven cutting the vein at a depth of 30 feet. At this point the ore was 12 feet wide. A drift was driven 200 feet to the west along the vein and the surface was worked 100 feet to the east of the crosscut. In places the ore changes to a mixture of horn rock and fluorspar which is easily cobbed and sorted.

The fluorspar is deep violet-blue, and Mr. John Evans states that a shipment of 200 tons of sorted ran from 72 per cent to 78 per cent calcium fluoride and from 12 per cent to 16 per cent silica.

Chancelor.—This property was formerly worked for gold. A new crosscut tunnel has been driven several hundred feet above the main tunnel, and the ore has been stoped to the surface, a distance of 25 feet. The vein is nearly vertical and strikes S. 80° E. It occupies a fissure in the granite and is irregular in width both horizontally and vertically.

Violet-blue ore which has a decidedly brownish tinge is mined from stopes above the tunnel level and shipped to the mill in Boulder.



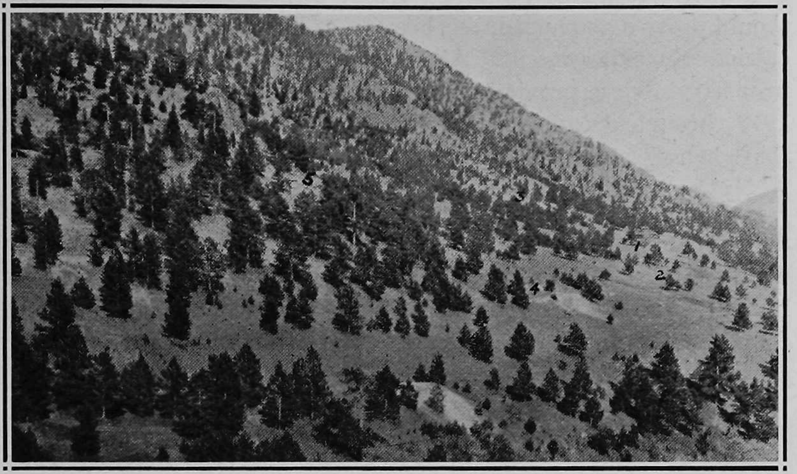
PORPHYRY MOUNTAIN FROM

6—Buchannan
7—Atkinson and Markt
8—Alice
9—Alice Cross Cut

Emmett.—The Emmett mine has been developed by a crosscut tunnel driven from a point on the west side of the road up Little Jim Creek, and by numerous drifts and stopes on the vein. In an upper drift the vein is vertical and strikes N. 60° W. until it comes in contact with a nearly vertical porphyry dike 14 feet wide. Here the vein turns and parallels the dike. On the other side of the dike the vein has the same direction N. 60° W., but where it comes in contact with the dike, it turns and parallels the dike to the east. It is a vertical fissure vein in granite. Some wall rock is enclosed in the ore, and in the upper drift near the porphyry dike great blocks or lenses of porphyry up to 10 feet in diameter are found in the vein.

The property has been a large producer of a purple-colored ore which is now shipped to the mill at Boulder.

Mrs. L. R. Evans's Claim.—This claim is located in an area of granite, and the veins occupy vertical fissures. The main vein has a strike S. 80° W. and is developed by an open cut 75 feet long. Beyond this the vein turns to N. 40° W. and is exposed in an open cut 40 feet long. A tunnel has been driven on a stringer of the main vein which it strikes in the open cut. Numerous other stringers, up to one foot in width, join the main vein from both walls. The main vein has a width of two feet in the end of the open cut. A dike of bronzite enclosing patches of deep purple fluorspar up to two inches in diameter, lies parallel to and 30 feet



MRS. L. R. EVANS' CLAIM.

1—Invincible 2—Brown Spar 3—Geo. Walker 4—Chancelor 5—Terry

north of that part of the vein which has a strike S. 80° W. Some good ore has been produced from this vein, but more work will have to be done before the extent of the deposit can be determined.

L. Evans's Lease.—L. Evans was one of three leasers on claims which are known as the Yellow Rose No. 1 and No. 2. They lie on the south side of Porphyry Mountain about 300 yards north of the Humboldt mine, and to the north of the road up Hill Gulch. The main vein is in granite and strikes N. 23° W. The main workings lie farthest north and consist of a 14-foot open cut to the vein and an open cut 20 feet long and 30 feet deep on the vein. The vein has a strike N. 23° W. and cuts the granite just south of Porphyry Mountain. Some very good ore was taken from this vein, and shipped to Pueblo.

Other veins are exposed to the south of this opening and some development work has been done. Some flakes of a lilac-colored mica found there proved to be muscovite, but the cause of the peculiar coloration could not be determined.

Invincible Mine.—The Invincible mine was formerly operated as a metalliferous mine, but during the past few years has been an intermittent producer of fluorspar. The property was not being operated early in 1917, although fluorspar was the principle mineral in a vein 12 feet wide, and was exposed in an open cut 50 feet long, 200 feet southeast of the shaft house.

The vein strikes N. 3° W. and although of varying width should prove a good producer, because of its persistency and its high calcium fluoride content. Although a shaft has been sunk on the property in close proximity to the vein, ore was being produced in 1918 through a tunnel and drift driven some distance below the shaft house.

Poorman Mine.—The Poorman mine which produced the first fluorspar mined in the Jamestown district and used for commercial purposes is located on the west side of Jim Creek on a hill overlooking Jamestown. The mine has not been operated for years, but ore found on the dump was a mixture of purple and brown fluorspar containing numerous fragments of the granite wall rock.

Silver Ledge Mine.—A 30-inch vein of fluorspar having a dip of 65° NE. and a strike of N. 72° W. has been exposed where it crosses the road, just east of the Silver Ledge mine. Development work in a tunnel shows that the vein varies greatly in width and contains a large number of granite fragments. It is said that other veins are known to exist in the mine but so far none have been developed for fluorspar. Further development work may result in the discovery of a better grade of fluorspar, but that now produced must be milled before it can be considered a commercial product.

Terry Claim.—The Terry claims consist of six or perhaps seven ore shoots in a vein 105 feet wide. The entire width of the vein, which strikes N. 30° E., contains fluorspar in irregular-shaped masses, the ore shoots being rather large and running in the same general direction through the vein.

The ore weathers to the same color as the vein material and country rock, so that it is hard for the inexperienced miner to determine just what is ore, without getting considerably below the surface. The unweathered ore is of a light violet-blue color.

The vein and ore shoots are exposed on the face, top, and sides of a large cliff, and the 400 or 500 tons of ore mined were taken from short tunnels in the foot of the cliff, and from gougings along its sides. Mr. E. R. Terry informed the writer that previous to 1917 the property had not been worked for four years.

George Walker Claims.—An opening on the hill directly north of Mrs. Evans's property shows the intersection of two fluorspar veins in the granite. One vein striking N. 85° W. has 4 feet of purple fluorspar, while the intersecting vein striking N. and S. contains four feet six inches of ore. Not enough work has been done to show the extent of the veins but from the character of the ore exposed in the opening further development should produce good results.

A number of veins have been opened on the hill, above and to the west and northwest of the Emmett mine. On the northeast side of the hill three veins radiate from a common center, striking S. 63° W., S. 84° W., and N. 43° W. All contain a very good grade of purple ore, and vary in width from two to three feet.

On the south side of the hill a vein striking S. 70° W. and turning N. 70° W. has been developed by a crosscut tunnel which strikes it just east of the angle. A drift has been driven a short distance to the east, and an open cut to the west. Very clean white to pale-green crystalline fluorspar was being mined from the vein in the open cut. The ore broke clean from the granite walls and very little wall rock was included.

Although the mineral was quite clear and nearly colorless it was too badly fractured to be of value as optical fluorspar. Care in mining might result in the finding of some material suitable for this purpose, as part of the fracturing is evidently the result of blasting in the mining of the ore.

Warren Mine.—The Warren mine is located on the northwest side of an east branch of Little Jim Creek between the Emmett and Alice mines. A crosscut tunnel 80 feet long follows a small stringer from the main vein. The vein strikes N. 49° E., lies between granite walls, and is developed by a drift 40 feet long. The ore has a maximum width of 17 feet. A shipment of 125 tons of ore from this vein contained 72 per cent of calcium fluoride. The grade of the ore was evidently lowered by the large amount of granite porphyry fragments it contained. Where the vein has a maximum width of 17 feet, over 100 tons has been mined by stoping, but no effort was being made to show either its extent or possibilities.

About 150 feet northeast of the main workings, a small tunnel 10 feet long, driven from the creek bottom, exposes a continuation of the main vein. Fragments of granite porphyry were scattered through the ore at this point. An analysis of a sample gave 62 per cent calcium fluoride and 31 per cent silica. The vein is well defined on the surface, and from indications the property could be made to produce a large tonnage with very little effort. The ore, however, will have to be milled, in order to raise the calcium fluoride content to the market standard.

VEINS NOT DESCRIBED

Many other veins of fluorspar have been exposed in the Jamestown district, but the writer has attempted to describe only those which are producing, or which show possibilities of becoming commercial producers under proper development. Some veins not described in detail are shown on the map of the Jamestown district, while many others not described or mapped were being discovered as a result of the renewed interest taken in the fluorspar industry.

CHAFFEE COUNTY

BADGER CREEK DISTRICT

Several fluorspar crystals of a light-purple color were received from the Badger Creek district east of Salida. No veins or deposits could be located in this area, although the writer made every effort to find the veins from which the specimens were supposed to have been taken.

MT. ANTERO DISTRICT

Early reports record the finding of occasional crystals in this district. Some kept as specimens in private collections would undoubtedly make excellent optical material as they are almost colorless, of good size, and apparently have very few if any fractures.

CLEAR CREEK COUNTY

Although fluorspar occurs as a gangue mineral in the gold and silver ores of the Georgetown and Idaho Springs districts, it is not plentiful. In the Mount McClellan and Argentine districts it is quite common and occurs as a green to purple-colored mineral in both the gold and silver ores. Numerous pieces of fluorspar were found on the dumps of mines in the district but very little information was obtainable as to its occurrences. The pieces found were badly fractured and when freshly mined were either light green or deep purple in color.

CUSTER COUNTY

ANTELOPE CREEK DISTRICT

A deposit of fluorspar occurs near one of the branches of Antelope Creek 16 miles southeast of West Cliff and 7 miles southeast of Rosita. The immediate area is one of pre-Cambrian granite and gneiss, and later eruptives which latter are not in close proximity to the vein. The fluorspar forms a shoot in a fissure vein cutting the granite and having a strike N. 41° E. and a dip of 80° to the southeast.

The property was badly caved, and an examination of an upraise and several drifts known to have been worked, was impossible. To the northeast of the main tunnel entrance, an open cut 110 feet long, and badly caved, showed a fluorspar shoot four feet wide in a vein which varied from four feet to fourteen feet in width. A tunnel, 100 feet long, driven along the vein from the north end of the open cut, was very badly caved, but showed decided irregularities in the width of the vein and the size of the ore shoot.

The following notes are from a description of the older workings by Burchard.[31] The property is developed by an adit and two drifts, 80 and 100 feet above the adit, all driven in the direction of the strike of the vein. There is one additional level 13 feet below the lower drift.

The adit, which is 200 feet long, was driven through barren vein material, and the ore shoot was reached about 50 feet higher, on a raise driven from the adit. The ore stoped in the levels was milled down the raise to the adit and then trammed to storage bins. The present surface workings are also connected with the lower adit, by means of a raise.

An examination of the workings of the lower level was impossible, so the writer's examination was confined to the surface workings. Some additional information was also obtained from former miners.

The fluorspar shoot varies from 20 inches to 4 feet in width, and averages 30 inches. It lies within the main vein which pinches and widens, and finally appears to end in some compact siliceous vein matter. On each side of the fluorspar is a band of brecciated siliceous matter cemented by fluorspar. This gets into the ore and makes sorting difficult.

[31]Burchard, Ernest F., U. S. Geol. Survey, Min. Res., pt. II, p. 612, 1908.

The fluorspar varies from light green to brown, which is the predominating color. It is finely fractured and at least part of the brown color is due to the infiltration of fine brown clay and iron oxides into the minute fractures which fill the ore. This brown color was noticeable even along the fine cleavages, and the thoroughly washed mineral when reduced to a fine powder would still show a slight brownish color, and would give a reaction for iron. Other pieces not so brown gave no reaction for iron and changed to a white color when heated. The ore appears to be free from siliceous matter except along the side walls. One small pile of ore on the dump was very free from foreign rock matter, and showed what could be done by careful sorting. Several pieces of violet-blue spar were found, but no clear transparent material was noticed.

The writer was informed by a former miner that the ore was always above the standard set by the Colorado Fuel and Iron Company at Pueblo. But it required exceptional care in sorting the ore to keep it above 80 per cent in calcium fluoride, because the siliceous rock of the sides of the ore shoot became mixed with the ore in mining.

The property has been idle for several years, and was last worked by J. C. Steiner and D. D. Moninger who organized the Jocomo Mining Company to develop the property, and it is now known by that name. Over 1,000 tons of fluorspar of very good grade was mined, hand sorted, and hauled 16 miles to the railroad at West Cliff, over a good road, the first 7 miles of which is quite hilly.

A considerable expense would be entailed in the opening up of the property, because of its badly caved condition, but if after opening it up a thorough examination still showed the existence of proper ore bodies, the ore could be jigged or milled nearby. A stream which might furnish enough water for small milling purposes flows within 100 yards of the property. This would enable the operator to get a product of higher grade and low in silica.

DOLORES COUNTY

RICO DISTRICT

Fluorspar is not a common mineral in the ores of the Rico district but is found sparingly as a gangue mineral in several of the mines. In the replacement deposits of the Black Hawk mine it occurs as a colorless to light purple gangue mineral associated with pyrite, chalcopyrite, sphalerite and galena. Ransome[32] reports it occurring as a gangue mineral in the large pay shoot outcropping at the back of the bunk houses of the Black Hawk mine but it is not now found in that ore shoot. Some small pieces were found on the dump of the Duncan mine where it occurs as a gangue mineral in a pyrite-chalcopyrite ore. The fragments were of a pale lilac to light green color, and very much fractured.

DOUGLAS COUNTY

DEVILS HEAD DISTRICT

Crystals of both green and purple fluorspar are found in the area of pre-Cambrian rocks around Devils Head. Some beautifully colored crystals up to one and one-half inches in diameter have been found, but at present crystals are found only occasionally and these are too deeply colored to be of value for optical purposes.

EL PASO COUNTY

PIKES PEAK DISTRICT

Crystals of fluorspar have been found in this district but no veins of the mineral are known to exist.

CASCADE AND UTE PASS DISTRICTS

Fluorspar has been found at Cascade and in several tunnels of the Colorado Midland Railroad in Ute Pass. No outcrops of veins however were found.

ST. PETERS DOME DISTRICT

This area is usually spoken of as the St. Peters Dome district but should really be divided into the Duffields and the Cather Springs districts.

Duffields Area.—About one-third mile east of Duffields the railroad cuts through a vein of fluorspar, which stands exposed high on both sides of the track. The vein is developed by a tunnel 85 feet long which starts in a gulch to the north of the tracks, and has been driven in the direction of the tracks.

A second outcrop developed by an open cut 35 feet long lies to the south of the tracks on the opposite side of the hill.

[32]Ransome, F. L., Economic geology of the Rico quadrangle, Colorado: U. S. Geol. Survey, Rico Folio 130, p. 15.

The vein developed by the tunnel strikes S. 10° E. and lies between walls of granite. It is very irregular in width both laterally and vertically and in places breaks up into a number of seams from 3 to 6 inches in width between which is a siliceous material, made up mainly of orthoclase and quartz. The vein varies in width from 30 inches to 10 feet and averages 5 feet. The mineral is deep purple and green and is badly fractured. The seams are filled with a fine brown clay material. The mineral also seems to be somewhat laminated, as if it had been pressed out through movement, but no faulting or other evidence of movement was observed.

The vein shows the same characteristics in the cut on the railroad tracks, where it reaches a width of 15 feet. It can be traced 2,000 feet to the north and is exposed in several old shafts where it is associated with galena and sphalerite. This district has been prospected for gold and the shafts were sunk on this supposed metalliferous vein. The tunnel is badly caved and will require a considerable expenditure to open it up. It was first worked for fluorspar in 1910-1911 when a small tonnage was hauled on a skid to Duffields for loading. The ore was cobbed and sorted. During later development some of the finer material was screened before being shipped.

The opening to the south of the tracks is either the same vein or a branch which has a trend S. 30° W. An open cut, now quite filled, had been made and the ore from a 3 foot vein was thrown on the side of the cut, where it still remains.

The fluorspar in this cut is lighter in color than that in the tunnel and contains a higher percentage of silica. No effort has been made to mine this ore during the past 8 years.

Cather Springs Area.—During June, 1917, a railroad spur was put in at Cather Springs and a road built along the side of the mountain, to a vein of fluorspar then being opened up one-half mile south of the railroad and known as the Cather Springs deposit.

A fissure vein two and one-half to four and one-half feet wide in the granite strikes S. 20° E., dips 80° N. 45° E., and is exposed along the hill side for 2,000 feet. It is developed by two shafts and a tunnel, used in the former development of the vein as a gold silver property. A large amount of quartz is found along numerous small water courses in the vein although some solid fluorspar of good grade occurs next the walls. The mineral is generally green but when it is bleached to a gray color it is almost impossible for the inexperienced to distinguish it from quartz and siliceous vein matter.

An effort was being made to sort over the dump from an old shaft 100 feet deep, and considerable good ore was being found and loaded on a car at the spur. The ore will not be hard to mine, but extreme care must be taken in the sorting, or the silica content will be excessive.

As no freight trains were being run over the railroad from Cripple Creek to Colorado Springs, cars had to be "set in" by a switch engine from Colorado Springs. A switching charge is made for this, which, added to the cost of mining, reduces the margin of profit considerably.

GILPIN COUNTY

No commercial veins of fluorspar are known to exist in this county. However, the mineral is found in a number of mines, where it occurs as gangue in both pyritic and telluride ores.

Bastin and Hill[33] in describing the ore deposits of the district show that where the ore is a replacement of the wall rock, the gangue minerals are the wall rock minerals or their alteration products, notably sericite. Where the ore is a filling of open spaces, the predominant gangue mineral is quartz. Siderite is a subordinate gangue mineral in certain deposits, and fluorite an abundant mineral in others. Fluorite is a characteristic gangue mineral in certain of the rich telluride ores, but it occurs also in certain pyritic ores, particularly those containing enargite. This association is not always the rule as is shown by its occurrence and absence in both types of veins. The fluorspar occurs as a green or purple or more rarely a colorless mineral in the pyritic veins, and is always a subordinate vein material. No optical fluorspar was found in the district.

Fluorspar is known to occur in the following mines: The War Dance, Treasure Vault, Chase, Togo, Silver Dollar-Hampton, Powers, Iroquois, Anchor, Hazeltine, Hill-Bunk House.

GUNNISON COUNTY

CRYSTAL DISTRICT

Fluorspar is found as a gangue mineral in the lead ores of the Lead King mine. Several colorless crystals up to one and one-half

[33] Bastin, Edson S., and Hill, James M., General features of the economic geology of Gilpin county and adjacent parts of Clear Creek and Boulder counties, Colorado: U. S. Geol. Survey, Prof. Paper 94, pp. 105, 106, 114, 134.

inches in diameter have been seen in private collections and are said to have come from this property, but no material of value was found in visiting the district.

HINSDALE COUNTY

Fluorspar has been found as a gangue mineral in the ores of the Hidden Treasure mine which is located within an area of andesitic rocks of the Picayune Volcanic group.[34] Some small pieces of fluorspar which were found on the dump of the mine, were of a pale green color, but too badly fractured for optical purposes.

JEFFERSON COUNTY

EVERGREEN DISTRICT

The area near Evergreen is one of pre-Cambrian granite and gneiss cut by fissure veins and dikes of pegmatite.

To the south and southwest of Evergreen the fissure veins contain mainly fluorspar, associated with lead, zinc, and copper minerals which occur in minor quantities only. Certain other veins which appear to run high in fluorspar, with small amounts of metallic sulphides, have been developed, but the fluorspar is only local and the vein filling changes to quartz. Pegmatite dikes often contain small amounts of fluorspar and metallic minerals, but these minerals are only of minor importance in the dikes.

A well-defined vein of fluorspar having a strike N. 35° E. crosses Cub Creek and has been opened in the workings of the Augusta mine one and a quarter miles south of Evergreen. The same vein outcrops on the northwest side of Cub Creek about three-quarters of a mile southwest of Evergreen, and again on the Brookvale road one-quarter of a mile west of the Evergreen-Bergen Park Road . This is locally known as the Augusta vein and can also be traced several miles to the south, through openings along its course.

A second vein known as the Bull Hill claim is located on the south side of Cub Creek one and three-quarters miles south and west of Evergreen. It can be traced for over a quarter of a mile. It is covered at one end by surface material, and ends in a mass of quartz at the other.

Augusta Mine and Vein.—This property was formerly worked for metalliferous ores and is developed by a crosscut tunnel 270 feet

[34]Bancroft, Howland and Irving, John D., Geology and ore deposits near Lake City, Colorado: U. S. Geol. Survey, Bull. 478, p. 46, 1911.

long which cuts the first and larger of the two veins at a depth of 95 feet, and a distance of 190 feet from the portal. The crosscut has been driven 80 feet beyond this point, but has not encountered the second vein. At the junction of the crosscut and the vein, a winze had been sunk 26 feet. Drifts have been driven to the south 50 feet, and to the north 20 feet. Practically the entire ground above the tunnel level has been stoped up to connect with old surface cuts.

The vein is of the fissure type, strikes N. 35° W. and dips to the southwest, having a horizontal displacement of 14 feet in each 100 feet of depth. The wall rock is a hornblende-biotite gneiss which in places changes to a granite. Movement has squeezed out the hornblende and biotite of the gneissoid walls which in places show considerable slickensiding. The vein varies in thickness from 1 to 5 feet, and averages 2 feet. The light purple and green fluorspar is sometimes replaced by kidneys of zinc, lead and copper ore weighing up to 50 pounds. In the end of the north drift the fluorspar crumbles rapidly on being broken, and in mining becomes mixed with quartz and orthoclase which form numerous stringers in the vein.

The fluorspar was formerly mined by surface workings and carted to Black Hawk for use as a flux. These workings are now badly caved, and the fluorspar, where it is found in place, appears very quartzy. On close examination this appearance is seen to be due to the clear colorless character of the mineral, the result of its bleaching in the sun, and to the presence of perfect cleavage surfaces and conchoidal fractures. No optical fluorspar was found, as the clear mineral was full of incipient fractures.

A second vein lies about 100 feet to the east and parallels the first but is narrow and cannot be profiitably worked under present conditions. The other openings to the northwest of the Augusta mine expose a body of fluorspar from 2 to 4 feet wide. with a dip to the southwest. The ore is of a fair grade, but is mixed with more or less quartz. Over 1,000 tons have been hauled from the property to the railroad at Morrison, a distance of 12 miles. From there it was shipped to Pueblo, where the greater part of the ore has been marketed. The property was idle during the fall of 1917 and spring of 1918.

Milling cannot be undertaken at Evergreen, as the City of Denver will not permit the dumping of tailings into either Cub Creek or Bear Creek.

Bull Hill Claim.—This property is located one and one-half miles south of Evergreen and is developed by a shaft, 105 feet deep, but now filled to 50 feet from the surface. Several drifts not exceeding 13 feet in length follow the vein to the northwest, and one extends 14 feet to the southeast. The vein strikes S. 45° E., dips 80° to the southwest and varies in width from 2 to 4 feet. The ore is of an extremely deep purple color and in places is quite honey-combed, through the leaching out of some other mineral. The holes thus formed were irregular in shape and the walls were so etched, that the mineral removed could not be determined.

The vein changes into a pure white quartz both to the northwest and southeast and unless the fluorspar persists in depth the deposit will not prove extensive.

Ore for an experimental mill run was being taken out by the operator, H. L. Littell, and was to be hauled by truck to Denver for milling. To avoid any unnecessary expense, especially in the purchase of hoisting machinery, the ore was being hoisted by means of a rope attached to an automobile and run over a pulley to the bucket.

BUFFALO DISTRICT

A small vein of fluorspar is found on the north side of the hill 300 yards west of the school house at Buffalo, and a second vein is located on a hillside 200 yards south of the Buffalo-Pine road three-quarters of a mile west of Buffalo.

The fluorspar found near Buffalo occurs as a small seam 2 to 3 inches wide, in a fissure vein which cuts an area of hornblende-biotite granite. The vein which is about 14 inches wide has a strike S. 35° E. and a dip of 80° N. 55° E. and is filled mainly with a dark brown siliceous vein matter. Fluorspar of a dark purple color is found near the center of the vein matter, which in places is broken up into alternate bands of quartz and fluorspar. The vein outcrops for a distance of 225 feet along the hillside and is developed by two tunnels one 80 feet long and the other 35 feet. Both tunnels were driven in 1897 and 1898, as the result of finding some galena mixed with the fluorspar of the vein.

The second vein is 14 inches wide and has a trend S. 17° E., in an area of granite. The fluorspar occurs as a gangue mineral associated with galena, pyrite, and barite, and is rather prominent in the vein. The property which was formerly worked for gold and silver is developed by two openings on the vein—the first a shaft 35 feet deep and the second an open cut 6 feet deep. The property has not been worked since 1898, and as a result is now badly caved.

The fluorspar is deep purple in color, very badly fractured, corroded, and covered with a brown iron oxide.

BERGEN PARK AND CLEAR CREEK CANYON DISTRICTS

Samples of fluorspar, said to come from the district between Bergen Park and Clear Creek Canyon have been handed the writer on two occasions, but a close search of the district failed to discover any outcrops of veins carrying fluorspar. The sample may however be from a very small area which was overlooked in the search.

LAKE COUNTY

Emmons[35] in describing the ore deposits of the Sweet Home mine at Leadville says: "This mine is interesting from the varieties of mineral species thus far obtained from it. Among these are cuprite, fluorite(pink and blue), jamesonite, melanterite, rhodochrosite, and zinkenite." Fluorspar undoubtedly occurs in other mines in the district, but these occurrences are local and of so little importance, that its presence is almost unnoticed. No investigative work was done in this district.

LA PLATA COUNTY

In the mines of the La Plata Mining district fluorspar and a number of other minerals such as quartz, calcite, rhodochrosite, dolomite, asbestos, garnet, chlorite, and kaolinite are found as gangue minerals in the ores.[36] No fluorspar of value, either for fluxing or for optical purposes, was located in the district, only small pieces being found on the dumps of several of the mines.

MINERAL COUNTY

WAGON WHEEL GAP DISTRICT

An extremely large deposit of fluorspar has been developed by the American Fluorspar Mining Company one and a quarter miles south of the Wagon Wheel Gap station on the Denver & Rio Grande R. R. This deposit is located on the east side of Goose Creek at a

[35] Emmons, S. F., Geology and mining industry of Leadville, Colorado: U. S. Geol. Survey, Mon. 12, p. 527.

[36] Purington, C. W., Economic geology of the La Plata quadrangle, Colorado: U. S. Geol. Survey, La Plata Folio 60, p. 13.

point directly opposite the Mineral Hot Springs, a resort well-known for its mineral waters.

The vein was located in the belief that it was an extension of the Amethyst vein at Creede. Both veins strike northwest and southeast and cut through country rock of the same type.[37] On account of the resemblance of the amethyst and purple fluorspar to the radiating amethyst-quartz crystals found in the Amethyst vein at Creede, no one appears to have known that it was fluorspar. As the fluorspar vein carries but little gold and silver but little attention was given to it. In 1911 the mineral was recognized by S. B. Collins, the president and general manager of the American Fluorspar Mining Company, and by 1913 development had progressed to the extent that 5,000 tons were shipped to Pueblo. During 1914 the mine was idle but reopened in 1915, and has been worked intermittently to the present time.

GEOLOGY

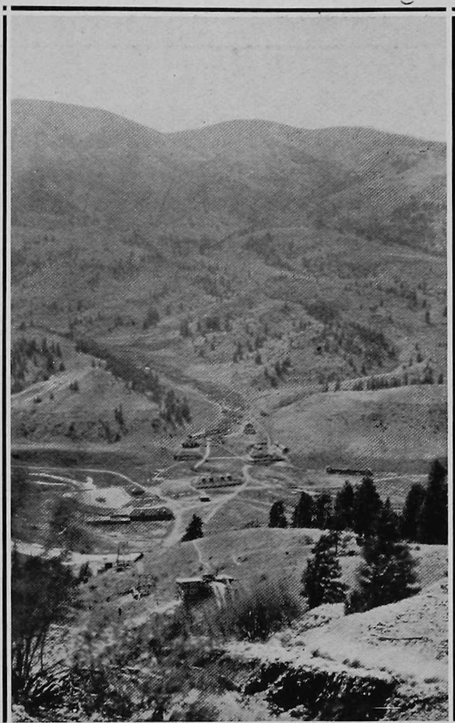
The vein which is exposed on the steep hillside to the east of Goose Creek, may be traced about 2,500 feet to the east where it appears to end in a small gulch or flat. The vein lies entirely within an area of Tertiary volcanic rocks consisting of beds of rhyolite tuff, with some quartz latite and andesite. On the top of the hill, and in close proximity to the vein, reddish rhyolite and quartz latite predominate, but in the vicinity of the present workings on the hillside, andesite appears as the predominant rock and forms the walls of the vein.

DEVELOPMENT

The property is developed by two tunnels, and several small shafts and open cuts have been dug in prospecting the vein at the extreme eastern end of the property. The lower tunnel has been driven over 600 feet along the vein from a point near the base of the hill. The main workings on the hill include several drifts, stopes and upraises all driven from a tunnel located about 600 feet above the lower tunnel, and about 700 feet above the stream. An aerial tram, with two supporting towers and operated by gravity, connects the upper workings with ore bins of 300 tons' capacity located at the foot of the hill, near Goose Creek. At the upper end of the tram a terminal with "grizzly," sorting plats, and bins of 75 tons' storage capacity provide for the production.

[37]Lunt, Horace F., A fluorspar mine in Colorado: Min. and Sci. Press, pp. 925-926, Dec. 18, 1915.

Prior to the summer of 1917 the ore was hauled by team to Wagon Wheel Gap and loaded on cars at a spur one-quarter mile above the station. In July, 1917, a tram track was laid along the base of the mountain on the east side of Goose Creek and the Rio

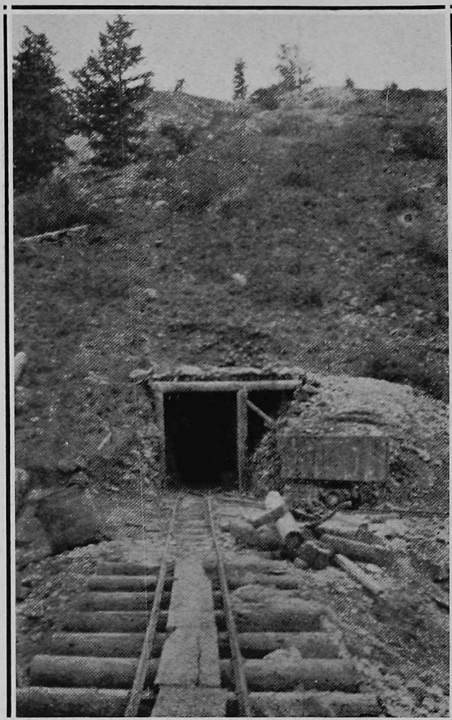


Colorado Fluorspar Company, Wagon Wheel Gap. Aerial Tram and Upper Terminal from Point on Vein above Present Workings.

Grande River, to a point where it crossed the river on an old wagon bridge just east of the station. Here the tracks were elevated so that the ore could be dumped directly into the railroad cars. The grade was such that a mule could pull a number of cars, and as the track had numerous switches, several trains could be run each way at once, and a large tonnage loaded on the railroad cars.

FLUORSPAR VEINS

The vein is of the fissure type and is very irregular in width both vertically and horizontally. In places it has a maximum width of 14 feet, but the average as seen in the main workings is about 4 feet. Numerous branches, offshoots of the main vein, occur in the upper workings. On the north side of the hill paralleling the vein, a great number of fluorspar boulders have been found covered with wash. The vein is persistent in its strike, which varies from N. 80° E. to due E., and throughout has a dip of 70° to 80° southward. That part of the vein at the extreme east end of the property has the same strike and dip. The vein at the east endline near



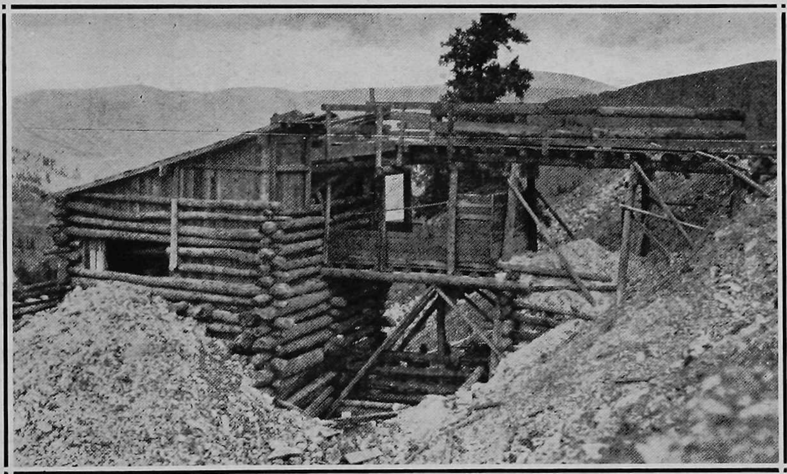
Colorado Fluorspar Company, Wagon Wheel Gap. Main Tunnel

where it disappears is about two to two and one-half feet wide. The wall rock of the vein, a rhyolite tuff, seems to be decomposed less than in the main workings, but this condition may change with depth.

In the lower tunnel the wall rock is much altered in many places and the vein varies in width, but apparently is not nearly as strong, the average width of the fluorspar being not over 20 inches.

FLUORSPAR

The ore in the main workings is mainly fluorspar, barite, creedite, fragments of country rock, and gouge. Very little barite is found below 25 feet and none below 200 feet. The fluorspar occurs in a number of forms, but (a) mainly as a white, sugary or granular fluorspar forming solid masses across the whole width of the vein; (b) as yellow-green, green, blue-green, yellow, brown, lilac, violet, blue, and purple fluorspar, either as an encrusting mineral on fragments of andesitic wall rock; (c) as banded material on the side walls of the vein; (d) as a massive vein-filling mineral; (e) as a crystalline mineral facing inward along water courses; (f) as a banded material with an apparent botryoidal form; (g) as typical concentric lenses in the ore body; (h) as an aggregate mass with crystalline barite. Along water courses the mineral may be entirely honeycombed, whether it be crystalline, granular or massive. Radiating crystals of fluorspar, which vary in color from the inside out, but usually terminate as a purple crystal, are quite numerous. The vein is composed of such a variety of types, colors and forms of fluorspar that their derivation and extent could only be determined by a prolonged study of the deposit.



Colorado Fluorspar Company, Wagon Wheel Gap. Upper Terminal and Ore House.

At the time of the writer's visit, ore of each type just described was being produced from various places in the mine. One large upraise which had reached the surface was driven in a fluorite-barite ore body from 12 to 14 feet in width, in which the barite occurred as perfect crystals among radiating crystals of fluorspar. This condition prevailed to a depth of 25 feet, below which the amount of barite became negligible. Fluorspar showing a banded coloration was common. The bands were either parallel or concentric, depending on the type of ore encountered.

The wall rock is badly weathered, but one wall is almost always good. The water courses which are numerous near the surface are continuous and are found even in the lower tunnel. The wall rock contains some finely disseminated pyrite, which is altered in some cases to limonite and hematite. In the upper workings a new mineral has been found which has been described by Larsen and Wells[38] under the name Creedite. Some of this mineral was found on the dump of the upper workings.

The fluorspar, where exposed at the east end of the vein, occurs as purple or amethyst-colored radiating crystals, in some cases covered with a thin film of silica, and in many other cases covered with a coating of brown iron oxide. In the lower tunnel the wall rock is badly weathered and at one place where it passes through a body of soft, highly altered country rock, a number of white balls of varying diameter were found. These have been described by Larsen and Wells as Gearksutite, which like Creedite is a fluorine mineral.

PRODUCTION

The ore is put over a ''grizzly'' after which the larger pieces are sorted, cobbed, thrown with the fines and carried by tram from the upper to the lower terminal, for storage until hauled to the railroad. Only the large pieces of barite, wall rock, and gangue are thrown out in this sorting. The ore is easily kept above 80 per cent in calcium fluoride. With extreme care and a choice of ore, the grade can be run up to 98 per cent calcium fluoride. Such ore may be shipped to eastern markets for chemical work.

Ore from this deposit has been shipped to both coasts, and while some is being shipped to the Colorado Fuel & Iron Company at Pueblo, a large quantity goes to eastern markets. No data were obtainable as to the total production, but in March of 1917, 1,440 tons were shipped. It is expected that this output will be doubled as soon as the new tram can be placed in operation.

The deposit is exceedingly interesting from a geological, mineralogical, and production standpoint, and should be thoroughly investigated at some future time.

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[38]Larsen, Esper S., and Wells, Roger C., Some minerals from the fluorite-barite vein near Wagon Wheel Gap, Colorado: Nat'l Acad. Sci., vol. 2, p. 360, July, 1916.

The published analyses of the mineral waters do not show the presence of fluorine, but it may be doubted whether they have been carefully examined for this element. It would seem probable that a more or less direct relationship may have existed between the thermal springs and the origin of the fluorspar veins.

MONTROSE COUNTY

A small deposit of fluorspar has been found 14 miles northeast of Montrose, along the south side of the Gunnison River, on Vernal Mesa. The property lies about three or four miles to the northwest of the point where the Government road reaches the top of Gunnison Canyon. From that point a road extends one and one-half miles toward the deposit, and beyond this there is a trail.

The area is one of pre-Cambrian granites and gneisses which show a large amount of folding. The vein cuts through a granite-gneiss complex and is easily traced for some distance down the walls of the canyon. The fluorspar occurs as an 8-inch shoot in a vein 20 feet wide which outcrops on the face of a cliff, on the west side of Gunnison Canyon. The vein is formed of highly siliceous rock matter and the ore shoot which occurs slightly to the north of the center of the vein has a strike S. 78° W. and dips 85° S. 12° E. The mineral is from green to salmon pink in color and has a hardness of about 5. The presence of a large amount of silica and iron oxide undoubtedly accounts for the pink color and the hardness of the mineral.

An analysis made by the Colorado Fuel and Iron Company at Minnequa, of a sample of ore from this deposit sent them by Harry Lighte of Montrose, gave the following results.

	Per Cent
SiO_2	46.08
Al_2O_3 & Fe_2O_3	10.04
$CaCO_3$	8.67
CaF_2	33.50
$BaSO_4$	.90
	99.19

Only a small amount of work had been done in opening up the ore shoot, so that very little could be learned of the extent of the deposit, as it did not outcrop on the surface of the mesa and could not be followed down the cliff. The small opening which has been run in 10 feet on the ore shoot is rather inaccessible, being located 100 feet below the rim of the Mesa and on the edge of the canyon, where there is a sheer drop of over 2,000 feet to the river below. The deposit does not look promising because of the poor quality of the ore and its inaccessibility.

OURAY COUNTY

BARSTOW MINE

Just prior to the visit of the writer to this district a vein of fluorspar was cut in the Barstow mine at Red Mountain. This property lies within an area of rocks belonging to the Silverton volcanic series and consisting mainly of tuffs, rhyolites, and andesites. The vein was cut while drifting on the main gold-bearing vein of the Barstow about 3,300 feet, on a straight line, from the portal of the tunnel, and at a depth of 1,040 feet from the surface. Before cutting the fluorspar, the main vein of the Barstow had a strike N. 45° W., but on passing through the fluorspar its course changed abruptly to N. 15° W. The fluorspar vein which has a bearing S. 69° E. and a dip of 85° to the NE. has walls of andesite which is very little weathered. Some little faulting has occurred in the main vein and is shown by a lateral displacement of about 5 feet to the southeast, but no slickensiding or striations have resulted from this movement, and no evidence of movement was noticeable in the fluorspar vein.

The fluorspar vein varies from 3 to 5 feet in width, and on the east side of the main vein a water course through the center of the vein has formed a slight coating of silica over the fluorspar, and has deposited a solid green fluorspar next the walls. On the west side the vein contained about 5 feet of massive fluorspar, quite badly fractured, through the blasting of ore in the main vein. Up to the point of intersection of the two veins the Barstow ore was of good grade. At, and for a distance beyond that point, it was lean. But as the distance from the fluorspar vein increased the tenor of the Barstow ore gradually rose and reached the normal. Before intersecting the fluorspar vein the Barstow vein was from 12 to 14 feet wide, but beyond the fluorspar it was reduced to five feet.

The fluorspar vein had not been developed, and all samples were taken from a point at the contact with the metalliferous vein of the Barstow. The spar is massive and appears to occur as large boulders or lenses in the vein, which as seen, was irregular in width both horizontally and vertically. The fluorspar is of pale to bright green color and is extremely clean. A number of large pieces were selected and shipped to Boulder in the hope that some material suitable for optical purposes might be found. However, all the material seemed badly fractured. Part of this fracturing was evidently due to blasting in the metalliferous vein of the Barstow, and it may be that by getting well away from these conditions and carefully mining and sorting the ore, some optical fluorspar will be found. Some of the fluorspar shows a decided banding evidently due to the method of deposition. One piece an inch in diameter has 18 distinct bands varying from yellow-green to violet.

C. R. Wilfley the manager of the property told me that he believed fluorspar had been found in a level 140 feet above the occurrence here described but that we would be unable to get into that part of the mine at that time. The part of the mountain where outcrop of the fluorspar vein should be found is covered with snow the year round, so no effort was made to trace the vein on the surface. This occurrence of fluorspar at a depth of 1,040 feet, where it is found as the principal filling mineral of a fissure vein, is perhaps the greatest depth at which a true fluorspar vein has ever been found. The vein as seen shows no signs of pinching out but should continue to greater depth.

The Barstow mine has been a producer of metalliferous ores for some years and is well equipped for the production and milling of fluorspar ore. It is located one mile by wagon road southwest of the Joker Tunnel, the nearest point on the railroad, and all hauling is down hill from the mine. The railroad, however, is open only seven months out of the year and during the winter months ore would have to be hauled to Ouray for shipment. During the winter of 1917-1918 some ore was shipped from Ouray, but the heavy snow and treacherous roads made the work extremely difficult.

During the spring of 1917 the writer received a letter from C. R. Wilfley who had acted as Ouray Manager for the Engineer's Corporation, then leasing on the fluorspar vein in the Barstow. A part of this letter, as printed below, gives some very interesting information concerning the further development of the vein, while still another part describes his experiments in milling the ore.

"We did work in drifting along the fluorspar vein on both our main levels, which were about 140 feet apart vertically. The two places where we cut the spar vein on the two levels are approximately 600 feet apart horizontally. We found that at both intersections with the gold vein, the spar was too badly mixed with quartz to be mined and shipped crude, though perhaps close milling might make salable products. We got out a little ore from the lower level, then stopped there.

"On the upper level we drifted about 80 feet north or into the hanging, and perhaps half as far the other way, on the spar vein. Just as soon as we got away from the intersection we got two to four feet of fine spar and we stoped both sides of the quartz vein, getting out perhaps a thousand tons. We have not really developed this vein enough to say just what it is and what it will do, for we are barely away from the influence of the main vein. We found a tendency, as soon as we got outside of the intersection for the spar vein to turn and parallel the main vein on both sides. Not quite parallel—it still diverges at an acute angle, as shown by the intersection in the lower level so far away.

"Then we went down forty or forty-five feet below the upper or No. One Level into some drifts on the main vein which ran westerly from an old stope. This was about half way between the intersections on the main levels. We developed good spar here, showing the spar vein to be pretty continuous between the two intersections, and indicating a considerable productive area close to the main vein—'main vein' meaning the main Barstow gold vein.

"You see our development so far is small and is limited to close proximity to the main vein. I am anxious to see the spar vein developed out into the country.

"The spar vein in stopes showed somewhat pockety. Hardly true pockets, but bodies and lenses, say. This has not at all been proven nor developed, but the tendency was for a body to narrow down in going up and going horizontally, sometimes showing a horse or barren portion; then the ore would come in again and widen to good wide spar. Some of the biggest, widest ore is the best grade.

"The spar is soft and easily mined, most of it being picked down. It is a slightly sticky, somewhat sandy mass of brown clayey mud and spar. We have great boulders of fine spar in this, as well as much smaller stuff. The fine mud is somewhat aluminous but nearly all sizes contain a high percentage of spar, some of the finest stuff being pretty good. The silica is sometimes in streaks or bunches, and sometimes, when too close to the main vein, in fine sizes of separate small pieces of quartz, from half inch down to fines. We have had more or less difficulty with the quartz—but most of this was due to mining too close to the main vein. We do not know whether we can develop any big solid stopes of pure spar but are inclined to think we can. We are shut down for the winter, but have some very good showings in the stopes ready for mining.

"We shoveled snow most of the bad part of the winter and brought a good deal of spar to Ouray for shipment. Much of this spar was shipped directly as crude ore without any sorting or treatment except a little sorting of boulders of waste in the stopes. It ran 85 to 90 per cent calcium fluoride and five per cent silica, the rest being calcium carbonate, alumina, a little iron oxide, etc. We could easily wash and sort it to a higher grade. Pure specimens—rather, straight washed lump in considerable quantity could be produced at 98.5 per cent purity.

"After considerable looking over, I concluded we would not have much luck getting lens material. However, most of my investigation was of a quartzy ore which was washed on the washer; this had been shot much harder than subsequent stuff which was not washed and hence offered much less chance of looking over. I still would like to see some of our fine large lumps examined with a view to scaling and peeling down, for we might get some pretty large lenses. In general, the spar seems to be naturally pretty badly fractured."

CAMP BIRD MINE

Light green fluorspar similar to that found in the Barstow mine has been found in the Camp Bird mine. Several pieces four inches in diameter were found on the dump of one of the upper workings, and from appearances could easily have been mistaken for ore from the Barstow mine at Red Mountain, as the color and fracturing were identical. Banding was also noticed. The property was closed at the time of the writer's visit and nothing definite could be learned of the fluorspar vein.

GRIZZLY BEAR AND MICKY BREEN MINES

Fluorspar of a bright green color occurs as a gangue mineral in these two mines in Poughkeepsie Gulch where it is associated with galena, pyrite, chalcopyrite, sphalerite, rhodochrosite and quartz. A number of small crystals were examined but were too deeply colored for optical purposes.

PARK COUNTY

ALMA DISTRICT

Fluorspar in the form of cubes up to one-half inch in diameter occur as a gangue mineral associated with chalcopyrite in the Kentucky Belle and Rainbow mines. In the Rhodochrosite mine, fluorspar occurs with rhodochrosite as a gangue mineral in a sulphide ore containing galena, chalcopyrite, pyrite and tetrahedrite as the principal minerals.

The fluorspar is very clear but of a deep purple color, and does not commonly occur in crystals of sufficient size for optical purposes. The rhodochrosite separated from the other minerals is sold to curio dealers, mineral collectors and to gem collectors who cut and polish the mineral. Some fluorspar from this district has also been cut and polished.

HALLS VALLEY DISTRICT

Fluorspar has been reported as a gangue mineral in the ores of some of the old and abandoned mines. The only property working in this district was the Whale mine near the head of Halls Valley, but the ore from that property does not contain any fluorspar.

JEFFERSON DISTRICT

A well-defined vein of fluorspar is located 4 miles north of Jefferson on the east side of Guernsey Gulch, and about 400 feet above the valley. The property can be reached by road from Hoosier and from Jefferson. Some ore was mined in 1913-1914 and hauled to Hoosier, a distance of four miles, where it was shipped to the Colorado Fuel and Iron Company at Pueblo.

The property is developed by two tunnels, one 75 feet above the other, from which short drifts have been driven along the vein. The lower workings consist of a crosscut tunnel, 75 feet long, from which a drift follows the vein in a direction N. 59° E. The drift was completely closed by a cave-in and the tunnel was partly closed where the timbering had given way. The upper workings were in much better shape and consisted of a crosscut tunnel, 25 feet long, and a drift, 15 feet long, at right angles to the crosscut.

The vein fills a vertical fissure in hornblende-biotite granite, and strikes N. 59° E. At the top of the hill to the northeast the vein takes a course N. 42° E. and outcrops for a distance of 2,500 feet to a small open cut where it contains a large amount of quartz. As exposed in both workings the vein varies in width from 3 to 15 feet and contains about 15 to 18 inches of good ore.

The fluorspar in the upper workings is a light leaf green, while that in the lower workings is a very deep purple. Large pieces appeared almost black. The greater part of the leaner ore in the upper workings contains thin films of silica along the many cleavage planes. This gives a peculiar sheen to the freshly broken surfaces. The size of the dump shows that the lower workings are quite extensive, but the drift was almost entirely closed by the caving of the roof and no examination could be made. Four or five cars of ore were shipped from the property about 1913, but since that time only assessment work has been done.

PLATTE RIVER DISTRICT

Specimens of crystallized amazonite, quartz and fluorspar have been found in the vicinity of the South Platte River, northwest of Florissant. Some of the fluorspars are of considerable size and would undoubtedly make fine optical material if the owners could be induced to part with them.

SAGUACHE COUNTY

BONANZA DISTRICT

Crystals of fluorspar, both cubes and octahedrons are found associated with crystallized rhodochrosite in the sulphide ores of the Eagle mine southeast of Bonanza. Fluorspar occurs as a gangue mineral in other mines of the district, but as the deposits were of no commercial value, further investigation was not undertaken.

LIBERTY DISTRICT

Fluorspar has been developed in an open cut and in two shafts on the north slope of the ridge between Short Gulch and a small gulch south of Pole Creek, just north of Liberty, a small settlement on the east side of the San Luis Valley, and in the region of Mosca Pass. The openings are located at an elevation approximately 800 feet above Liberty and are reached by a trail starting in the gulch just north of that place. Both shafts are badly caved.

The workings expose the fluorspar in what appear to be branches of a small vein which has been developed by a small open cut in Short Gulch. A vein of fluorspar 20 inches wide, having a strike S. 52° W. and a dip 28° to the southeast, cuts the quartzites of the district. In a shallow shaft on the north end of one branch of the vein the white to green ore covers a much fractured bluish quartzite.

At the south end of this same vein, a shaft 12 feet deep exposes an ore shoot 20 inches wide. The vein here varies from S. 53° W. to S. 20° W., dips about 30° to the southeast and is 4 feet wide. The ore occurs mainly as a coating of fluorspar over irregular fragments of quartzite, and as a filling between the various fragments. It is badly fractured and varies from white to a deep green. It is covered with a white coating of material which, on analysis, proved to be mainly calcium carbonate, with some silica.

Boulders of green fluorspar up to 10 inches in diameter were found at an open cut in the other branch of the vein which is 2 feet wide and contains an ore shoot 14 inches wide. It strikes N. 82° W. and appears to join the other vein near the center ridge of the hill. No trace of either vein was found on the surface, although at the "sheep lick" a vein containing no fluorspar but having the same characteristics and direction as the first fluorspar vein described, is exposed in a small cut driven into the hillside.

SAN JUAN COUNTY

ASPEN MINE

In the Aspen mine near Silverton a deep green crystalline fluorspar is found in the lower tunnel where an 8-inch vein of fluorspar associated with some quartz, cuts one of the metalliferous veins. This vein having a strike S. 37° E. and a dip of 85° N. 42° E. cuts through the latite walls and directly across the ore shoot. The ore in the metalliferous vein was of much lower grade on both sides of the fluorspar vein, but the tenor rose as the distance from the fluorspar vein became greater. A small amount of fluorspar was found as a gangue mineral in the ore shoot near the fluorspar vein, whereas none was found at a distance from it.

A water course about 2 inches wide followed the hanging wall side of the vein, and on the side next the hanging wall rock some crystalline fluorspar was found covered with small crystals of drusy quartz. Material found on the surface of the dump where it had been exposed to the sunlight was nearly colorless while other pieces dug from a distance below the surface of the dump were of the same dark green color as that in the mine. Pieces of the colorless variety, although very clear, were somewhat fractured, and none of real optical value were found. One of the miners told of finding fluorspar in an upper level, and from his description and explanations, it was evidently from the same vein.

DAKOTA MINE

The Dakota mine has from time to time produced gold ore from a large fluorspar vein which outcrops in Boulder Gulch, near the forks of Boulder Creek. The vein at that point strikes S. 67° E. and appears to be nearly vertical. One end of the vein on passing into Tower Mountain branches out into several smaller veins that can be seen extending to the top of the mountain. The other end branches out on the north side of Boulder Mountain forming nine distinct veins which can be traced some distance beyond the top of the mountain.

The vein ranges in width from 4 to 25 feet. Its dip is generally to the south at an angle of not less than 80°. The fluorspar when mined is lilac and green but soon bleaches to a white, when left on the dump. It is very badly fractured and generally quite opaque.

The profiitable part of the vein which runs as high as $60.00 in gold, is found in the fluorspar, and in a few quartz stringers. The fluorspar has a high silica content and could hardly be used for commercial purposes. The mine has not been worked for some years and the shaft through which the work was done is badly caved. The property is reached by a trail, up Boulder Canyon and can only be worked six or seven months out of the year, because of the deep snow and the danger from snow slides.

ANGLO SAXON MINE

An ore containing pyrite and chalcopyrite with fluorspar and hubnerite as gangue minerals was formerly mined in this property, as is shown by ore still on the dump. Fluorspar is found as a gangue mineral in small amounts in many other mines of the district,[39] many of which are now closed or abandoned. But at present no commercial ore is produced in the district.

SAN MIGUEL COUNTY

The presence of fluorspar is quite common in this district, where it occurs as a gangue mineral in the sulphide veins. A number of pieces up to four inches in diameter were found on the dumps of the Tomboy mine. The fluorspar occurs as a badly-fractured green-colored mineral which bleaches nearly white on exposure to the sunlight. Purington [40] says that the secondary gangue minerals of the Tomboy vein consist largely of white, coarsely saccharoidal quartz, with subordinate amounts of calcite, fluorspar and sericite. The presence of fluorspar in the veins of the Tomboy mine is regarded as a favorable sign, indicating the proximity of gold ore.

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[39]Ransome, F. L., Economic geology of the Silverton quadrangle, Colorado: U. S. Geol. Survey, Silverton Folio 120, p. 29.

[40]Purington, C. W., Economic geology of the Telluride quadrangle, Colorado: U. S. Geol. Survey, Telluride Folio 57, p. 16.

TELLER COUNTY

CRIPPLE CREEK DISTRICT

Fluorspar is a common mineral in many of the ores of the Cripple Creek district, where it occurs in intimate association with quartz, forming the brilliant violet-blue ore characteristic of many of the prominent mines. It very often occurs as a filling in seams, as finely disseminated mineral, or in parallel bands in the ore.

Penrose[41] says: "The presence of fluorite may possibly have some connection with the presence of gold, but the quantity of one is no definite indication of the quantity of the other."

Very few crystals are found, and those that are found are of no use for optical purposes, as they are too deeply colored. Although the mineral is of common occurrence, no commercial deposit is found in the district.

FLORISSANT DISTRICT

Exceedingly fine specimens of fluorspar have been found in the Crystal Peak district six miles northeast of Florissant. The mineral occurs as crystals associated with microcline, amazonstone, smoky quartz, topaz and phenacite, and varies in color from green to purple. Many of the crystals appear to have lost their former color through exposure to the sun light. Crystals up to 6 inches in diameter have been found in this area of pre-Cambrian granites, but the district has been so thoroughly searched that very few are now found.

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[41] Penrose, R. A. F., Jr., Mining geology of the Cripple Creek district, Colorado: U. S. Geol. Survey, 16th Ann. Rept., pt. II, p. 158.

CHAPTER V

MINING, MILLING AND MARKETING

ANALYSES OF COLORADO FLUORSPAR

The samples for these determinations were taken from the ore in bins, waiting haulage, in the Jamestown and Bear Creek districts, and directly from the veins in the other districts. Other analyses have been given from time to time which show similar results.

Boulder County—	Calcium Fluoride CaF_2	Silica SiO_2	Oxides, Mostly Iron (Fe_2O_3) and Alumina (Al_2O_3)	Calcium Carbonate $CaCO_3$	Barium Sulphate $BaSO_4$
Alice mine	74.18	18.17	5.02	2.02	....
Argo	86.14	9.07	3.09	1.07	....
Blue Bird	84.22	11.19	3.16	1.01	....
	79.82	12.02	5.19	2.14	....
Brown	82.76	11.91	3.72	1.37	....
Buchannan	73.13	19.47	4.16	1.78	....
Buster	81.46	10.62	4.82	2.97	....
Chancelor	86.42	8.61	3.41	1.31	....
Emmett	83.89	12.46	4.34	2.12	....
Mrs. Evans	80.87	13.06	3.93	1.79	....
L. Evans	78.12	15.76	4.32	1.27	....
Invincible	81.46	13.09	4.09	1.11	....
Markt and Atkinson	74.41	18.36	4.34	1.28	....
Poorman	70.07	21.76	4.78	2.97	....
Silver Wing	78.97	15.29	4.19	1.13	....
Terry	71.96	20.42	3.96	2.84	....
Warren	64.81	26.24	6.09	2.56	....
Geo. Walker	96.37	1.57	1.31	.67	....

Custer County—	Calcium Fluoride CaF_2	Silica SiO_2	Oxides, Mostly Iron (Fe_2O_3) and Alumina (Al_2O_3)	Calcium Carbonate $CaCO_3$	Barium Sulphate $BaSO_4$
Antelope Creek:					
Ore on dump	87.42	8.64	2.80	1.04	....
Vein	81.76	12.17	4.06	2.01	....
El Paso County—					
Cather Springs	80.35	14.75	3.17	1.40	....
Jefferson County—					
Augusta mine	74.97	19.31	2.78	1.97	....
Littell mine	76.42	16.13	4.87	2.16	....
Mineral County—					
Wagon Wheel Gap:					
Bin material	88.92	3.07	1.96	1.23	4.16
Sugary white	98.89	0.62	0.07	0.11	....
Brown banded	98.16	1.09	0.37	0.09	....
Green banded	98.23	0.98	0.21	0.19	....
Ouray County—					
Barstow mine:					
Green ore	97.96	1.31	0.47	0.26	....
Park County—					
Jefferson:					
Lilac green ore	69.78	25.16	3.12	1.37	....
Purple ore	81.36	11.41	5.57	1.44	....

THE MILLING OF COLORADO FLUORSPAR

The washing, screening, and concentration of Colorado fluorspar was tried for the first time during the latter part of 1917. The main purpose was that of increasing the calcium fluoride content of the ores, and at the same time decreasing the silica content.

The following letter was received from C. J. Wilfley of Ouray, describing the various experiments, which he carried on in an effort to produce and ship a better grade of fluorspar from the Barstow mine at Red Mountain.

"Part of the time we operated a washing, sorting and screening plant at Ouray, making lump, gravel and fines. We had a rather ingenious arrangement which we developed and which might be useful in other lines. We took a regular Wilfley table and discarded the deck; in its stead we put a long box about 2 feet wide, 2 deep and 18 feet long open on the top side. A few inches above the bottom we placed a false bottom of screens from 12 to 30 mesh, properly supported. The box reciprocated like a Wilfley table and minus-3-inch stuff was fed from the undersize of a grizzly.

"By giving a slight slope from the feed end and adjusting the length of table stroke the machine was capable of great variations to suit conditions of the ore and to obtain tonnage. Over the first half were a number of water sprays which disintegrated the mud and washed it through the screens as fines, the washings being removed through spouts in the bottom. The latter half of the machine was a very good sorting table, where we threw out the waste.

"We were able also to screen out stuff as coarse as, I think, three-eighths inch, though the screening was not very efficient without a special spray over this screen.

"But little other mineral was found with the spar, although practically all of it was accompanied by a little more than traces of lead and by quite a little pyrite. Much of this was in soft decomposed gangue or scattered through the vein, and it was all removed through the fine screens. I concentrated the fines several times for an iron concentrate; this assayed a little gold and several ounces silver with very little copper or lead, but was not a commercial product."

In the Chesbro Mill at Boulder, the fluorspar ores were put through a set of rolls, then over concentrating tables and slimers, after which the concentrates were allowed to stand and later were shipped while still wet.

The Hoffnung Mill at Jamestown was being overhauled early in the spring of 1918, and it was announced that the mill would produce fluorspar concentrates as soon as the work was finished. The mill is equipped with a crusher, five stamps, a concentrating table, and a slimer.

At Wagon Wheel Gap, a large amount of fluorspar and barite was noticed in the dump at the upper terminal. A considerable tonnage of both of these minerals could be produced by either jigging or method of concentrating the dump, while at the same time the fluorspar content of "fluorite-barite" ores could be raised, and the barite saved by the same treatment.

Trial runs were being made on ore from a number of properties during the spring of 1918, and it was rumored that several old mills in the Jamestown district were to be reopened for the commercial treatment of ores from that district.

GRADES OF FLUORSPAR

Fluorspar is classed as lump, gravel, ground, and concentrates. The lump and gravel ores are usually divided into three classes while the ground fluorspar is divided into four grades. "Gravel" is a term now used to classify all that product resulting from the breaking up of lump, through natural causes, and the crushed fluorspar from mills.

The highest grade No. 1 fluorspar is usually white or colorless, and should run 96 per cent or more in calcium fluoride. The remainder consists of silica, iron oxides, alumina, calcium and magnesium carbonates, alkalies, hydrocarbons, and moisture. Dark-colored fluorspars usually run higher in their silica and hydrocarbon contents, especially if shattered, or iron stained, since in that condition silica filters into the small cracks and increases the detrimental products. It is used mainly in the chemical industry.

No. 2 grade includes colored fluorspar and will run 90 per cent or over in calcium fluoride, and less than 4 per cent of silica. Colored fluorspar and crushed mill products nearly all fall into this class. This grade is used in the production of ferrosilicon and ferromanganese, and in the basic open hearth steel furnaces, to give increased fluidity to the slag and reduce the phosphorus and sulphur contents.

No. 3 grade includes all the fluorspar containing from 60 to 90 per cent of calcium fluoride, and in excess of 4 per cent of silica. Unwashed gravel belongs to this class as does fluorspar mixed with excessive amounts of calcite, limestone, barite, and mill dirt. This product is used mainly as a flux in the smelting of iron; and in brass foundries, where it is of value in making the alloy more fluid, and where it also permits the use of larger quantities of low grade scrap, because it carries phosphorus, sulphur and other impurities into the slag.

Ground fluorspar is nearly all made from the No. 1 grade of fluorspar, and is classed as Extra No. 1, No. 1 and No. 2. No 1 ground contains 98 per cent of calcium fluoride and about one per cent of silica. Extra No. 1 ground contains less than one per cent of silica, while No. 2 ground contains from 96 to 98 per cent of calcium fluoride and up to two per cent of silica. No. 3 ground is an English product corresponding to No. 3 fluorspar. The ground fluorspar averages about 85 mesh in fineness and is used in the manufacture of glass, enamels, and terra cotta. It is also used in the chemical industry.

Most of the fluorspar produced in Colorado is classed as "gravel" and would be placed in the No. 3 class, although some No. 1 and No. 2 have been produced from the Wagon Wheel Gap and Barstow deposits.

The concentrates now being produced in Colorado will most likely be placed in the No. 3 class, although some may be classed as No. 2. The physical character of the product will necessitate the making of an entirely new class for this material.

FLUORSPAR PRODUCTION

During 1917 the fluorspar production of Colorado increased to 17,104 short tons,[42] valued at $196,633.00, an average of $11.50 per ton. This tonnage is a decided increase over the fluctuating and relatively small tonnage produced in previous years.

During the early spring of 1918 the demand for fluorspar was good, and the activity in the Colorado fields had developed considerably over that of 1917, when Colorado produced 7.8 per cent of the total tonnage of fluorspar mined in the United States.

The production of fluorspar in the United States during 1917 amounted to 218,828 short tons; valued at $2,287,722.00. This production brought an average price of $10.40 per ton, as compared to an average price of $6.37 per ton, paid during 1913, the year previous to the war.

Imports decreased for several years, prior to the war, and reached a minimum in 1915. During 1917 manufacturers were forced to take imports, on account of difficulties encountered in the delivery of American fluorspar, and 13,616 short tons were imported during that year. The imported fluorspar brought an average price of $8.42 per ton, which was somewhat lower than the average price paid for American fluorspar. The American product was, however, of a higher average grade than the imported fluorspar.

The accompanying diagram, showing the production of fluorspar in the United States, and imports from 1910 to 1917, was taken from Mineral Resources of the United States, 1917, part II, page 298.

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[42]Burchard, Ernest F., U. S. Geol. Survey, Min. Res., pt. II, pp. 293-304, 1917.

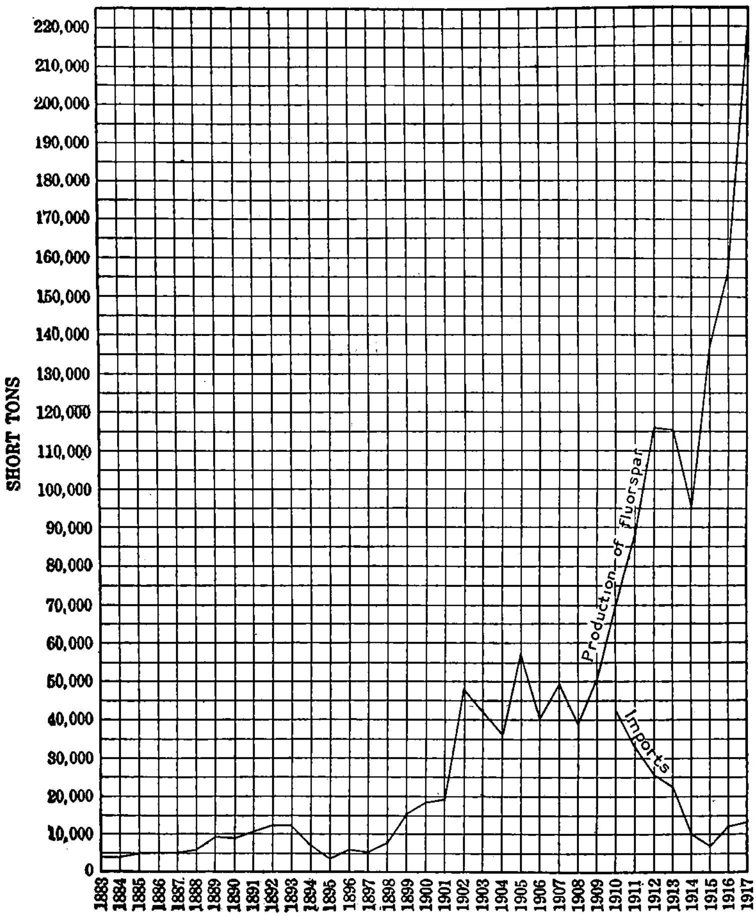

FIGURE 10.—Diagram showing production of fluorspar in the United States, 1883-1917, and imports 1910-1917.

MARKETS FOR FLUORSPAR

Fluorspar used in the various industries is bought directly from the producer, or through dealers in that product. The United States Geological Survey[43] has published the following list of buyers, to aid the producer in marketing his ore.

[43]Burchard, Ernest F., U. S. Geol. Survey, Min. Res., pt. II, pp. 293-304, 1917.

BUYERS OF FLUORSPAR

A. D. Mackay, 130 Pearl Street, New York, N. Y.
Alan Wood Iron & Steel Co., Philadelphia, Pa.
Allegheny Steel Co., Pittsburgh, Pa.
Aluminum Ore Co., East St. Louis, Ill.
Aluminum Co. of America, Pittsburgh, Pa.
American Cyanamid Co., New York, N. Y.
American Stamping & Enameling Co., Bellaire, Ohio.
American Tube & Stamping Co., Bridgeport, Conn.
American Steel & Wire Co., Cleveland, Ohio.
Bethlehem Steel Co., Bethlehem, Pa.
Binney & Smith Co., 81 Fulton Street, New York, N. Y.
Brier Hill Steel Co., Youngstown, Ohio.
L. H. Butcher & Co., San Francisco, Calif.
Cambria Steel Co., Pittsburgh, Pa.
Carnegie Steel Co., Pittsburgh, Pa.
Central Pigment Co., Strand Building, Forty-seventh Street and Broadway, New York, N. Y.
George W. Chesebro, Boulder, Colo.
Chrome Steel Works, Chrome, N. J.
J. G. Clark, Boulder, Colo.
Colorado Fuel & Iron Co., Denver, Colo.
Commercial Chemical Co., 1100-1110 Wasbash Avenue, Chicago, Ill.
Debevoise-Anderson Co. (Inc.), 56 Liberty Street, New York, N. Y.
Eagle Glass & Manufacturing Co., Wellsburg, W. Va.
Engineers Corporation, Boulder, Colo.
Ferro-Alloy Co., Denver, Colo.
Feuchtwanger & Co., New York, N. Y.
Ford Motor Co., Detroit, Mich.
Fostoria Glass Co., Moundsville, W. Va.
Franco-American Chemical Co., New York, N. Y.
General Chemical Co., Pittsburgh, Pa.
Glover Machine Works, Marietta, Ga.
Gulf States Steel Co., Birmingham, Ala.
Hamilton Facing Mill Co. (Ltd.), Hamilton, Ontario.
Hazel-Atlas Glass Co., Wheeling, W. Va.
Harshaw-Fuller & Goodwin Co., Cleveland, Ohio.
Illinois Steel Co., Chicago, Ill.
Inter-State Iron & Steel Co., Chicago, Ill.
J. M. Jackson, Rosiclare, Ill.
Jones & Laughlin, Pittsburgh, Pa.
Kentucky Fluor Spar Co., Marion, Ky.
La Belle Iron Works, Steubenville, Ohio.
La Clede Steel Co., Alton, Ill.
Lackawanna Steel Co., Lackawanna, N. Y.
E. J. Lavino Co., Philadelphia, Pa.
Lee Mineral Co., 201 Park Avenue, Baltimore, Md.
Lower California Metals Co., Nogales, Ariz.
Lukens Iron & Steel Co., Coatesville, Pa.

Matthew Addy Co., Cincinnati, Ohio.
McKinney Steel Co., Cleveland, Ohio.
Metalores Corporation, 56 Pine Street, New York, N. Y.
Midvale Steel & Ordnance Co., 14 Wall Street, New York, N. Y.
National Enameling Co., St. Louis, Mo.
National Ore & Metals Co., 601-602 Symes Building, Denver, Colo.
National Sales Co., Cincinnati, Ohio.
Noble Electric Steel Co., San Francisco, Cal.
Pacific Coast Steel Co., Seattle, Wash.
Penn Seaboard Steel Corporation, Philadelphia, Pa.
J. S. Perry, 520 South Canal Street, Chicago, Ill.
Pine Iron Works, Pine Forge, Pa.
Pittsburgh Crucible Steel Co., Pittsburgh, Pa.
Pittsburgh Steel Co., Pittsburgh, Pa.
A. H. Reed, Marion, Ky.
Republic Iron & Steel Co., Youngstown, Ohio.
J. C. Rice, Dome, Ariz.
Roberts Fluor Spar Co., Marion, Ky.
Rogers, Brown & Co., Cincinnati, Ohio.
Sizer Forge Co., Buffalo, N. Y.
Southern Minerals Co., Hopkinsville, Ky.
Frederick B. Stevens, Detroit, Mich.
J. D. Taylor, St. Louis, Mo.
Chas. S. Trench & Co., 81-83 Fulton Street, New York, N. Y.
Trumbull Steel Co., Warren, Ohio.
Tungsten Products Corporation, Boulder, Colo.
United States Stamping Co., Moundsville, W. Va.
Whitaker-Glessner Co., Portsmouth, Ohio.
John C. Wiarda & Co., Green, Provost and Freeman Streets, Brooklyn, New York.
H. L. Wilson, Marion, Ky.
Woods, Huddart & Gunn, San Francisco, Cal.
Youngstown Steel Co., Youngstown, Ohio.

APPENDIX.

FLUORSPAR DEPOSITS OF THE UNITED STATES

During 1917, Hardin and Pope counties in Illinois led the United States in the production of fluorspar. Kentucky stood next to Illinois in production, with Crittenden, Livingston and Caldwell as producing counties, and some encouraging prospecting was being done in Mercer County. Fluorspar was produced as a jig product incidental to the concentrating of lead and silver ores, at Castle Dome, Yuma County, Arizona.

Near Deming, New Mexico, some ore was mined and the finding of favorable deposits was reported from San Bernardino County, California. At Albermarle, Virginia, fluorspar is produced as a by-product in the milling of lead and zinc ores. Fluorspar has been reported as occurring in commercial quantities in Smith and Trousdal counties in central Tennessee. In New Hampshire a small tonnage is being produced.

FLUORSPAR IN ENGLAND[44]

In England fluorspar occurs abundantly in the Carboniferous limestone and its associated shale, limestone, and sandstone of the Yoredale group. The whole of the present British production comes from these strata, where it is found as the gangue of metalliferous veins. It is usually associated with calcspar, quartz, or barytes, though this is not universally the case.

Derbyshire leads in the production of fluorspar, and Durham takes second place. The greater part of the production is obtained by working the old lead-mine dumps, in which the fluorspar exists as the waste material of lead-mining operations dating from remote times. Some mines are now producing fluorspar, but the tonnage obtained in that way is far less than that produced by working the dumps.

Fluorspar from the Blue John mine at Castleton, Derbyshire is noted for its unique characteristics. Ore from that property is cut into vases, the color and the results obtained being very extraordinary.

[44]The Engineer, London, pp. 185-187, Aug. 21, 1908.

A very interesting publication by the Geological Survey of Great Britain,[45] issued in 1916, deals with the fluorspar resources of Great Britain . This report which is brief, consists of a preface and three chapters treating of the supply, uses, statistics, and technology of the deposits.

In stating the sources of supply the following was given:

"Although some thousands of tons of fluorspar are annually raised in France and Germany (Bavaria and Saxony), and a little also in Spain, the bulk of the world's supply comes from Britain and the United States, the latter being also the chief consumer."

Notes from this publication will be found on page 317 of the Mineral Resources of the United States, United States Geological Survey, 1916, pt. 2, pp. 309-325.[46]

FLUORSPAR IN CANADA

Shipments of fluorspar have been made from Madoc, Ontario, and others are reported from British Columbia. During 1916 the production from Ontario amounted to 1,284 tons.[47]

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[45]Carruthers, R. G., Pocock, R. W., Wray, D. A., with contributions by Dewey, H., and Bromehead, C. E. N., Fluorspar: Special reports on the mineral resources of Great Britain, vol. 4 (Geol. Survey Mem.), p. 38, 1916.

[46]Burchard, E. F., Fluorspar in Great Britain: U. S. Geol. Survey, Min. Res., pt. II, pp. 317-322, 1916.

[47]Preliminary report on the mineral production of Canada during 1916, Canada Dept. Mines. Mines Branch.

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INDEX

COLORADO GEOLOGICAL SURVEY
BOULDER
R. D. GEORGE, State Geologist

BULLETIN 19

The Cretaceous Formations of Northeastern Colorado

AND

The Foothills Formations of North-Central Colorado

BY

JUNIUS HENDERSON

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GEOLOGICAL BOARD

LETTER OF TRANSMITTAL

State Geological Survey,
University of Colorado, November 15, 1920.

Governor Oliver H. Shoup, Chairman, and Members of the Advisory Board of the State Geological Survey.

Gentlemen: I have the honor to transmit herewith Bulletin 19 of the Colorado Geological Survey.

Very respectfully,

R. D. GEORGE,
State Geologist.

CONTENTS

CONTENTS

ILLUSTRATIONS.

The Cretaceous Formations

OF THE

Northeastern Colorado Plains

BY JUNIUS HENDERSON

AGE OF COLORADO COAL-BEARING ROCKS

The present paper is the outcome of work originally undertaken in 1912 for the purpose of determining the stratigraphic position of the northeastern Colorado coal beds. As work progressed it seemed desirable to re-examine the problem of the underliyng Montana group, especially the upper portion of it.

The age of the various coal-bearing formations of the Rocky Mountain region has been much under discussion for some years. In the earlier stages of the discussion most of the coal was supposed to be in the Laramie formation. That supposition found a place in geologic literature even as late as 1901.[1] As time passed, various extremely important coal beds of Colorado and adjoining states were found to be in pre-Laramie and post-Laramie formations. In the Yampa and Durango districts coal occurs in both the Mesa Verde and the Laramie formation, separated by the Lewis shales, with a little in the upper Dakota and possibly the upper Mancos in the latter region.[2] In the Danforth Hills, Grand Hogback, Book

[1]Endlich, F. M., "Report on the Geology of the White River District," U. S. Geol. & Geog. Surv. Terr. (Hayden Survey), 10th Ann. Rept. (for 1876), pp. 109-110, 1878. Lakes, Arthur, Geology of the Colorado Coal Deposits, Ann. Rept. Colorado State School of Mines for 1889, pp. 23, 41, 57, 80, 88, 109, 119, 139, 148, 155, 162, 167, 173, 197, 223. Hills, R. C., "Coal Fields of Colorado," U. S. Geol. Surv., Mineral Resources of the United States for 1892, p. 320. Storrs, L. S., "The Rocky Mountain Coal Fields," U. S. Geol. Surv., 22nd Ann. Rept., 1901-1902, Vol. III, pp. 422, 428. Emmons, Cross and Eldridge, U. S. Geol. Surv., Geologic Atlas of the United States, Anthracite-Crested Butte Folio, No. 9, 1894.

[2]Holmes, William H., "Geological Report on the San Juan District," 9th Ann. Rept. U. S. Geol. & Geog. Surv. Terr. (Hayden Survey), for 1875, p. 245, 1877. Schrader, F. C., "The Durango-Gallup Coal Field in Colorado and New Mexico," U. S. Geol. Surv., Bull. No. 285, pp. 243-244, 1906. Taff, Joseph A., "The Durango Coal District, Colorado," U. S. Geol. Surv., Bull. No. 316, Part II, p. 322, 1907. Shaler, M. K., "A Reconnaissance Survey of the Western Part of the Durango-Gallup Coal Field of Colorado and New Mexico," U. S. Geol. Surv., Bull. No. 316, Part II, p. 380, 1907. Fenneman, N. M., and Gale, Hoyt S., "The Yampa Coal Field, Routt County, Colo.," U. S. Geol. Surv., Bull. No. 285, pp. 227-228, and No. 287, pp. 23-30, 1906. Cross, Whitman, and Ransome, F. L., U. S. Geol. Surv., Geologic Atlas of the United States, Rico Folio No. 131, p. 5, 1905.

Cliffs, Rangeley, Grand Mesa, West Elk Mountains, Ouray and La Plata districts, all the coal has been assigned to the Mesa Verde formation, except a little in either the Dakota or the lower Mancos.[3] The assignment of the lower coal to the base of the Mancos instead of to the Dakota in the Grand Mesa and West Elk Mountains, by Lee, and in southwestern Colorado, by Holmes, does not seem sound, but this is not the place to discuss that subject. It is sufficient for the present purpose to point out that it is much older than the Laramie formation. Storrs assigned some of the Yampa district coal to the post-Laramie, possibly due to his supposing the Mesa Verde coal to be Laramie, and all the coal horizons of the Durango district he assigned to the Montana group.[4] In 1911 it was discovered that the important coal beds of North Park are post-Laramie, probably Eocene.[5] In addition to the works hereinbefore cited, mentioning coal in the Dakota formation, Hills mentions it for southwestern Colorado, Cross notes it in the Rico and Engineer Mountain quadrangles and on the Dolores River, and Storrs notes it in western Colorado south of the Grand River drainage, where the State Geological Survey parties also found it quite generally in the Dakota shales of Montrose and San Miguel counties during the field season of 1914.[6] While the Dakota coal is not of great commercial importance, it is much mined for local use, and is quite as important as much of the Laramie coal of northeastern Colorado. Until very recently the coal beds of the Trinidad district were still considered Laramie.[7] In 1909 Lee discovered an unconformity between two distinct coal horizons in the Raton, New Mexico, field, which has since been extended into Colorado. As a result the important coal below the unconformity has now been assigned to the

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[3]Gale, Hoyt S., "Coal Fields of the Danforth Hills and Grand Hogback in Northwestern Colorado," U. S. Geol. Surv., Bull. No. 316, Part II, pp. 265-266, 1907; Geology of the Rangeley Oil District, Rio Blanco County, Colorado, U. S. Geol. Surv., Bull. No. 350, pp. 22-23, 1908; "Coal Fields of Northwestern Colorado and Northeastern Utah," U. S. Geol. Surv., Bull. No. 415, pp. 63-70, 1910. Richardson, G. B., "The Book Cliffs Coal Field, Between Grand River, Colorado, and Sunnyside, Utah," U. S. Geol. Surv., Bull. No. 316, Part II, pp. 304-305, 1907, and No. 371, pp. 12-19, 1909. Lee, Willis T., Coal Fields of Grand Mesa and West Elk Mountains, Colorado, U. S. Geol. Surv., Bull. No. 510, pp. 65-66, 1912; (abstract) Wash. Acad. Sci., Journ., Vol. III, pp. 362-363, 1913; "The Grand Mesa Coal Field, Colorado," U. S. Geol. Surv., Bull. No. 341, pp. 316-334, 1909. Cross, Whitman, Howe, Ernest, and Irving, J. D., U. S. Geol. Surv., Geologic Atlas of the United States, Ouray Folio, No. 153, p. 6, 1907. Cross, Whitman, Spencer, A. C., and Purington, C. W., Id., La Plata Folio, No. 60, pp. 4-5, 1899.

[4]Storrs, 22nd Ann. Rept., *ante*, pp. 437-438.

[5]Grout, F. F., Worcester, P. G., and Henderson, Junius, Reconnaissance of the Geology of the Rabbit Ears Region, Routt, Grand and Jackson Counties, Colorado, Colo. Geol. Surv., Bull. No. 5, Part I, pp. 23, 34, 1913.

[6]Hills, Mineral Resources for 1892, *ante*, p. 320. Cross, Whitman, and Purington, C. W., U. S. Geol. Surv., Geologic Atlas of the United States, Rico Folio, No. 130, p. 5, 1905. Cross, Whitman, and Purington, C. W., Id., Telluride Folio, No. 57, 1899. Cross, Whitman, Id., Engineer Mountain Folio, No. 171, field edition, pp. 59-60, 1910.

[7]Richardson, G. B., "The Trinidad Coal Field, Colorado," U. S. Geol. Surv., Bull. No. 381, Part II, p. 387, 1910.

Vermejo formation, of upper Montana age, including the Canyon City coals; while the less important coal above the unconformity is in the Raton Tertiary, approximately equivalent to the Denver formation.[8]

All these changes still left the coals of the Colorado Springs and northeastern Colorado districts all in the Laramie,[9] but the discovery that so large a proportion of the coal of the state is not Laramie created some uncertainty as to the age of the beds in these districts. This uncertainty was greatly augmented by the following statements of Stevenson concerning the discovery of marine Fox Hills fossils above the coal near Platteville and Evans:

"When we reach St. Vrain's Creek, nearly fifty miles north from Denver, where the general section is the same as at Cañon City, these bands are very numerous and rich in fossils. Some of the beds contain *Halymenites major* in such profusion as to be fairly matted with it; while interstratified with these are other layers containing *Ammonites lobatus, Mactra alta, Anchura, Nucula cancellata* and many other species very characteristic of the upper Cretaceous. These fossils overlie the lignite beds of Platteville."[10]

"Following this rock down the South Platte River, we find the lower part of the section well exposed for many miles below the junction of St. Vrain's Creek and the river. Here, at a horizon above that of the Platteville coals, the exposure is similar to that at Cañon City. At the river level are shales, argillaceous and arenaceous, gradually passing up into a bluish-gray, very friable sandstone, on which rests a red, friable sandstone, containing many thin layers which are slightly calcareous. Owing to the superior hardness of the calcareous layers this red sandstone, in weathering, assumes excentric forms similar to those common on Monument Creek and illustrated in Dr. Hayden's reports. These

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[8]Lee, Willis T., "Unconformity in the So-called Laramie of the Raton Coal Field, New Mexico," Geol. Soc. Amer., Bull., Vol. XX, pp. 357-368, 1909; "Unconformity Separating the Coal-bearing Rocks in the Raton Field, New Mexico," (abstract) Science, n. s., Vol. XXIX, p. 624, 1909; "Criteria for an Unconformity in the So-called Laramie of the Raton Mesa Coal Fields of New Mexico and Colorado," (abstract) Science, n. s., Vol. XXXIII, pp. 355-356, 1911; "Further Evidence of an Unconformity in the So-called Laramie of the Raton Coal Field, New Mexico," (abstract) Geol. Soc. Amer., Bull., Vol. XXII, p. 717, 1911. Knowlton, F. H., "Results of a Paleobotanical Study of the Coal-bearing Rocks of the Raton Mesa Region of Colorado and New Mexico," Amer. Journ. Sci., 4th Ser., Vol. XXXV (whole number CLXXXV), pp. 526-530, 1913; (abstract) Geol. Soc. Amer., Bull., Vol. XXIV, p. 114, 1913. Lee, Willis T., and Knowlton, F. H., Geology and Paleontology of the Raton Mesa and other regions in Colorado and New Mexico.

[9]Washburne, Chester W., "The Florence Oil Field, Colorado," U. S. Geol. Surv., Bull. No. 381, Part II, p. 387, 1910; "The South Park Coal Field, Colorado," Id., p. 16; "The Canon City Coal Field, Colorado," Id., p. 342. Martin, George C., "Coal of the Denver Basin, Colorado," Id., p. 297. Goldman, Marcus I., "The Colorado Springs Coal Fields, Colorado," Id., p. 319. Hills, R. C., U. S. Geol. Surv., Geologic Atlas of the United States, Spanish Peaks Folio, No. 71, 1901; Elmoro Folio, No. 58, 1899; Walsenburg Folio, No. 68, 1900. Darton, N. H., Preliminary Report on the Geology and Underground Water Resources of the Central Great Plains, U. S. Geol. Surv., Professional Paper, No. 32, pp. 372-375, 1905; Geology and Underground Waters of the Arkansas Valley in Eastern Colorado, U. S. Geol. Surv., Professional Paper, No. 52, p. 33, 1906.

[10]Stevensón, J. J., "Age of Western Lignites," Proc. N. Y. Lyc. Nat. Hist., 2nd Ser., No. 4, p. 94, 1874.

harder layers are richly fossiliferous. Some of them are made up wholly of *Halymenites major* Lesq., others are literally crowded with remains of Mollusca, and one contains many leaves of dicotyledonous plants. The whole section overlies the important coal beds at Platteville, and is traceable down the river for a long distance, the dip in that direction being very slight. Near Evans, and in the highest portion of the sandstone, the layers containing the fucoid alternate with those containing Mollusca, and the leaf-bed is underlaid and overlaid by both fucoidal and molluscan layers. Unfortunately the impressions of the leaves are not sharp, and but one specimen was preserved. The molluscan species obtained from a layer overlying the leaf-bed are as follows: *Nucula cancellata*, M. & H.; *Cardium speciosum*, M. & H.; *Mactra warrenana*, M. & H.; *Mactra alta*, *Lucina* sp. undt.; *Pholodomya*, sp. undt.; *Lunatia*, sp. casts; *Anchura*, sp. casts; *Ammonites lobatus*, Tuomey; *Ammonites pedernalis*, Roemer; and other species not determinable in any way owing to the imperfect condition. With the coal there occurs in great numbers and in excellent preservation, an oyster not unlike *Ostrea patina*, M. & H."[11]

These statements were brought to my attention by Dr. G. B. Richardson, of the United States Geological Survey, and Professor R. D. George, State Geologist of Colorado. The latter directed me in 1912 to examine the deposits in the region mentioned by Stevenson, and also to examine the Laramie-Fox Hills contact at as many northeastern Colorado localities as possible. Mr. Roy M. Butters acted as field assistant during the first part of the season. The work was done during the summer of 1912.

The locality of the marine deposits mentioned by Stevenson is unmistakable. It is the long bluff culminating in Wildcat Mound, northwest of Platteville, and on the opposite side of the river, reappearing on the north side of Thompson Creek south of west from Evans.[12] The Platteville coal mines are on the east side of the river, several miles from the bluffs. Instead of the marine deposits overlying the coal, as supposed by Stevenson, they plainly pass beneath the coal at Platteville, as well as at every locality in northeastern Colorado where we could find exposures. The Platteville coal and the marine bluffs are some distance apart, so that their relative positions in the geologic column are only determinable by means of the dips and topography. Finding the marine beds, with a rich Fox Hills fauna, passing beneath the coal beds throughout

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[11]Stevenson, John J., "Report on the Geology of a Portion of Colorado Examined in 1873," Geog. & Geol. Expl. & Surv. W. of 100th Meridian (Wheeler Survey), Vol. III, Part IV, p. 406, 1875. As *Ostrea glabra* is very common in the formation containing the coal, and we found no other oyster common anywhere in that region, this is likely the oyster he refers to, as he could hardly have overlooked it. His *A. lobatus* is likely *Placenticeras lenticularis*, and his *A. pedernalis* is likely one of the *Scaphites* which occur sparingly in the Fox Hills formation of that region.

[12]See U. S. Geol. Surv., Topographic Map of the United States, Greeley sheet.

the region, at the numerous exposures examined, and the coal beds themselves interstratified with sandstones and shales which contain many species of fresh-water and brackish-water invertebrates usually found in the Laramie formation, leaves no present reason for doubting the Laramie age of the coal-bearing rocks of the region, as the term Laramie is now generally understood.[13]

LARAMIE FORMATION

As we have seen, the Laramie problem was rendered difficult by the early assignment of nearly all the coal of the southern Rocky Mountain region to that formation, and the inclusion within it of formations much older and others younger. The problem was further complicated later by the discovery of a decided unconformity in the brackish-water and fresh-water series overlying the marine beds of late Montana age, in the Laramie plains, generally considered the type locality of the Laramie formation. Upon discovery of this unconformity, Veatch[14] proposed to retain the name for the strata above the unconformity, and give a new name to the underlying formation, or to abandon the name Laramie altogether. Under the general rules of nomenclature neither course is necessary, and the former would only add to the confusion. No definite type locality was designated by the early writers. The term Laramie Plains was used in a loose sense to cover a wide area. It seems clear that the King and Hayden Surveys intended the name Laramie formation, or Laramie group, to cover the brackish-water and fresh-water strata conformably resting upon the upper Montana marine beds and unconformably beneath the upper fresh-water beds.[15] This should outweigh any conclusion based upon a purely suppositious definite type locality. Hence the use in the Denver district of the name Laramie for the coal-bearing beds immediately and conformably overlying the upper Montana marine beds, giving the name Denver Beds[16] and Arapahoe Beds to the formations above the unconformity, is entirely justifiable.

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[13]Knowlton, F. H., A Catalogue of the Mesojoic and Cenozoic Plants of North America, U. S. Geol. Surv., Bull. 696, p. 750, and table of formations opposite p. 10.

[14]Veatch, A. C., "On the Origin and Definition of the Geologic Term Laramie," Journ. Geol., Vol. XV, pp. 526-549, 1907; (abstract) Amer. Journ. Sci., 4th Ser., Vol. XXIV, pp. 18-22, 1907.

[15]Peale, A. C., "On the Application of the Term Laramie," Amer. Journ. Sci., 4th Ser., Vol. XXVIII, pp. 45-58, 1909.

[16]Emmons, S. F., Cross, Whitman, and Eldridge, George H., Geology of the Denver Basin in Colorado, U. S. Geol. Surv., Mon. Vol. XXVII, pp. 23-36, 1895.

The unconformity also has a bearing upon the old question of the position of the true Laramie in the geologic column. Early geologists disagreed as to whether it is Cretaceous or Tertiary, until 1883, since which time it has been quite uniformly placed in the Cretaceous.[17] The widespread unconformity above it tends to confirm this view, now that the term is used in a restricted sense.

As would be expected in a formation of brackish-water and fresh-water origin, it varies locally in the relative quantities of shale and sandstone. It also varies greatly in thickness, owing to the erosional unconformity at the top, as well as to the unequal recent erosion. The thick, massive, white to yellowish sandstone at the base of the formation in the Denver basin,[18] so well exposed at White Rock, east of Boulder, is absent or weak farther north and east. This adds to the difficulty of fixing the exact geographic and geologic boundaries between the Laramie and Fox Hills formations on the level or rolling plains.

The Laramie fauna in the Denver basin is very limited, the only species at all common being *Ostrea glabra* M. & H. On the other hand, east of a line drawn north and south through Greeley and north of the Cache la Poudre there is an abundant, varied and interesting fauna. There *Corbicula* of several species and *Ostrea glabra* occur in great numbers at several horizons, with fewer *Melania wyomingensis* Meek and *Tulotoma thompsoni* White, all brackish-water forms, while other horizons contain fresh-water species, though not usually in large numbers, perhaps owing to the fragile nature of the shells of many common fresh-water gastropods, such as *Physa, Lymnaea* and *Planorbis.* Crow Creek, northeast of Greeley, is the type locality of several species described by Dr. White. A large percentage of the described species of American *Corbiculas* occur in that locality.

MONTANA GROUP

Whatever doubt there may be as to the exact boundary between the Pierre and Fox Hills formations, or as to the propriety of using those names at all for formations in northeastern Colorado, there is no doubt of the propriety of using the name Montana to cover all the strata commonly assigned to the Pierre and Fox Hills formations in this region, because the name was first proposed to

[17] See numerous citations in North American Geologic Formation Names, U. S. Geol. Surv., Bull. No. 191, pp. 231-232.

[18] Emmons, Cross and Eldridge, Geology of the Denver Basin in Colorado, U. S. Geol. Surv., Mon. Vol. XXVII, p. 73, 1896.

include just those formations in the vicinity of Denver, embracing all the marine strata above the Niobrara.

Prior to 1861 it was customary to designate the upper Cretaceous formation of the Rocky Mountains and adjacent plains by numbers. In 1861 Meek and Hayden perceived the need of formation names, and so replaced the numbers 1, 2, 3, 4 and 5 with the names Dakota, Fort Benton, Niobrara, Fort Pierre and Fox Hills. More recently Fort Benton and Fort Pierre have been shortened to Benton and Pierre, by common consent. Meek and Hayden's description of the Pierre and Fox Hills formations appears to have been drawn chiefly from the upper Missouri region, and does not in all respects fit the Colorado section, though in case of the Fox Hills they definitely include the South Platte River. Their description is as follows:[19]

[19]Meek and Hayden, "Descriptions of New Lower Silurian (Primordial), Jurassic, Cretaceous and Tertiary fossils, Collected in Nebraska by the Exploring Expedition under the Command of Capt. Wm. F. Raynolds, U. S. Top. Engrs., with some Remarks on the Rocks from which they were Obtained," Proc. Acad. Nat. Sci. Phila., Vol. XIII, pp. 418-447, 1861. This section was reprinted in the 1st Ann. Rept. U. S. Geol. and Geog. Surv. Terr. (Hayden Survey), for 1867, reprint edition of 1873, at p. 49, and 4th Ann. Rept., for 1870, at p. 87.

		Localities.	Estm. Thickness.
Fox Hills Beds. Formation No. 5.	Gray, ferruginous and yellowish sandstone and arenaceous clays, containing *Belemnitella bulbosa, Nautilus dekayi, Ammonites placenta, A. lobatus, Scaphites conradi, S. nicolletti, Baculites grandis, Busycon bairdi, Fusus culbertsoni, F. newberryi, Aporrhais americana, Pseudobuccinum nebrascensis, Mactra warrenana, Cardium subquadrata*, and a great many other molluscous fossils, together with bones of *Mosasaurus missouriensis*, etc.	Fox Hills, near Moreau River—near Long Lake above Fort Pierre. Along base Big Horn Mountains, and on North and South Platte Rivers.	500 feet
Fort Pierre Group. Formation No. 4.	Dark gray and bluish plastic clays, containing near the upper part, *Nautilus dekayi, Ammonites placenta, Baculites ovatus, B. Compressus, Scaphites nodosus, Dentalium gracile, Crassatella evansi, Cucullaea nebrascensis, Inoceramus sagensis, I. nebrascensis, I. vanuxemi*, bones of *Mosasaurus missouriensis*, etc., etc., etc.	Sage Creek, Cheyenne River and on White River above the Mauvaises Terres.	700 feet
	Middle zone nearly barren of fossils.	Fort Pierre and out to Bad Lands—down the Missouri on the high country to Great Bend.	
	Lower fossiliferous zone, containing *Ammonites complexus, Baculites ovatus, B. compressus, Helicoceras mortoni, H. tortum, H. umbilicatum, H. cochleatum, Ptychoceras mortoni, Fusus vinculum, Anisomyon borealis, Amauropsis paludiniformis, Inoceramus sublaevis, I. tenuilineatus*, bones of *Mosasaurus missouriensis*, etc.	Great Bend of the Missouri, below Fort Pierre.	
	Dark bed of very fine unctuous clay, containing much carbonaceous matter, with veins and seams of gypsum, masses sulphuret iron and numerous small scales fishes. Local; filling depressions in the bed below.	Near Bijou Hill, on the Missouri.	

Further notes pertinent to the present discussion are found on subsequent pages of the same report in the proceedings of the Philadelphia Academy, as follows:

At the base of the Fort Pierre Group—the inferior member of the upper series of Nebraska Cretaceous rocks—there is, at some localities along the Missouri below the Great Bend, a local bed ten to thirty feet in thickness, composed of very dark unctuous clay, containing great numbers of small scales of fishes, much iron pyrites and carbonaceous matter, with crystals, veins and seams of sulphate of lime. This bed usually occupies depressions in the previously eroded upper surface of the formation beneath. With the exception of the local deposit just mentioned, the Fort Pierre Group consists of a vast accumulation of fine gray and dark colored clays in moderately distinct layers, but never presents a laminated or slaty structure like the Fort Benton Group. When wet, these clays are soft and plastic, but in drying they often crack and crumble so as to obliterate the marks of deposition in vertical exposures. (p. 424.)

The Fort Pierre Group generally abounds in fossils in Nebraska,[20] though they are not equally distributed through the whole formation, there being an upper and a lower fossiliferous zone, while a considerable thickness of the middle beds contain few organic remains. * * * Those occuring in the lower fossiliferous zone, at the base, are *Mosasaurus missouriensis*, *Callianassa danae*, *Ammonites complexus*, *Baculites ovatus and B. Compressus*, *Hilicoceras* [*Helicoceras*] *mortoni*, *H. cochleatum*, *H. tortum*, *H. umbilicatum*, *Fusus viniculum*, *F. shumardi*, *Buccinum constrictum*, *Amauropsis paludinaeformis* *Anisomyon borealis*, *Inoceramus sublaevis*, *I. incurvus*, etc., etc. In the upper fossiliferous zone, organic remains are more abundant than in the lower. The following list contains the names of many of those usually found at this horizon, viz.: Bones of *Mosasaurus missouriensis*, with *Nautilus dekayi*, *Ammonites placenta*, *Scaphites nodosus*, *S. nicollettii*, *Baculites ovatus*, *B. compressus*, *Aptychus cheyennensis*, *Fusus subturritus*, *F.? tenuilineatus*, *Gladius cheyennensis*, *Margarita nebrascensis*, *Dentalium gracile*, *Tectura occidentalis*, *Anisomyon patelliformis*, *A. alveolus*, *Bulla nebrascensis*, *Xylophaga elegantula*, *Corbulamella gregarea*, *Cardium rarum*, *Lucina occidentalis*, *Crassatella evansi*, *Modiola meekii*, *Inoceramus convexus*, *I. mortoni*, *I. nebrascensis*, *I. sagensis*, *I. vanuxemi*, etc., etc. Several of these fossils pass up into the formation above. (p. 427.)

Fox Hills Beds.—This formation is generally more arenaceous than the Fort Pierre Group, and also differs in presenting a more yellowish or ferruginous tinge. Towards the base it consists of sandy clays, but as we ascend to the higher beds, we find the arenaceous matter increasing, so that at some places the whole passes into a sandstone. It is not separated by any strongly defined line of demarcation from the formation below, the change from the fine clays of the latter to the more sandy material above, being usually very gradual. Nor are these two formations distinguished by any abrupt change in the organic remains,

[20]It must be remembered that at the time these words were written, in 1861, the Territory of Nebraska included, in addition to the present State of Nebraska, portions of the states of North Dakota, South Dakota, Montana, Wyoming and Colorado.

since several of the fossils occurring in the upper beds of the Fort Pierre Group pass up into the Fox Hills beds, while at some localities we find a complete mingling in the same beds of the forms usually found at these two horizons. Indeed, we might with almost equal propriety, on paleontological principles, carry the line separating these two formations down so as to include the upper fossiliferous zone of the Fort Pierre Group, as we have defined it, in the formation above. All the facts, however, so far as our present information goes—taking into consideration the change in the sediments at or near where we have placed the line between these two rocks—seem to mark this as about the horizon where we find evidences of the greatest break in the continuity of physical conditions. (p. 427.)

A portion of this same discussion appears in the ninth Monograph of the Hayden Survey, at pages 35 to 38, but with no important additions or changes.

In their reports on northwestern Colorado White[21] and Endlich[22] dropped the name Pierre entirely, and included under the name Fox Hills all strata which otherwise they would have assigned to both these formations. The inevitable result of this change in the sense in which the name was used is confusion. Later, owing to a radical difference in sedimentation in western Colorado, as compared with the region east of the Continental Divide, the names Pierre and Fox Hills have been abandoned for the formations west of the divide, the name Mancos being now used for the formations which represent Benton, Niobrara and earlier Pierre time, and the name Mesa Verde being used for those which represent middle Pierre time.

Again, in the following year, White[23] included the Pierre of eastern Colorado under the name Fox Hills, saying:

For the purpose of avoiding confusion in the minds of those who shall read this report, it may be well to repeat the statement already made in a foot-note, that the original grouping of the Cretaceous strata adopted by Hayden and Meek for the Upper Missouri region, which is still regarded as entirely appropriate there, has been so modified for Colorado and the Territories adjacent as to include the equivalent strata of both the Fort Benton Group (Cretaceous No. 2) and the Niobrara Group (Cretaceous No. 3) in a single group, under the name of Colorado Group. Also the consolidation of the Fort Pierre Group (Cretaceous No. 4) and the Fox Hills Group (Cretaceous No. 5) under the single name of Fox Hills Group. It is in this sense that the latter name will be used in all references to

[21]White, C. A., "Report on the Geology of a Portion of Northwestern Colorado," 10th Ann. Rept. U. S. Geol. & Geog. Surv. Terr. (Hayden Survey), for 1876, pp. 19, 21, 22, 31.

[22]Endlich, F. M., "Report on the Geology of the White River District," 10th Ann. Rept. U. S. Geol. & Geog. Surv. Terr., for 1876, pp. 76, 109, 125-126.

[23]White, C. A., "Report on the Paleontological Field-Work for the Season of 1877," 11th Ann. Dept. U. S. Geol. & Geog. Surv. Terr., for 1877, pp. 179, 186-187.

the Cretaceous strata of Colorado and adjacent Territories; but for the Upper Missouri River region it will continue to be used in the restricted sense applied to it by its authors.

It was unfortunate that the old name was used in a new sense, instead of adopting a new name. As new names have been adopted for western Colorado formations, we need not now concern ourselves with the use by various authors of the name Fox Hills to designate strata west of the Continental Divide which rest upon what has been called the Colorado Group, nor with the use of the name Colorado Group to include not only Benton and Niobrara strata, but also lower Pierre.

In 1888 Eldridge sought to correct this confusion by introducing the term Montana Group to cover both Pierre and Fox Hills strata, saying in a footnote to his paper before the Colorado Scientific Society (Proc., III., pp. 93-94):

Since first writing the above, careful consideration has led to the belief that it would be better to adopt, instead of the nomenclature of the maps of the Hayden Survey—by which confusion and inconvenience is likely to arise from the fact that one of the old established names, 'Ft. Pierre,' is entirely discarded, and another of them, 'Fox Hills,' is elevated in rank and made to include the former—a nomenclature which contains an entirely new term and by which the old formation names of Fort Pierre and Fox Hills may still be retained in their early signification. The name since suggested for this group is 'Montana,' a notice of which will be published in a forthcoming number of the Am. Journ. of Science. Briefly, it is to be understood as replacing the group name 'Fox Hills' as used in their article and on the Hayden maps, and to include the formations Fort Pierre and Fox Hills as originally understood in the Upper Missouri section of Messrs. Meek and Hayden. This suggestion is made with the approval of Dr. C. A. White, whom the change most closely affects, *vide* the volume for 1876 of the U. S. Geological and Geographical Survey of Territories. Hayden, p. 22. White's classification.

In 1896 Gilbert[24] and Eldridge[25] used the names Pierre and Fox Hills in their original sense in discussing eastern Colorado formations. Gilbert says, among other things:

"Pierre Group—Above the Niobrara Group is a great deposit of laminated argillaceous shales, not interrupted by sandstone, limestone, or other hard layers. In the vicinity of Florence, where the shale of the group is seen, its thickness has been estimated as more than 4,000 feet. In other parts of the district only the lower part of the group occurs, and it is probable that the thickness does not exceed 2,500 feet. There are considerable variations in color, texture and contents, from bottom to

[24]Gilbert, G. K., "The Underground Waters of the Arkansas Valley in Eastern Colorado," 17th Ann. Rept. U. S. Geol. Surv., for 1895-1896, Part II, pp. 567-569, 1896.

[25]Eldridge, George H., "Mesozoic Geology," Geology of the Denver Basin in Colorado, U. S. Geol. Surv., Mon., Vol. XXVII, pp. 68-72, 1896.

top of the series, and by their aid several zones have been recognized, but none of them are sharply limited, and it has not been practicable to distinguish definite formations.

Fox Hills Group—The Fox Hills Group is composed chiefly of sandy shale, which grades downward into the argillaceous shale of the underlying Pierre and upward into a yellow sandstone. Within the district it occurs only in a small tract near Florence, where its thickness is reported by Eldridge as 450 feet."

In south central Colorado the difficulty of exactly correlating the upper part of the Montana Group with the Fox Hills formation has been recognized by the adoption of the name Trinidad for a portion of it, while that portion lying above the unconformity is assigned to the Vermejo formation as we have seen.[26] In the Walsenburg Folio, Hills describes the Trinidad formation as follows:

Trinidad Formation.—This is the upper division of the Montana Group, and the uppermost of the marine Cretaceous beds of the district. It probably corresponds to the upper portion of the Fox Hills formation, the basal portion being very much better developed northward on the Arkansas River and in the Denver Basin. The lower portion consists of from 85 to 90 feet of thin-bedded, fine-grained, dark-gray sandstone in layers from 2 to 4 inches thick, separated from one another by thin partings of shale. The upper portion, from 75 to 80 feet in thickness, consists of greenish-gray, heavy-bedded or massive sandstone which is light gray on the weathered surface. This bed of sandstone is characterized by the presence throughout of the fucoid *Halymenites*, easily recognized by the pitted, cylindrical casts of the branching stems. In the lower portion poorly preserved *Baculites* were found in making an excavation near Rouse. The massive sandstone is of close texture and, as it resists erosion more strongly than the beds above and below, generally appears as a prominent escarpment defining very clearly the base of the coal-bearing formation overlying it.

The essential portions of Eldridge's description of the Montana Group in the Denver Basin Monograph are as follows:

MONTANA GROUP

The Montana Group occupies a highly inclined position along the foothills, and, with the exception of an area in the northwest portion of the field, the width of its outcrop is but little in excess of its thickness. The latter, under more normal conditions, reaches a maximum of approximately 8,700 feet, of which the Pierre constitutes the lower 7,700 to 7,900 feet and the Fox Hills the upper 1,000 or 800 feet. (pp. 68-69.)

PIERRE

This formation is, in the main, a great body of plastic clays, carrying small, lenticular bodies of impure limestone and, at a horizon about

[26]Hills, R. C., Geologic Atlas of the United States, Walsenburg Folio, No. 68; Elmoro Folio, No. 58. See on the Vermejo, citations to Lee's and Knowlton's papers, *ante*.

one-third the distance from base to summit, a zone of sandstone from 100 to 350 feet thick. (p. 69.)

ZONE TRANSITIONAL TO FOX HILLS

Between the Pierre and overlying Fox Hills formation there is a change from the pure clay of the one to the arenaceous shales of the other. Limestones and small ferruginous nodules, similar to those already described, are present throughout this transitional zone, extending well into the Fox Hills. Fossils also occur, but the life of the zone is marked by the sudden increase in the members of the genus *Mactra*, a genus which below has only been occasionally met with, but which from this up is frequently found. (p. 71.)

FOX HILLS

The Fox Hills formation has a normal thickness of between 800 and 1,000 feet, falling below this only at Golden, where its decrease to 500 feet is attributable to the nondeposition of its lower portion. The formation consists mainly of soft, friable, arenaceous shales, with occasional interstratified bands of clay. At the summit is a persistent and characteristic sandstone, usually about 50 feet thick. The entire formation has a yellowish cast, but while the shales are generally of a grayish-yellow the sandstone itself has a pronounced tint of green. The composition of both shales and sandstones is very uniform. * * * The sandstone at the summit of the formation is noteworthy on account of its position as cap to the great mass of Cretaceous clays, from its wide occurrence over the West, from the fossil remains in its upper stratum, and from the marked difference displayed in its materials from those of the basal sandstones of the Laramie which overlie it. Its composition is chiefly quartz, but it carries an appreciable amount of biotite and muscovite, and iron oxide is distributed throughout its entire mass. It is fine-grained, of close texture, and usually occurs as a single bed. Occasionally it becomes concretionary. It is in close union with the basal sandstone of the Laramie; no transition bed exists; the passage from the one to the other is direct; combined they frequently enter into the formation of a single bluff 150 feet high. Notwithstanding this, the formations are easily distinguished by their lithological contrasts and by the fossil horizon marking the summit of the older. (pp. 71-72.)

LARAMIE FORMATION

The formation is from 600 to 1,200 feet thick and is divisible into two parts, a lower of sandstones, and an upper, composed of clays. The former has a uniform thickness of about 200 feet; the latter varies. Both divisions carry workable seams of coal. (p. 73.)

The sandstone referred to by Eldridge, about one-third the distance from base to top of the Pierre, has since been named the Hygiene sandstone, by Fenneman,[27] who does not give it the rank of a formation, but designates it as the Hygiene sandstone mem-

[27]Fenneman, N. M., Geology of the Boulder District, Colorado, U. S. Geol. Surv., Bull. No. 265, pp. 31-33, 1905.

ber of the Pierre. It is not well defined above or below, and divides apparently into two portions at the north. It includes the highly fossiliferous beds at Fossil Ridge (south of Fort Collins), Rocky Ridge (north of Fort Collins), and Round Butte (north of Wellington).[28] We have traced it from Boulder through Fossil Ridge, Fort Collins, Rocky Ridge and Round Butte, to where it passes under the Tertiary bluffs near the northern boundary of Colorado. A somewhat similar sandstone occurs at about the same place in the western part of Middle Park, indicating a widespread change in sedimentation conditions in central and northern Colorado at that period, which is approximately synchronous with the change from the marine Mancos conditions to the non-marine Mesa Verde conditions in western Colorado.

A comparison of Meek and Hayden's original Upper Missouri section of the Pierre and Fox Hills with that of the Denver Basin reveals considerable difference in sedimentation conditions. The Pierre of the Upper Missouri is described as consisting entirely of gray and dark-colored clays, while in the Denver Basin a very important sandstone is found. The Fox Hills of the Upper Missouri region is described as consisting of sandy clays below, the arenaceous matter increasing above, "so that at some places the whole passes into a sandstone. It is not separated by any strongly defined line of demarcation from the formation below, the change from the fine clays of the latter to the more sandy material above being usually very gradual," and the two formations are not "distinguished by an abrupt change in the organic remains." The same is true of the Denver section. It appears that no definite lower limit can be assigned to the Fox Hills, unless we confine the name to the upper massive sandstone, which would not be consistent with the sense in which it was originally used or is now generally used. Eldridge designated an indefinite thickness of strata as a "zone transitional to Fox Hills," where "there is a change from the pure clay of the one to the arenaceous shales of the other."

Fenneman's description of the Montana clearly exhibits the difficulty of separating the Fox Hills from the Pierre in the Boulder district, and is as follows:[29]

Color.—Above the Niobrara are the Pierre shales, which are more than 5,000 feet thick. They are slate-colored, leaden gray, dark brown and sometimes nearly black. Weathering gives to them a greenish-drab hue,

[28]Henderson, Junius, "The Sandstone of Fossil Ridge in Northeastern Colorado and Its Fauna," Univ. Colo. Studies, Vol. V, pp. 179-192, 1908.
[29]Fenneman, N. M., Bull. 265, *post*, pp. 31-33.

which, at any considerable distance from the foothills, is their color to a depth of 30 feet, more or less. It is therefore the one ordinarily seen. Near the base of the formation, however, just in front of the hogbacks, erosion is more active and the shales are often seen with their original dark colors.

Limestone Beds.—While in general noncalcareous, the Pierre has local limy beds. At places these form continuous strata, as, for example, 4 miles north of Boulder, one-half mile east of the contact with the Niobrara. Here, for a thickness of nearly 40 feet, strong limestone beds are so closely grouped as to give the outcrop the appearance of the basal Niobrara. At other places the limestone beds are smaller and more isolated, or are divided into concretionary masses often containing fossils. Less prominent calcareous masses may be found at any horizon either in beds or in more or less perfect concretions. Concretions of iron occur in similar but less massive forms, ranging from clear-cut beds to well-formed nodules. The lime and the iron may or may not occur in the same concretionary mass. Many of the calcareous nodules mentioned contain much iron carbonate, which, in progressive oxidation toward the center, gives rise to sharply marked concentric shells differing in color.

Hygiene Sandstone Member.—Sandy beds may occur at any place in the section. The most prominent and persistent of these is about one-third way up from the base, or a little higher. Its outcrop is chiefly at the northern end of the field, where it forms a considerable ridge, though disappearing under Table Mesa. Where it reappears north of this broad mesa its outcrop again forms a strong ridge, which is almost continuous for many miles. The ridge passes within a mile and a half of the village of Hygiene, where the sandstone is typically developed. The name Hygiene sandstone has, therefore, been adopted for this member of the Pierre formation. * * *

From these pure sands at one extreme to pure clay shales at the other, the Pierre shows all gradations in composition. The sandy layers are generally firm and gritty, almost as dark colored as the shales themselves, and not very porous. In rare instances light-colored, friable sands are encountered in drilling oil wells. The thickness of the sandy beds is as variable as their constitution, while the lateral extent of such beds, as indicated by occasional outcrops and by the records of wells, is, in a large majority of cases, a small fraction of a mile. * * *

Within the limits of this area the great body of the Fox Hills is but indefinitely distinguished from the Pierre. In mild contrast with the latter its shales are yellowish instead of slate colored, and are also more arenaceous. This latter quality is plainly shown in the soil produced. At some places the transition zone spoken of by Eldridge, as marked by limestones and small ferruginous nodules, is plainly seen. No attempt has been made to trace on the accompanying map the contact between these two formations, as definite points of contact are infrequent and separation of the areas of the two terranes in a detailed way must rest largely on the character of the soils. This distinction is frequently masked by the outwash from the foothills. The topmost stratum of the Fox Hills is, however, a very definite feature in the stratigraphy. For many feet below it there are occasional sandstone beds, and the intervening shales are highly sandy, but at the top is a continuous bed of sandstone 40 feet thick. It is best exemplified just east of the area mapped, where a fine fault brings it up to view alongside the basal Laramie. The sandstone is here fine grained and yellow, very slightly calcareous, and encloses great calcareous, iron-stained concretions. The entire thickness of the Fox Hills near Niwot is about 1,300 feet.

From a careful consideration of what has been said by the various writers who have made special studies of the Cretaceous formations of eastern Colorado, it is doubtful if any of them would have attempted to divide the Montana group where they have divided it, if at all, except for the fact that it doubtless represents the same period of time as the combined Fox Hills and Pierre, and for the conception that it must be divided and by means of names correlated with those formations. It seems likely that, if the group had been first studied in eastern Colorado, before the publication of anything concerning the formations of the Upper Missouri region, it would not have been divided at all, or would have been separated at a much higher horizon—at the base of the massive upper sandstone which is hereinafter discussed, thus throwing all the inseparable series of shales and irregular sandstones together into one formation. The reasons for such a course seem even clearer from an examination of the very fine but little discussed exposures of Upper Montana strata to the north and northeast of the areas covered by the Denver Monograph and the Boulder Bulletin. However, while the Pierre and Fox Hills horizons cannot in this field be sharply separated, they remain convenient horizon names by which to designate loosely the lower and upper Montana strata respectively, and will probably long continue to be generally so used. In the region under discussion, the upper, massive sandstone hereinbefore referred to is so sharply defined as to deserve a distinct name as a separate member of the Fox Hills horizon, of the same rank as Fenneman's Hygiene member of the Pierre. This I designate the Milliken sandstone member, because of the excellent exposures near Milliken station, west of LaSalle.

The Milliken Sandstone.—The best exposures we have found are in the bluffs on the north side of the Thompson below the mouth of Little Thompson, at Wildcat Mound, near the mouth of the St. Vrain, and on the south side of the Cache la Poudre, southeast of Windsor. The best exposures of the underlying strata is in the bluff at the last-named locality. The base of the bluff is occupied by black and dark-gray clay shales, with numerous arenaceous layers. Passing upward, these give way abruptly to a massive, rather soft, usually greenish-yellow sandstone, from 100 to 150 feet in thickness, almost entirely free from shales except a few one-inch bands in the lower part. The sandstone contains many large, brown concretions and bands, more or less ferruginous and calcareous and usually highly fossiliferous. The more gentle slopes above are occupied by alternating shales and soft sandstones, containing marine fossils, and not sharply separated from the overlying Laramie shales and sandstones. The Laramie is not well exposed in this region, owing largely to the absence or weakness of the massive, thick, white sandstone which is such a conspicuous and persistent feature of the lower Laramie in Boulder County. The Milliken sandstone is so persistent and distinct from the underlying and overlying shaly members, as to be a fine horizon marker.

PALEONTOLOGY

The Dakota formation, so-called, and the Colorado Group, are not specially treated in this report, but it may be well to briefly point out their stratigraphic and paleontological relations. The Dakota sandstone, conglomerates and shales constitute the outer ridge or "first hogback" of the foothills. The formation consists of a basal conglomerate and sandstone, a medial shale zone and an upper sandstone member. No specifically identifiable fossils have been found in this formation in the region under discussion. Fragments of land plants are common in some portions of the strata. In the upper part of the medial member have been found at several localities north of Boulder, poorly preserved specimens of *Inoceramus* sp. (near or identical with *labiatus*), *Avicula* sp. (near *linguiformis*), *Ostrea* sp. and other fossils indicating marine origin, though probably the upper and lower members are partly of fresh-water origin. In 1920 we found *Halymenites*, a marine alga, in the upper Dakota sandstone at the mouth of Little Thompson Canyon and ten miles north of Boulder. The Colorado group, which rests upon the Dakota and lies beneath the Montana group, includes the Benton and Niobrara limestones and shales. They are calcareous throughout. These two formations, steeply upturned, occupy a narrow band along the western edge of the plains, at the base of the foothills. The Benton, which is next to the Dakota, is characterized in its upper part by the presence everywhere of *Inoceramus labiatus* in one or more thin limestone bands, with rarer specimens of *Acanthoceras coloradoensis* and *Metoico-*

ceras swallowi. The lower Niobrara is characterized by *Inoceramus deformis* and *Ostrea congesta.* The uniformity of these three formations over large areas, and the fact that they have been somewhat fully treated in previous publications[30] available to students, makes further comment unnecessary.

The Montana group presents two rather distinct paleontological zones, though there is considerable intermingling of species. The lower, or Pierre, portion of the formation is characterized by a great preponderance of ammonoid Cephalopods and of pelecypods of the genus *Inoceramus,* of which several species are common. On the other hand the Milliken sandstone member at the top of the group contains comparatively few cephalopods and *Inoceramus,* but abounds in *Mactra, Nucula, Cardium* and gastropods. The Hygiene sandstone, which is at perhaps the middle of the Pierre member, at Fossil Ridge[31] contains quite a number of species which are also found in the Milliken sandstone. The fauna of the group as a whole is strictly marine.

The Laramie formation, which includes the coal beds of northeastern Colorado, contains many leaf impressions. They are especially abundant at Marshall, south of Boulder. In Boulder county the formation is quite barren of animal remains except *Ostrea glabra,* but to the north and northeast an extensive fresh-water and brackish-water molluscan fauna occurs. From Crow Creek eastward for many miles great quantities of *Ostrea glabra* and various species of *Corbicula* may be found at numerous localities. In fact, a surprisingly large proportion of the known American species of Cretaceous *Corbiculas* have been found in that region. *Melania wyomingensis* and *Ostrea glabra* are not determinative of this formation, as they are also found in the upper Fox Hills at many localities, but the *Corbiculas* are characteristic of the Laramie in this region.

[30]Marvine, Arch. R., "Report of Arch R. Marvine, Assistant Geologist Directing the Middle Park Division," 7th Ann. Rept. U. S. Geol. & Geog. Surv. Terr. (Hayden Survey), for 1873, pp. 100-105, 1874. Stanton, T. W., The Colorado Formation and Its Invertebrate Fauna, U. S. Geol. Surv., Bull. No. 106, 1893. Emmons, Cross and Eldridge, Geology of the Denver Basin in Colorado, U. S. Geol. Surv., Mon. Vol. XXVII, pp. 62-69, 1896. Fenneman, N. M., Geology of the Boulder District, Colorado, pp. 28-31, 1905. Henderson, Junius, "The Foothills Formations of North Central Colorado," First Rept. Colo. Geol. Surv., pp. 172-177, 1909; "Paleontology of the Boulder Area," Univ. Colo. Studies, Vol. II, pp. 95-106, 1904.

[31]Henderson, Junius, "The Sandstone of Fossil Ridge in Northeastern Colorado and its Fauna," Univ. Colo. Studies, Vol. V, pp. 179-192, 1908.

Lists of species from various localities and horizons are given on subsequent pages of this report.[32]

MAPS

Aside from the maps of the Hayden Survey Atlas of Colorado, and the State map recently published by the Colorado Geological Survey, maps treating the geology of portions of the region under discussion may be found in the following publications: The Denver Basin Monograph, Fenneman's Boulder bulletin, Darton's paper on the Geology and Underground Waters of the Central Great Plains, and the papers by the present writer on the Foothills Formations and the Fossil Ridge Sandstone. The cartographic results of the present investigation have been incorporated into the Geologic Map of Colorado, published in 1913. The following topographic sheets of the United States Geological Survey may be found very useful in locating the various points mentioned in the following discussion: Denver Basin, Boulder, Niwot, Loveland, Livermore, Eaton and Greeley Quadrangles. Topographic maps of the region east of Weld County have not been published.

It is not practical to exactly fix the boundaries of the formations upon the map. Low dips and lack of dip, softness of strata and the heavy mantle of Tertiary and Quaternary debris covering large areas, combine to make definitely identifiable outcrops of Cretaceous rocks rather few. As the upper Montana-Laramie contact marks a change from marine to brackish-water and fresh-water conditions, which change would not likely be entirely uniform over so large a region, it is quite probable that the upper part of the marine strata in some places are exactly synchronous with the lower strata assigned to the Laramie in other places. The variable character of the lower Laramie and upper Montana sediments adds to the difficulty of exactly identifying a limited outcrop in the absence of fossils. Hence the boundaries placed upon the map are in many places only approximate, and based to a great extent upon probabilities, rather than direct observation, though many outcrops have been definitely identified.

THE MARSHALL DISTRICT

This district, south of Boulder, has been discussed by Emmons, Cross and Eldridge, in the Denver Basin monograph, and we have

[32]See also White's "Report on the Paleontological Field Work of 1877," and "Contributions to Invertebrate Paleontology, No. 1; Cretaceous Fossils of the Western States and Territories," U. S. Geol. & Geog. Surv. Terr. (Hayden survey), 11th Ann. Rept. ,for 1877, pp. 161-319, 1879. (Contains lists of species from Crow Creek, Cache la Poudre Valley, Little Thompson, Fossil Creek, Bijou Creek, etc., and describes many species.)

nothing of importance to add. A little of the Milliken sandstone is found exposed beneath the white basal Laramie sandstone. *Ostrea glabra* M. & H. and many species of dicotyledonous plants are found in the Laramie in this neighborhood, but it would be best not to discuss the latter herein, pending the completion of Dr. Knowlton's work on the Laramie flora. We have done no new work south and east of this locality, as that region was rather carefully covered by the Denver Basin monograph. At Coal Creek, southwest of Marshall, the following species were obtained from Pierre shales:

Inoceramus oblongus Meek
Inoceramus barabini Morton
Inoceramus sagensis Owen
Inoceramus vanuxemi M. & H.
Baculites ovatus Say
Baculites compressus Say
Scaphites nodosus Owen
Heteroceras nebrascense M. & H.

THE BOULDER DISTRICT

This region has recently been discussed so fully[33] that it is unnecessary to go into details as to the geology, but a few remarks upon the paleontology may be of use for comparison with other regions.

The brick yard, east of the University Hospital, yielded the following:

Fossil wood
Nucula sp.
Inoceramus sagensis Owen
Avicula linguiformis E. & S.
Avicula nebrascana E. & S.
Ostrea sp.
Anomia raetiformis Meek
Lucina occidentalis (Morton)
Callista deweyi (M. & H.)
Mactra holmesii (Meek)
Teredo? sp.
Anchura cf. americana (E. & S.)
Baculites ovatus Say
Scaphites nodosus Owen
Scaphites nodosus quadrangularis M. & H.
Placenticeras sp.
Fish bones
Dinosaur bones

The brick yard at the west end of Lover's Hill, on the north side of town, yielded the following, including one insect wing, associated with marine shells:

[33]Emmons, Cross and Eldridge, "Geology of the Denver Basin in Colorado," U. S. Geol. Surv., Mon. XXVII. Fenneman, N. M., "Geology of the Boulder District, Colorado," U. S. Geol. Surv., Bull. No. 265, 1905. Henderson, Junius, "Paleontology of the Boulder Area," Univ. Colo. Stud., Vol. II, pp. 95-106, 1904; "The Foothills Formations of North Central Colorado," First Rept. Colo. Geol. Surv., pp. 145-188, 1909.

Nucula planimarginata M. & H.
Inoceramus barabini Morton
Lucina occidentalis (Morton)
Scaphites nodosus Owen
Petropteron mirandum Ckll.
Fish scales

At every exposure of the basal massive limestone of the Niobrara from Boulder northward *Inoceramus deformis* Meek and *Ostrea congesta* Conrad occur. The latter, attached to crushed *Inoceramus* shells of great size, possibly *I. deformis,* also enters largely into the composition of a persistent thick bed in the Middle Niobrara and at mouth of Little Thompson Canyon extends nearly to the top of the formation. Thin limestones in the upper Benton, five or six miles north of Boulder, contain many *Inoceramus labiatus* (Schl.) and *Ostrea* sp., and a few *Placenticeras* sp.

In the Pierre shales from three to six miles north of Boulder, above the Hygiene sandstone, we have found the following species (compare also Stanton, Proc. Colo. Sci. Soc., II, 1888, pp. 184-187):

Hemiaster? cf. humphreysanus M. & H.
Nuculana subequilaterata Whitf.?
Yoldia evansi (M. & H.)
Avicula cf. linguiformis E. & S.
Inoceramus barabini Morton
Inoceramus oblongus Meek
Inoceramus sagensis Owen
Inoceramus sublaevis M. & H.
Inoceramus vanuxemi M. & H.
Ostrea inornata M. & H.
Cuspidaria ventricosa (M. & H.)?
Lucina occidentalis (Morton)
Callista deweyi (M. & H.)
Thetis circularis (M. & H.)?
Mactra sp.
Teredo? in fossil wood
Dentalium gracile H. & M.?
Anchura nebrascensis (E. & S.)
Fasciolaria sp.
Anisomyon borealis (Morton)
Anisomyon sp.
Nautilus dekayi Morton
Ptychoceras crassum Whitf.
Ptychoceras mortoni M. & H.
Baculites ovatus Say
Baculites compressus Say
Scaphites nodosus Owen
Scaphites nosodus quadrangularis M. & H.
Placenticeras whitfieldi Hyatt
Placenticeras intercalare (M. & H.)
Heteroceras cochleatum (M. & H.)?
Heteroceras nebrascense (M. & H.)
Heteroceras tortum (M. & H.)
Ancyloceras jenneyi Whitf.
Ancyloceras tricostatus Whitf.
Mosasaur bones

Below the Hygiene sandstone in the same vicinity *Baculites ovatus* and *Inoceramus barabini* are common and*Baculites anceps* Lam.? rare. A few Mosasaur fragments have also been found.

Specimens of *Scaphites nodosus* in the state university cabinets are labelled "five miles northeast of Boulder."

Outside the foothills at the mouth of Bear canyon, four miles south of Boulder, at about the Hygiene sandstone horizon, we found:

Inoceramus sagensis Owen
Inoceramus oblongus Meek
Inoceramus cf. vanuxemi M. & H.
Baculites ovatus Say

At a somewhat lower horizon one specimen of *Baculites anceps* Lam. was found.

About four miles east of Boulder, just north of the fortieth parallel of latitude, is a rather poor exposure of upper Fox Hills strata, probably the Milliken sandstone, which yielded the following species:

Halymenites major Lx.
Nucula sp.
Ostrea glabra M. & H.
Cardium speciosum M. & H.
Callista sp.
Mactra warrenana M. & H.
Mactra formosa M. & H.
Dentalium cf. gracile H. & M.
Lunatia subcrassa (M. & H.)
Melania wyomingensis (Meek)
Pyrifusus? cf. newberryi (M. & H.)
Gastropoda undetermined

THE HAYSTACK BUTTE DISTRICT

On the slopes of Haystack butte and the fields to the westward, east of north from Boulder, we have found the following:

Inoceramus sagensis Owen
Inoceramus sublaevis M. & H.
Inoceramus barabini Morton
Inoceramus oblongus Meek
Ostrea inornata M. & H.
Lucina occidentalis (Morton)
Mactra gracilis M. & H.
Ptychoceras sp.
Baculites compressus Say
Baculites ovatus Say
Scaphites nodosus Owen
Helicoceras mortoni (H. & M.)
Heteroceras cochleatum (M. & H.)?
Heteroceras nebrascense (M. & H.)
Ancyloceras jenneyi Whitf.

THE LEFT HAND DISTRICT

Not far from the base of the foothills, north of Left Hand Creek, at the type locality of *Acanthoceras coloradoensis* Henderson, we found also the following species in the thin limestone layers of the upper Benton:

Inoceramus labiatus (Schl.)
Ostrea sp.
Metoicoceras swallowi (Shumard)
Helicoceras? corrugatum Stanton?

THE WHITE ROCK DISTRICT

As shown in the Denver Basin monograph, a fault through the White Rock bluff, east of Valmont, brings the Milliken sandstone (upper Fox Hills) at the east end of the bluff up to a level with the Laramie. East and northeast of this fault we obtained from the Milliken sandstone the following species:

Halymenites major Lx.
Nucula cancellata M. & H.
Nucula sp.
Yoldia evansi (M. & H.)
Avicula haydeni H. & M.?
Avicula nebrascana E. & S.
Ostrea cf. glabra M. & H.
Pholadomya subventricosa M. & H.
Tancredia americana (M. & H.)
Lucina sp.
Sphaeriola? cordata (M. & H.)
Cardium speciosum M. & H.
Callista nebrascensis M. & H.
Baroda subelliptica White
Tellina scitula M. & H.
Tellina equilateralis M. & H.
Mactra warrenana M. & H.
Mactra alta M. & H.
Pachymya? herseyi White
Dentalium gracile H. & M.
Fusus cheyennensis Whitf.
Cyclichna scitula M. & H.
Gastropoda undetermined
Shark teeth
Reptile teeth

THE LONGMONT DISTRICT

In the university cabinets there are specimens of *Mactra holmesii* (Meek) labeled "Reservoir Hill, ¼ mile west of Longmont," which are probably from middle or upper Pierre strata. The Milliken sandstone at Coffin ranch, about five miles east of Longmont, yielded the following species:

Ostrea glabra M. & H.
Veniella humilis (M. & H.)
Lucina cf. occidentalis (Morton)
Sphaeriola? cf. cordata (M. & H.)
Tancredia americana (M. & H.)
Cardium speciosum M. & H.
Callista nebrascensis M. & H.
Mactra cf. warrenana M. & H.
Dentalium gracile H. & M.
Lunatia subcrassa (M. & H.)
Melania wyomingensis (Meek)
Cylichna sp.
Gastropoda undetermined
Reptile teeth

A fine lot of *Crenella elegantula* M. & H. was obtained from the Milliken sandstone at Dixon Mill, two miles south of east from Longmont.

THE BERTHOUD DISTRICT

Berthoud is located on upper Pierre or lower Fox Hills strata. No good exposures were found near the town. Several miles to the west, in a fold just within the first hogback of the foothills, in the sandy shales of the upper part of the medial member of the "Dakota," we found *Avicula* aff. *linguiformis, Inoceramus* cf. *labiatus, Ostrea* sp., and some unidentified fragments of other species. In the Benton shales just outside the hogback we found:

Inoceramus labiatus (Schl.)	Acanthoceras coloradoensis Henderson
Inoceramus cf. fragilis H. & M.?	Metoicoceras swallowi (Shumard)
Ostrea undescribed	

At the mouth of Little Thompson Canyon, southwest of Berthoud, *Ostrea congesta* Conrad occurs nearly throughout the Niobrara, and the basal Niobrara limestone contains very large *Inoceramus deformis* Meek, some of which are deformed by a decided concentric sulcus separating the unbones from the younger portions of the shell, a character I have found also in large *Inoceramus sagensis* Owen from the Pierre north of Boulder. In 1920 we found *Halymenites* sp., a marine alga, in the upper sandstone of the Benton at this locality, *Inoceramus labiatus* Schl. at a lower horizon, *Ostrea* undescribed abundant at about the middle of the formation and fish scales abundant 25 feet above the base. The contact of the Benton with the Dakota is here beautifully shown, erosion along the dip exposing fine Benton shales in a ten-foot wall resting directly and conformably upon the strong upper Dakota sandstone. In the upper Dakota south of the creek we found *Halymenites,* the lowest horizon at which it has been found, so far as I am aware. We found it at the same horizon ten miles north of Boulder. East of the mouth of Little Thompson Canyon the Pierre yielded *Inoceramus sublaevis* H. & M. and *Baculites ovatus* Say.

West and southwest of Berthoud the "tepee butte" and Hygiene sandstone horizons of the Pierre yielded the following:

Membranipora sp.
Avicula sp.
Inoceramus barabini Morton
Inoceramus sagensis Owen
Inoceramus sp.
Ostrea pellucida M. & H.
Lucina occidentalis (Morton)
Pelecypoda undetermined
Margarita nebrascensis (M. & H.)
Gastropoda undetermined
Ptychoceras crassum Whitf.
Baculites ovatus Say
Baculites compressus Say
Scaphites nicolleti (Morton)
Heteroceras cochleatum (M. & H.) ?

Callista sp. and *Cardium speciosum* M. & H. were found in Fox Hills sandstone four miles east and one mile south of Berthoud. A specimen of *Sphaeriola ? cordata* (M. & H.) in the State University Museum cabinets is labeled "six miles southeast of Berthoud," and is evidently from Fox Hills strata.

THE LOVELAND DISTRICT

There are no good exposures about Loveland, which is situated on upper Pierre strata. In the foothills to the west, in the "Dakota" shale about 40 feet below the upper sandstone of the formation, we found the following species:

Inoceramus cf. labiatus
Ostrea sp.
Fish vertebrae
Plesiosaur teeth

The Hygiene sandstone passes under Loveland reservoir, at the northwest edge of the town. Along the east shore of the lake at low water we found *Scaphites nodosus* Owen.

FOSSIL RIDGE

Fossil Ridge is a low, rounded ridge composed of the Hygiene sandstone, with low easterly dip. Destruction of the overlying shales to the eastward and the underlying shales to the westward leave the slightly upturned sandstone standing above the plain. It is bisected by Fossil Creek. Numerous large concretions contain marine fossils in great abundance. Reports published several years ago record the following species:[34]

[34]White, C. A., "Report of the Paleontological Field Work for the Season of 1877," 11th Ann. Rept. U. S. Geol. & Geog. Surv. Terr. (for 1877), pp. 176-177. Henderson, Junius, "The Sandstone of Fossil Ridge in Northeastern Colorado and Its Fauna," Univ. Colo. Studies, Vol. V, pp. 179-192, 1908; "New Species of Cretaceous Invertebrates from Northern Colorado," Proc. U. S. Nat. Mus., Vol. XXXIV, pp. 259-264, 1908.

Halymenites major Lx.
Beaumontia solitaria White
Chaetetes?? dimissus White
Serpula markmani Henderson
Membranipora sp.
Panope berthoudi (White)
Pinna lakesi White
Inoceramus barabini Morton
Inoceramus oblongus Meek
Inoceramus sagensis Owen
Inoceramus proximus Tuomey?
Inoceramus vanuxemi M. & H.
Tellina scitula M. & H.
Mactra warrenana M. & H.
Teredo? borings in wood
Margarita nebrascensis (M. & H.)
Capulus spangleri Henderson
Gyrodes abyssina (Morton)
Gyrodes crenata (Conrad)
Gyrodes sp.
Anchura haydeni White
Anchura americana (E. & S.)
Fasciolaria cf. Culbertsoni (M. & H.)
Volutoderma? clatworthyi Henderson
Avicula liguiformis E. & S.
Avicula nebrascensis (E. & S.)
Ostrea inornata M. & H.
Ostrea patina M. & H.
Ostrea pellucida M. & H.
Anomia raetiformis Meek
Modiolus meeki (E. & S.)
Pholadomya subventricosa M. & H.
Anatina doddsi Henderson
Thracia gracilis (M. & H.)
Neaera sp.
Cardium speciosum M. & H.
Callista deweyi (M. & H.)
Haminea sp.
Anisomyon borealis (Morton)
Anisomyon shumardi M. & H.
Anisomyon patelliformis (M. & H.)
Nautilus dekayi Morton
Ptychoceras sp.
Baculites ovatus Say
Baculites compressus Say
Scaphites nodosus Owen
Scaphites nicolleti (Morton)
Placenticeras whitefieldi Hyatt
Placenticeras intercalare (M. & H.)
Lamna sp.

THE FT. COLLINS DISTRICT

From the northern end of Fossil Ridge the Hygiene sandstone passes across the Cache la Poudre Valley, but is concealed beneath the alluvial deposit, appearing again in Rocky Ridge, north of the valley, whence it may be traced into Round Butte. No time was spent at Rocky Ridge, but *Inoceramus oblongus* and *Chaetetes? dimissus* were noted. At various places north and northwest of Fort Collins, in or below the Hygiene sandstone, were found:

Avicula linguiformis E. & S.
Inoceramus barabini Morton
Inoceramus sagensis Owen
Baculites ovatus Say

West of Fort Collins the Niobrara is tilted up along the base of the foothills, and contains *Inoceramus deformis* Meek and *Ostrea congesta* Conrad, as usual. The upper half of the medial shally sandstone member of the "Dakota" in the foothills contains marine fossils at every point where it was examined, as follows: Two miles north of Bellvue, *Avicula* aff. *linguiformis, Inoceramus* cf. *labiatus, Ostrea* sp., fish scales and vertebrae. Where Owl Canyon drainage breaks through the foothills, *Avicula* aff. *linguiformis, Inoceramus* cf. *labiatus, Ostrea* sp. *Anchura*?? sp. Where Boxelder Creek breaks through the foothills, *Ostrea* sp.

THE WELLINGTON DISTRICT

Wellington is situated in a rather flat valley, occupied by upper Pierre shales, covered by alluvium, with few and poor exposures of the shales. Along the road three-fourths of a mile west and three miles north of the town we found typical Pierre shales in the bank of a small stream. A short distance west of this point several years ago *Inoceramus sagensis* Owen and *Anisomyon shumardi* M. & H. were obtained. A moment's search in the bank of a canal cut about half a mile northeast of the town brought to light *Yoldia scitula* (M. & H.) ? and *Baculites ovatus* Say.

Three miles east of Wellington, in what appears to be the horizon just below the Milliken sandstone, dipping ten degrees southeast, we found *Veniella humilis* M. & H. A few miles farther east this species is abundant in concretions just beneath the Milliken sandstone, as at Windsor. Here the typical greenish-yellow Milliken sandstone is exposed in the upper part of the slope, and yielded the following species:

Halymenites major Lx
Cardium speciosum M. & H.
Baroda subelliptica White
Mactra formosa M. & H.
Dentalium gracile H. & M.

Below this are gray and slightly yellowish sandstones and dark shales, the exposures being mostly small sandstone knobs and iron-stained concretions, which at the top are highly fossiliferous, as at Windsor, and yielded the following species:

Avicula nebrascana E. & S.
Veniella humilis (M. & H.)
Lucina? sp.
Sphaeriola? cordata (M. & H.)
Cardium speciosum M. & H.
Callista sp.
Tellina scitula M. & H.
Mactra? sp.
Lunatia sp.
cf. Anchura americana E. & S.
Haminea minor (M. & H.)
Cylichna scitula M. & H.
Dentalium gracile H. & M.
Scaphites nodosus quadrangularis M. & H.
Reptile tooth

This horizon may be traced in scattered exposures for several miles north and south along the east side of Boxelder Valley, the strata having a slight easterly inclination. East of this point for some distance no satisfactory exposures were noted. Seven miles east of Wellington, in the east bank of a small stream, a "coal bank" is indicated on the Eaton topographic sheet. This small exposure consists of a white sandstone containing large, iron-stained concretions, shale, and a two-foot vein of coal, of poor quality. No identifiable fossils were found. Concretions of the same character are numerous in a valley a mile farther east, beyond which the flat country offers no good exposures for many miles.

A mile and a half north and two miles east of Wellington the North Poudre ditch cuts into shales alternating with thin sandstone layers, dipping ten degrees southeast, probably assignable to the lower Fox Hills member of the Montana Group. Three miles north of the town typical Pierre shales are exposed for some distance in the east bank of a small intermittent stream. A mile or so farther north, near a high trestle of the Colorado and Southern Railway, west of south from Bulger station, the Mountain Supply ditch cuts into a fine exposure of Pierre shales and alternating thin sandstone layers, dipping ten degrees, northeasterly, where we obtained the following fossils:

Nucula cancellata M. & H.
Yoldia sp.
Avicula fibrosa M. & H.
Tellina sp.
Mactra holmesi (Meek)
Fasciolaria cheyennensis (M. & H.)
Baculites compressus Say
Scaphites nicolleti (Morton)
Scaphites conradi cf. intermedius Meek
Placenticeras intercalare (M. & H.)

The *Baculites* were very numerous, mostly quite small and all retaining the original pearl. This same horizon has been detected at various localities in Elbert and Lincoln counties, which is unusual in this region. About half a mile west of Bulger the following were obtained:

Avicula fibrosa M. & H.
Pholadomya subventricosa M. & H.
Baculites compressus Say
Scaphites conradi (Morton) ?

A mile northeast of Bulger, at a higher horizon, occurs a soft, irregular, grayish, calcareous sandstone, capped by a little yellowish sandstone. It yielded *Halymenites major* Lx., *Crenella elegantula* M. & H. and *Dentalium* cf. *gracile* H. & M.

Gullies running westward from a sharp point about six miles northeast of Wellington afford a good exposure of strata below the Milliken sandstone. In the gully at the base of the steep slope occurs a massive sandstone, exposed to a thickness of 30 to 40 feet, yellowish below, light gray above, with concretions at the top which contain the following species, *Veniella* being quite abundant.

Avicula nebrascana E. & S.	Cardium speciosum M. & H.
Veniella humilis (M. & H.)	Mactra? sp.
Sphaeriola? cordata (M. & H.)	Dentalium gracile H. & M.

This is capped by 25 feet of softer yellowish and grayish sandstone and sandy shale, at the top of which was found one *Dentalium* and some *Halymenites.*

INDIAN SPRINGS MINE DISTRICT

Indian Springs coal mine is two miles east and eight miles north of Wellington. The mine was locked at the time of our visit. It is on a west-facing slope. The air shaft exposed a considerable thickness of clay shale, with a slight easterly dip. The slope for 500 to 600 yards downhill is a debris-covered zone, including perhaps 200 feet of strata, probably soft sandstone and shale. Such a hard, massive sandstone as that at the base of the Laramie in Boulder County would surely show in the gullies, if it occurred here. Below this covered zone is the Milliken sandstone, poorly exposed, but apparently more than 100 feet in thickness, containing *Halymenites major* Lx., *Cardium speciosum* M. & H. and *Mactra formosa* M. & H. On the two points southwest of the mine, 20 feet of shale are exposed above the Milliken sandstone.

Down the gulch, several hundred yards farther west and perhaps 200 to 300 feet geologically below the Milliken sandstone, in a darker, but slightly yellowish sandstone, one *Sphaeriola ? cordata* (M. & H.)and a number of *Callista owenana* M. & H. were found. Half a mile to the westward the irregular sandstone noted northwest of Bulger is exposed. A mile northward the Milliken sandstone draws down to the creek bottom, where it is underlaid by dark shales. Proceeding northward, the Laramie formation is found swinging westward. Coal is exposed in a one or two foot vein in various places, overlaid by concretionary sandstone. West of Meadow Spring ranch *Ostrea glabra* M. & H. occurs in abundance on the slope east of Spottlewood Creek. Above the oysters a coal outcrop was noted, overlaid by 40 feet of shale and very light-yellowish sandstone.

ROUND BUTTE DISTRICT

Round Butte is fourteen miles north and two miles west of Wellington. North of the butte a bluff, bounding a mesa, extends for a long distance southeast and west. It is capped by a coarse, red conglomerate, with a calcareous cement, which is either Tertiary or Pleistocene. It contains large pieces of fossil wood, and lies unconformably upon the upturned edges of middle and upper Montana strata. Gravel on top of the mesa includes large chert pebbles containing Mississippian fossils. The Hygiene sandstone member of the Pierre Group, in its northward extension from Fort Collins, may be traced by numerous exposures through the butte and on northward until it passes beneath this bluff. Half a mile east of the butte the dip is 58° southeast. At the sharp point of the mesa two and one-half miles east of the butte the Fox Hills sandstone dips 9° N. 53° E. The Hygiene sandstone just south of the butte dips 54° N. 58° W. It contains large, hard concretions, as at Fossil Ridge, south of Fort Collins. These concretions yielded the following fossils:

Nucula sp.
Inoceramus barabini Morton
Inoceramus sagensis Owen
Inoceramus oblongus Meek
Inoceramus vanuxemi M. & H.
Avicula linguiformis E. & S.
Avicula nebrascana E. & S.
Ostrea patina M. & H.
Tellina scitula M. & H.
Modiolus meeki E. & S.
Mactra gracilis M. & H.
Callista deweyi M. & H.
Teredo? burrows in wood
Dentalium gracile H. & M.
Cylichna sp.
Chemnitzia? sp.
Margarita nebrascensis (M. & H.)
Anchura haydeni White
Fasciolaria cf. culbertsoni (M. & H.)
Anisomyon shumardi M. & H.
Anisomyon patelliformis (M. & H.)
Anisomyon subovatus (M. & H.)?
Capulus spangleri Henderson
Baculites compressus Say
Baculites ovatus Say
Scaphites nodosus Owen
Turrilites sp.
Reptile tooth

Inoceramus sagensis Owen was found also at the foot of the bluff directly north of the butte. Fox Hills strata occupy the bluff and slope of the mesa from one and a half to two and a half miles east of the butte. About half way up the mesa, where the talus slope passes into the bluff, the following fossils were obtained several years ago:

Halymenites major Lx.
Bryozoa undetermined
Serpula markmani Henderson
Nucula cancellata M. & H.
Avicula haydeni H. & M.
Ostrea glabra White?
Crenella elegantula M. & H.
Callista owenana M. & H.
Veniella humilis (M. & H.)
Spheriola? cordata (M. & H.)
Sphaeriola? cf. endotrachys Meek
Cardium speciosum M. & H.
Crassatella cf. cimarronensis White
Baroda subelliptica White
Tellina scitula M. & H.
Mactra formosa M. & H.
Mactra warrenana M. & H.
Dentalium gracile H. & M.
Gastropods undetermined
Pyrifusus newberryi M. & H.?
Anchura americana E. & S.
Actaeon concinna H. & M.
Cylichna scitula M. & H.
Cylichna volvaria (M. & H.)
Lunatia subcrassa (M. & H.)
Chemnitzia? sp.
Odontobasis sp.
Fasciolaria cf. culbertsoni (M. & H.)
Scaphites nodosus Owen
Fish scales
Shark tooth
Reptile tooth

The sandstone forming the bluff is yellowish, gray and white, massive below, less so above. These fossils were obtained just below the Milliken sandstone. About two and a half miles east of the butte shales, apparently Laramie, overlie the sandstone.

WILDCAT MOUND

This is the prominent hill on the west side of the South Platte River, near the mouth of the St. Vrain, two miles west and five miles north of Platteville, hereinbefore referred to in the quotations from Stevenson's reports, where he erroneously supposed the marine strata to be geologically above the Platteville coal. It is much dissected by erosion, thus affording an excellent exposure of the Milliken sandstone, capped by a remnant of Laramie, overlaid by a few feet of conglomerate, probably Pleistocene, on the highest point, which is somewhat more than 200 feet above the bed of the river. The dips average less than seven degrees, north of east, hence follow approximately the slope of the country, which results in exposures at intervals along the river for many miles down stream.

At the base of the bluff south of the highest point twenty feet of dark-gray to black shales and thin, soft sandstone layers are exposed, as at Windsor, passing upward abruptly into the massive, more or less greenish-yellow Milliken sandstone, which forms the greater part of the hill. This sandstone we estimated at about 100 feet in thickness. Within about 50 feet of the top of the hill the sandstone gives way to shales, containing selenite, which in turn are overlaid by an irregular, cross-bedded sandstone, containing *Ostrea glabra* M. & H. in great abundance, with a very few specimens of *Corbicula cleburni* White, *C. fracta* Meek, *C. macropistha* White, *Anomia micronema* Meek, *Halymenites major* Lx., and large pieces of fossil wood. These fossils indicate the Laramie age of this upper horizon. The Fox Hills-Laramie contact is discussed under the Windsor district.

The Milliken sandstone contains numerous large, iron-stained concretions and some highly fossiliferous bands, which are more or less calcareous and ferruginous. Some of them are fairly matted with the *Halymenites major Lx.,* a marine alga. In addition to this, the following species were obtained from this sandstone at this locality:

Nucula planimarginata M. & H.
Ostrea sp.
Pholadomya subventricosa M. & H.
Tancredia americana (M. & H.)
Cardium speciosum M. & H.
Tellina scitula M. & H.
Baroda subelliptica White
Mactra alta M. & H.
Teredo? burrows in wood
Lunatia subcrassa M. & H.
Melania wyomingensis (Meek)
Fasciolaria? sp.
Physa sp.
Gastropoda undetermined
Placenticeras intercalare (M. & H.)
Corax sp.
Lamna sp.
Fish vertebrae
Reptile teeth

This is the type locality of White's *Baroda subelliptica.* The leaf bed mentioned by Stevenson in his report we failed to find.

THE PLATTEVILLE DISTRICT

Iron-stained concretions resembling those of the Milliken sandstone occur on the slope east of the town, below the coal horizon.

Farther up the slope, to the south, is the Platteville coal mine, sometimes known as the Johnson mine. The material from the shaft consists of arenaceous clay and soft, grayish sandstone, quite unlike anything we found in the upper Fox Hills horizon of the Montana Group. The gentleman in charge of the property informed us that there are here two coal seams aggregating four feet in thickness, separated by eighteen inches of clay, and that ten feet or more of clay overlies the coal, containing fossil shells. The timbering of the shaft prevented access to the shell horizon. In the first gully to the north, about half a mile distant, coal is exposed which, from its position, is likely at the same horizon. It is immediately underlaid by a ten-foot exposure of soft, weathered, white sandstone, and overlaid by a thin sandstone containing poorly preserved dicotyledonous leaves, and an unidentified palm leaf. The Greeley topographic sheet indicates that this coal and the top of the marine beds on Wildcat Mound are at about the same altitude, and the dips show that the Milliken sandstone should pass well beneath the coal. This conclusion is confirmed by the observed relations near Milliken and in other localities, and by the fact that if the massive Milliken sandstone overlies the coal at Platteville or elsewhere, as asserted by Stevenson, surely many remnants of it would be found above the coal somewhere in the large territory examined. To the eastward the whole country is a rolling prairie, with gentle slopes and few rock exposures. Loose, fine sand prevails, with debris in some places which indicates weathered Arapahoe conglomerate. A mile south of the Black Prince mine, about fifteen miles northeast of Platteville, a thin sandstone exposed in an irrigating canal bank resembles the one below the coal at Platteville. The coal here occurs up the slope to the northeast, with easterly dip of six degrees. South of the Black Prince, the Farmers' mine reaches the upper coal vein 72 feet below the surface, the lower one 24 feet farther down, each about two feet in thickness. A well drilled to a depth of several hundred feet failed to reach any coal below the second vein. In this neighborhood the White Ash mine was also in operation, while several others within a radius of a few hundred yards were abandoned. In the dump of a new shaft we found *Anomia micronema* Meek, *Corbicula* sp., *Corbula subtrigonalis* M. & H. and *Melania wyomingensis* (Meek). At the bottom of the shaft the dip is six degrees east. In the Farmers' mine a six-inch band of fossiliferous shale 35 feet below the surface contained poorly preserved fossils of the same species as those last mentioned. Just below the surface a fifteen-foot bed of very soft sandstone occurs, below which clay shales extend down to the coal.

THE MILLIKEN DISTRICT

The Milliken sandstone exposure of Wildcat Mound is interrupted in its northward extension by the flat alluvial valley of Thompson Creek and its tributary, the Little Thompson. It reappears on the north side of the valley in the bluffs near the station of Milliken. Here, as at Wildcat Mound and Windsor, an exposure of from 20 to 25 feet of dark-gray shales and soft sandstone layers begins at the base of the bluff and extends down beneath the alluvium of the valley. Above this horizon is the greenish-yellow, concretionary, Milliken sandstone. It is much thinner here than at Wildcat Mound and Windsor, not averaging more than fifty feet in thickness. It is cross-bedded in places, and at the base contains a few very thin shale layers as at Windsor. It yielded the following species:

Membranipora sp.
Nucula cancellata M. & H.
Nucula sp.
Yoldia cf. evansi (M. & H.)
Ostrea glabra M. & H.
Tancredia americana M. & H.
Cardium speciosum M. & H.
Baroda subelliptica White
Tellina equilateralis M. & H.?
Mactra alta M. & H.
Mactra formosa M. & H.
Pachymya? herseyi White
Lunatia subcrassa (H. & M.)
Melania wyomingensis (Meek)
Pyrifusus ? cf. newberryi (M. & H.)
Actaeon prosocheila (White)
Cylichna scitula M. & H.
Dentalium gracile H. & M.
Shark teeth

The specimens originally described by White as *Pachymya herseyi* were from the mouth of the St. Vrain, the Cache la Poudre Valley and near Morrison, and the mouth of the St. Vrain (probably Wildcat Mound) is the type locality of *Actaeon prosecheila.*

Up the slope northward from the bluff, shales overlie the sandstone, and from 100 to 150 feet up in the shale is an abandoned coal mine, about six miles due west of LaSalle. From the material on the dump and its position it appears to be at the same horizon as the Platteville coal. Almost certainly the Laramie extends clear across the top of the divide between the Thompson and the Cache la Poudre from the top of the Milliken sandstone to the top of the same sandstone in the bluff southeast of Windsor.

THE WINDSOR DISTRICT

South of the Cache la Poudre extensive exposures of upper Montana strata occur. South and southwest of Windsor a thick series of clay shales, sandy shales and soft, shaly sandstones is dissected by numerous gullies in the steep slope bounding the valley. Calcareous concretions abound. This portion of the formation represents the lower Fox Hills of the Boulder Bulletin and Denver Monograph. It is mostly dark gray or somewhat yellowish, much darker than the Milliken sandstone and otherwise quite different. Only a few unidentifiable fragments of marine fossils, including *Mactra* sp., were found here.

A steep thirty-foot cliff on the south bank of the river, four miles southeast of Windsor, exposes, as at Wildcat Mound and Milliken, dark gray to black clay shales and thin sandstone layers, some of the latter with a slight yellowish tinge. At the top of the cliff and at the same horizon along the bluffs for some distance are somewhat calcareous concretions containing many *Veniella humulis* (M. & H.), a species not found at all in the overlying sandstone. These concretions yielded the following species:

Bryozoa undetermined
Nucula planimarginata M. & H.
Avicula nebrascana E. & S.
Anatina doddsi Henderson
Crenella elegantula M. & H.
Pholadomya subventricosa M. & H.
Veniella humilis (M. & H.)
Sphaeriola? cordata (M. & H.)
Cardium speciosum M. & H.
Tellina scitula M. & H.
Callista owenana M. & H.
Mactra cf. warrenana M. & H.
Mactra gracilis M. & H.?
Mactra alta M. & H.
Dentalium gracile H. & M.
Lunatia subcrassa (M. & H.)
Pseudobuccinum nebrascense (M. & H.)
Fasciolaria sp.
Pleurotoma contortus (M. & H.)
Cylichna scitula M. & H.
Scaphites conradi (Morton)
Scaphites nicolleti (Morton)

At the top of this shale-sandstone series is a ten-foot band of nearly black clay shales, passing abruptly upward into the light greenish-yellow Milliken sandstone. The latter in the lower part contains a few seams of clay about an inch or less in thickness. These soon disappear, leaving only the clear sandstone above. This abrupt change from dark shales and thin sandstones to the clear, massive, greenish-yellow sandstone is so marked in nearly all good exposures of the localities thus far discussed, as to leave no doubt as to the exact lower boundary of the Milliken sandstone. Above, the boundary is almost as well marked, though the gentle slope and the debris from the overlying softer formation usually obscure the contact. A short distance above the Milliken sandstone a few specimens of *Halymenites* and an undetermined bryozoan were found. The latter also occurs below the Milliken. Probably the contact of the marine Fox Hills formation and the Laramie is in the soft clay-sandstone slope above the bryozoan horizon, the Laramie in all probability covering the divide to the southward and southeastward. The few upper exposures of the slope consist of black to dark gray clay shales, with some thin sandstones, the latter having a yellowish cast, unlike the greenish yellow of most of the Milliken sandstones. Some of the clay strata contain plant fragments.

The Milliken sandstone is here nearly 150 feet in thickness and contains the usual large, brown concretions. It yielded the following fossils, which are easily recognized in the matrix, but usually very soft, and thus difficult to remove from the rock in recognizable condition, though some excellent specimens were obtained:

Halymenites major Lx.
Ostrea glabra M. & H.
Tancredia americana (M. & H.)
Cardium speciosum M. & H.
Tellina scitula M. & H.
Tellina equilateralis M. & H.
Mactra alta M. & H.
Pachymya? herseyi White
Lunatia subcrassa (M. & H.)
Melania wyomingensis (Meek)
Cylichna scitula M. & H.
Cylichna volvaria M. & H.
Gasteropods undetermined
Placenticeras intercalare (M. & H.)
Shark teeth
Fish scales

CROW CREEK VALLEY

To western paleontologists Crow Creek, northeast of Greeley, is classical ground. The Laramie strata and fauna of the valley have been discussed at some length by White.[35] On page 164 of his report he gives the following section:

		Feet
1.	Sandy soil or debris of the plains	10
2.	Grayish siliceous marl	5
3.	Sandy and calcareous layers; with *Corbicula*, etc.	3

[35]White, C. A., "Report of Paleontological Field Work for the Season of 1877," U. S. Geol. & Geog. Surv. Terr. (Hayden Survey), 11th Ann. Rept. (for 1877), pp. 163-175, 1879.

4.	Soft, sandy and argillaceous material; with *Ostrea* and *Anomia*	5
5.	Arenaceous rock, somewhat concretionary; with numerous fresh-water forms	2
6.	Arenaceous marly strata	20
7.	Carbonaceous shale	6
8.	Gray siliceous marl	6
9.	Carbonaceous shale	3
10.	Gray siliceous marl	25
11.	Unexposed to the surface of the creek	5

He lists the following 24 species from the valley, this being the type locality of those marked with a star, the fossils all being from layers No. 3 and No. 5:

Anomia micronema Meek
Anomia gryphorhynchos Meek
Ostrea glabra M. & H.
*Modiolus regularis (White)
*Anodonta parallela White
Unio sp.
*Corbicula cleburni White
*Corbicula obesa White
*Corbicula cardiniaeformis White
Corbicula subelliptica M. & H.
Corbicula fracta Meek
*Corbicula macropistha White
Corbicula planumbona Meek
Corbula subtrigonalis M. & H.
*Bulinus disjunctus White
Bulinus subelongatus M. & H.
*Physa felix White
Goniobasis gracilenta M. & H.
Goniobasis nebrascensis M. & H.
Melania wyomingensis (Meek)
*Viviparus prudentia White
Tulotoma thompsoni White
Campeloma multilineatum M. & H.
Corydalites fecundum Scudder

In this connection it may be also mentioned that South Platte Valley is the type locality of *Corbicula augheyi* White, *Corbicula berthoudi* White, and *Corbicula umbonella* Meek. East of Cornish, on the east side of the valley, we obtained the following:

Ostrea glabra M. & H.
Anomia micronema Meek
Modiolus regularis (White)
Corbicula cleburni White
Corbicula umbonella White
Corbula subtrigonalis M. & H.
Melania wyomingensis (Meek)

The *Melania wyomingensis* were here much the largest I have seen. All the fossils here were below a thin coal seam. Southeast of Cornish, on the east side of the valley, east of the trees some years ago occupied by a heron colony, we obtained:

Ostrea glabra M. & H.
Anomia micronema Meek
Corbicula cleburni White
Corbicula obesa White
Corbicula macropistha White
Corbicula cardiniaeformis White
Corbicula berthoudi White?
Corbicula fracta Meek
Corbula subtrigonalis M. & H.
Viviparus plicapressus White
Viviparus prudentia White
Campeloma multilineatum (M. & H.)
Tulotoma thompsoni White
Melania wyomingensis (Meek)
Goniobasis tenuicarinata (M. & H.)
Goniobasis gracilenta Meek
Physa sp.
Aplexa? disjuncta White

A mile east of Fosston, on the east side of the valley, we obtained:

Ostrea glabra M. & H.
Anomia micronema Meek
Corbicula cleburni White
Corbicula augheyi White
Corbicula planumbona Meek
Corbula subtrigonalis M. & H.

At an abandoned reservoir dam on the creek, about two miles north of Fosston, we obtained:

Corbicula cleburni White
Corbicula berthoudi White
Corbicula fracta Meek
Corbicula planumbona Meek
Corbicula augheyi White
Modiolus regularis (White)
Viviparus plicapressus White?
Campeloma multilineatum (M. & H.)
Melania wyomingensis (Meek)

Thin coal outcrops are abundant on the east side of the valley and in the minor gullies on the divide to the eastward, usually or always in close association with *Corbicula* and *Ostrea,* generally above these fossils, though in some cases, at least, fossiliferous strata were also found above the coal. Time did not permit a determination of the question as to whether there is more than one coal seam.

THE OSGOOD DISTRICT

Osgood post office is about 22 miles east and six miles north of Greeley, well up the slope north of the South Platte River. Greasewood Lake, a little over two miles southeast of the post office, is one of the completely landlocked, shallow, flat-bottomed "ephemeral lakes" so common on the plains of Colorado. It desiccates in dry seasons, and never contains much water. At the time of our visit it contained about a foot in depth of very alkaline water, the water surface being about a quarter of a mile in diameter. The thick lacustrine deposits about the edge of the lake and their fossil contents are indicative of a long cycle of greater precipitation or less evaporation at no very remote period. We could find no living animals or plants in the lake, but the shore deposits to a height of five feet or more above the present water level contain multitudes of shells of fragile mollusks, of species still living elsewhere in Colorado, and other animal remains, mostly in a good state of preservation, as follows:

Physa sp.	Succinea grosvenori Lea
Planorbis trivolvis Say	Succinea avara Say
Planorbis parvus Say	Sphaerium sp.
Lymnaea caperata Say	Crayfish forceps
Lymnaea palustris Mull	Rotten fish scales?

All except the *Succineas* are fresh-water forms, and *S. grosvenori* may be considered semi-aquatic, being found along the muddy shore line of ponds and sluggish streams. *Lymnaea palustris,* although common in the mountain lakes to the westward and the permanent lakes with tributaries and outlets west of Greeley, we have been unable to find alive in the state east of Greeley. This fauna could probably not live in the lake under present conditions. To give these species such a foothold as they once had here, and build up a thick shore deposit containing the shells of many generations, the lake must have, for many years, contained water to a considerable depth, with at least occasional periods of overflow, to prevent excessive salinity. There are a number of reasons for belief that within 2,000 years there has been a slight change of climate in the Southwest, resulting in the desiccation of the region. The change, if any, has not been great, but with precipitation at the stress point, it would take but very little to vitally affect faunas and floras.[36] Whether such a change is attributable to fluctuations of solar radiation, which are known to take place, or to some other cause, is not settled, but that climatic changes have taken place frequently in the geologic past is well known. As the question of climatic changes within comparatively recent times and the possibility of other changes in the near future is an important one, it is advisable that all evidence bearing in any way upon the problem be placed on record. Hence it may not be out of place to here record some other observations of the same nature as the

[36]Henderson, Junius, and Robbins, Wilfred William, "Climate and Evidence of Climatic Changes," U. S. Bur. Ethn., Bull. No. 54, pp. 43-70, 1913.

one just noted. In 1911 I visited a lake about twelve miles northeast of Rabbit Ears, in North Park, and found it to be very shallow and alkaline, probably desiccating in very dry seasons. No living creatures whatever were found in the water, but on the shore were numerous shells of *Physa gyrina* Say, *Lymnaea palustris* Mull. and *Succinea grosvenori* Lea. The bank of a dry ravine on the east side of Wildcat Valley, north of Fort Morgan, contains shells of *Lymnaea palustris* Mull. and *Succinea retusa* Lea (another shore-loving species) in abundance. Even allowing for great changes in topography, it is difficult to conceive of permanent water having existed there long enough to produce such a deposit under present climatic conditions, even aside from the fact that this species of *Lymnaea* has not been found alive in that vicinity. Just below Greenacre ranch, northwest of Fort Collins, the excavation for a ditch has exposed a deposit filled with *Physa* cf. *forsheyi* Lea. No *Physas* were found alive in that region, though live *Lymnaea caperata* Say and *Planorbis parvus* Say were abundant in a pool not far distant, and no shells of either *Lymnaea* or *Planorbis* were found in the *Physa* deposit. The most significant case, however, is that of Greasewood Lake. Some marked changes in the aquatic molluscan fauna have been observed as a result of irrigation. Thus in Lodgepole Creek some years ago a number of species of Unionidae were found living, by Simpson. A recent search failed to bring to light a single specimen except of one species. This is likely due to the fact that irrigation has taken all the water at times and has thus destroyed the other species. There is no possibility of applying that theory to the cases enumerated above, however, and at least in case of Greasewood Lake no explanation suggests itself except that the basin is not now as well supplied with water as it was not many hundreds of years, or perhaps even not many decades ago.

Exposures of Fox Hills strata are traceable back on the divide almost to the road which runs eastward from Osgood, but not so far back on the higher ground to the westward. Typical Fox Hills concretions weathering from the rock south and southwest of Greasewood Lake yielded the following marine species:

Halymenites major Lx.	Tellina scitula M. & H.
Nucula sp.	Mactra sp.
Cardium speciosum M. & H.	Dentalium cf. gracile H. & M.
Baroda subelliptica White	Lunatia sp. M. & H.

To the east, north and west of Osgood, *Ostrea glabra* M. & H. and various species of *Corbicula* may be found almost anywhere, weathered out on the surface of the ground. Coal outcrops are plentiful, usually about eighteen inches thick, and so far as we ascertained only one vein. It has been more or less mined in various places in open banks for use of near-by farms. The coal generally lies above the best fossil horizon.

Four miles north of east from the post office we found:

Ostrea glabra M. & H.
Anomia micronema Meek
Modiolus regularis White
Corbicula cardiniaeformis White

The type locality for both *Modiolus regularis* and *Corbicula cardinaeformis* is Crow creek, fifteen miles above its confluence with the South Platte. Six miles north of east from Osgood we obtained:

Corbicula cardiniaeformis White
Corbicula cleburni White
Corbicula obesa White
Melania wyomingensis (Meek)
Planorbis sp.

About four or five miles northeast of Osgood is a coal outcrop at an old stone corral. Down the gully a quarter of a mile or more is a highly fossiliferous outcrop a few feet in thickness, one stratum a foot thick being crowded with *Corbicula cardiniaeformis* White. This locality yielded the following species:

Ostrea glabra M. & H.
Anomia micronema Meek
Mytilus sp.
Modiolus regularis (White)
Corbicula cleburni White
Corbicula cardiniaeformis White
Corbula subtrigonalis M. & H.

Four miles west of Osgood *Corbicula augheyi* White was found in large numbers.

COTTONWOOD SPRING DISTRICT

Cottonwood Spring is at the head of Cottonwood Draw, about fifteen miles N. 20° E. from Orchard. Typical Fox Hills concretions and occasional exposures of sandstone occur on both sides of the draw. The concretions yielded:

Halymenites major Lx.
Cardium speciosum M. & H.
Mactra warrenana M. & H.
Dentalium gracile H. & M.
Micrabacia cf. americana Meek

At Cottonwood Spring the section is as follows:

		Feet
1.	Soft sandstone, irregularly gray, white, yellowish and reddish, with at least one harder, thin-bedded sandstone a few inches thick, and one *Halymenites* concretion band, all containing ferruginous nodules, about	50
2.	Sandstone filled with *Ostrea glabra*	1
3.	Clay and sandy shale	8
4.	Thin-bedded, dark-brown, flaky shale	4
5.	Soft sandstone, gray above, iron-stained yellow streaks and spots below	15
6.	Clay with thin sandstone layers to bottom of gulch	15

The upper sandstone is here very regularly bedded and forms cliffs from 10 to 30 feet high. Two miles east it is strongly and irregularly cross-bedded. At the top is a rather persistent cone-in-cone zone. Chert fragments up to two feet in diameter lie upon the divide and upper slopes of the gulch, evidently weathered from a post-Laramie formation, likely the Arapahoe conglomerate. Some small remnants of a conglomerate are found in the region. Horizon No. 3 yielded the following:

Ostrea glabra M. & H.
Anomia micronema Meek
Corbicula cleburni White
Corbicula fracta Meek
Corbula subtrigoualis M. & H.
Melania wyomingensis (Meek)
Reptile tooth

This fauna indicates the Laramie. The shales and sandstones of Nos. 5 and 6 yielded a Fox Hills marine fauna, as follows:

Nucula planimarginata M. & H
Baroda subelliptica White
Cardium speciosum M. & H.
Turritella? sp.

These two horizons doubtless represent the shales and sandstones overlying the Milliken sandstone at Wildcat Mound, Windsor and other localities. Nothing referable to the Milliken is exposed here, erosion not having yet cut deeply into the formations to reach it. If it occurs it is covered by the later deposits.

THE WILDCAT CREEK DISTRICT

Wildcat Creek is an intermittent stream flowing in a southeasterly direction and entering the South Platte below Fort Morgan. The boundaries of its valley in the lower stretches are gentle slopes, becoming more abrupt and higher upstream. About nine miles north from Fort Morgan, lower Fox Hills shales containing selenite and concretions are exposed on the southwest side of the valley, but we found no fossils here. Upstream a short distance, just below the North Fort Morgan (Jack Pot) ditch we found:

Veniella humilis (M. & H.)
Pholadomya subventricosa M. & H.
Lucina occidentalis (Morton) ?
Tellina scitula M. & H.

It is worthy of note that nowhere except five miles west of Fort Morgan have we found *Lucina cleburni* White, and nowhere have we found *Cantharus julesburgensis* White. They were described from "the vicinity of Julesburg."

This horizon is below the Milliken sandstone, the material being just such as lies below that formation at Windsor. At the head of small draws some three miles farther north typical greenish-yellow Milliken sandstone was found exposed to a thickness of about 15 feet, just above *Lucina* sp. and *Nucula sp.* The divides between gulches are usually strewn with large pebbles of jasper, chalcedony, silicified wood and other debris, probably derived from weathering of Tertiary conglomerates, perhaps the Arapahoe formation.

BIJOU CREEK VALLEY

We did not visit the valley of Bijou Creek, but White visited the valley many years ago and described it, recording the following species of Laramie fossils:[37]

Anomia micronema Meek
Ostrea glabra M. & H.
Corbicula obesa White
Corbicula subelliptica M. & H.
Corbicula macropistha White
Corbicula planumbona Meek
Corbula subtrigonalis M. & H.
Melania wyomingensis (Meek)

THE CANTON DISTRICT

The bluff southeast of town resembles the one southeast of Windsor in the character of the deposits exposed. An irrigating canal passes along the foot of the bluff. Just above the ditch is

[37]White, C. A., "Report of Paleontological Field Work for the Season of 1877," U. S. Geol. & Geog. Surv. Terr. (Hayden Survey), 11th Ann. Rept., for 1877, pp. 189-191, 1879.

an exposure of twenty feet of dark shales, abruptly above which is soft, yellowish Milliken sandstone occupying the upper part of the bluff and slope above for twenty feet or more to the top, with some thin, harder layers. Debris from the weathering of this sandstone also occurs some distance up the more gentle slope for a mile back from the river. We were informed that back on the divide water was obtained by drilling down to this sandstone. The only fossils we found in the bluff are one *Tellina scitula* M. & H. and an undetermined marine gastropod which occurs in this sandstone at a number of localities. Below the bluff is a Pleistocene conglomerate, usually unconsolidated but in some places hard and coarse, which was evidently formed at some time during the cutting, refilling and recutting of the South Platte Valley. Southwest of Canton, back some distance from the river, at the edge of the valley, from 75 to 100 feet at least above the Milliken sandstone bluff, is a light gray, hard sandstone, containing numerous ferrruginous nodules, which may be Laramie. Chalcedony pebbles are numerous on the higher ground, perhaps from the weathering of Arapahoe conglomerate. This phenomenon is quite general on the divides both north and south of the river throughout this region.

THE WELDON DISTRICT

Below Weldon the north slope of the valley is thickly strewn over large areas with varicolored jasper, chalcedony, quartz, quartzite, chert, silicified wood and other such debris. At the bluff just above the railroad track is an exposure of fifteen feet of sandstone, containing large concretions, overlaid by fifteen feet of shales, including a selenite zone. No fossils were found, but it is evidently lower Fox Hills. Well up the gentle slope five to six miles northeast of town concretions evidently belonging to the strata below the Milliken sandstone yielded:

Protocardia subquadrata (E. & S.) ?
Lunatia cf. subcrassa (M. & H.)
Scaphites nicolleti (Morton)

About five miles nearly due north of the town, a greenish-yellow sandstone, evidently Milliken, yielded:

Halymenites major Lx.
Cardium speciosum M. & H.
Mactra alta M. & H.
Lunatia cf. subcrassa (M. & H.)
Fasciolaria sp.

THE MESSEX DISTRICT

A low bluff a mile or so below the station exposes 15 feet of light colored sandstone, sandy shales and thin, dark clay shales just above the railroad track. It yielded one *Nucula* cf. *planimarginata* M. & H. and a fragment which appears to be *Lucina* sp. This is evidently a lower Fox Hills horizon.

THE STERLING DISTRICT

In a half day spent north of Sterling nothing was observed except Tertiary clays and coarse sandstones and conglomerates. There were rumors of striking coal in sinking wells a few miles to the northwest, which would not be at all improbable.

THE CROOK DISTRICT

A half day north of the river in this locality brought under observations only Tertiary clays, coarse sandstones and conglomerates, the latter containing in some places many fragments of mammal bones.

THE JULESBURG DISTRICT

No Cretaceous rocks come to the surface and not very good exposures of Tertiary were noted. The high ground south of the river is thickly covered with well rounded jasper, chalcedony, silicified wood, etc., besides fragments evidently derived from the mountains.

HISTORY OF SOUTH PLATTE VALLEY[38]

The excavation of the South Platte Valley probably began in late Tertiary or early Pleistocene time. The valley was excavated to a considerable depth, the river valley at LaSalle being now several hundred feet below the divides to the south and north. It was then refilled to a depth of from at least 50 to 200 feet or more, with sand and gravel. In some places the deposits were afterwards well consolidated, but usually they are unconsolidated or only loosely so. Then a second period of erosion began and continued until the valley assumed its present condition. This leaves the Pleistocene sands and gravels exposed in many places in more or less abrupt bluffs, where they are sufficiently compact to stand. This may be well studied in West Denver. At Goodrich, above

[38]See also Henderson, Junius, "Topographic Development of Chalk Bluffs and Pawnee Buttes," Proc. Colo. Sci. Soc., VIII, pp. 247-256, 1907.

Fort Morgan, the prominent bluffs south of the river are composed of river sand, rather fine and regularly bedded, not consolidated but compact enough to stand in nearly vertical walls. About 40 feet are exposed in the bluffs, with over 20 feet more in the talus sloping to the river. These deposits through the greater part of the valley mantle the slopes and prevent good exposures of the underlying Cretaceous rocks. The sand and gravel in most places extend below the level of the river, and usually good water may be obtained by sinking wells through the sand nearly to the Cretaceous shales, which are nearly impervious. Near Canton the gravels are consolidated into a well-marked conglomerate, as has been already noted in discussing that district.

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THE FOOTHILLS FORMATIONS OF NORTH CENTRAL COLORADO[1]

BY JUNIUS HENDERSON

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.[2] Fossils found both north and south of this area in formations supposed to be synchonous 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 farther 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

[1]The following paper is revised and reprinted from the First Report of the Colorado Geological Survey, 1908. The numbers in parenthesis refer to the bibliography at the end of the paper.

[2]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.

Professor R. D. Crawford, Dr. James Underhill, Mr. G. S. Dodds, and Mr. B. H. Jackson. Mr. H. W. Clatworthy assisted 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. 3, 4 and 5). 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 prominent headlands 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 Bellvue 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

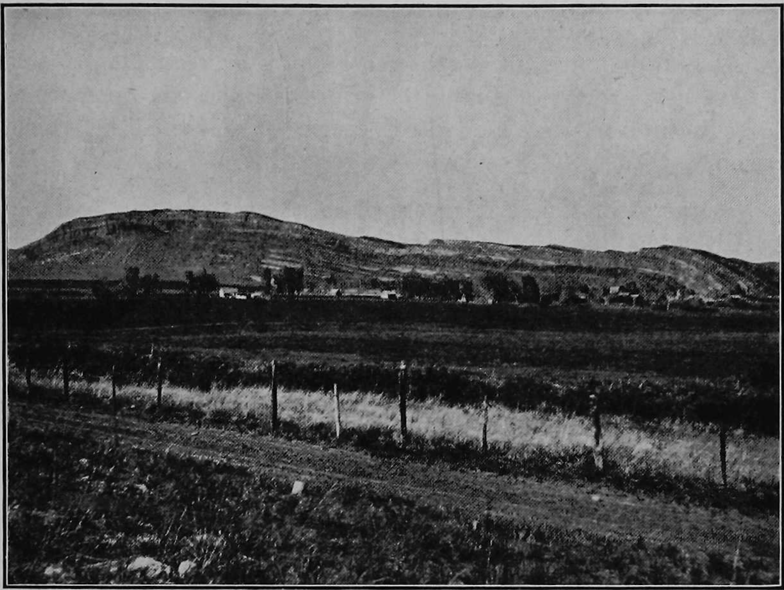

Fig. 1. Bellvue fold, looking north of east, with the village at south end of fold. Lyons formation at the top of cliff, Fountain at the base.

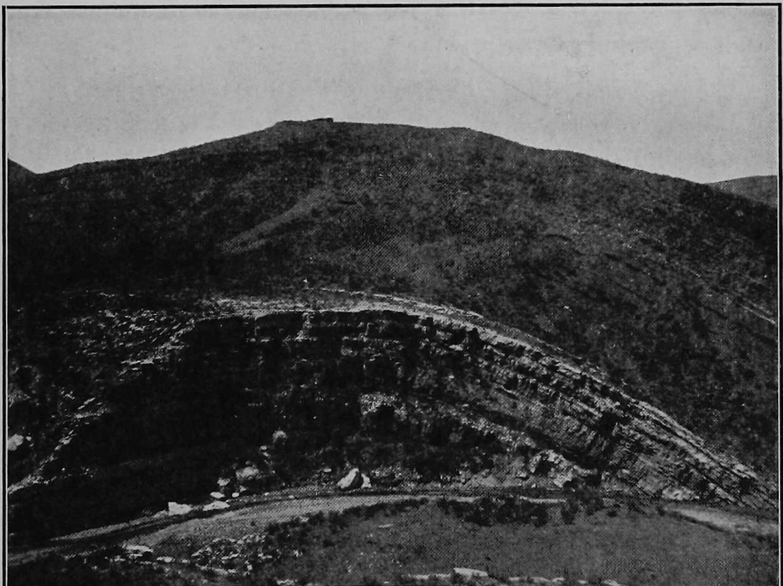

Fig. 2. Sand Creek fold, looking south. The cliff is the Lyons formation, with a little Fountain at the base, and the Lykins sloping upward from the top of the cliff to the top of the hill.

the granite 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 remnants, 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 angle 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 details 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.

Though portions of the formations are evidently of non-marine origin, neither deformation nor erosion produced strongly marked differences in dips.

STRATIGRAPHY

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

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

These 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 and Lyons of this region are now known to be Pennsylvanian, the lower Lykins Pennsylvanian or Permian.

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 toadstool 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 farther north, rests some distance down its east slope, and the valley, instead of cutting into the Fountain, as it does farther north, cuts into the granite or the granite-Fountain contact. (Compare Figs. 3, 4 and 5.)

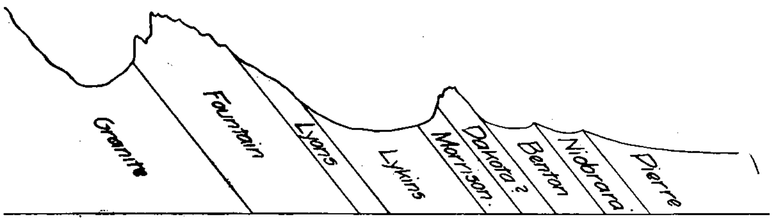

Fig. 3. Generalized section at Boulder.

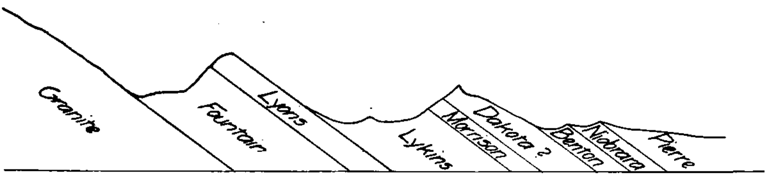

Fig. 4. Generalized section in Northern Larimer County.

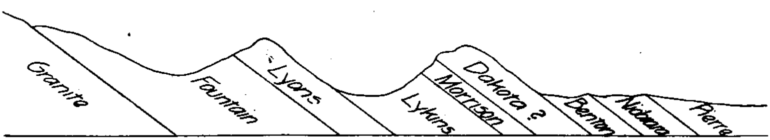

Fig. 5. Generalized section at Left-Hand Creek.

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 Fort 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 Lefthand Creek and at some other places we find a compromise, the upper Fountain being non-resistant, with a resultant valley, while the lower Fountain is resistant and extends well up the granite slope of the mountains, as shown in Fig. 5. 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 suspicion that the lower deposits in such places may be Lower Carboniferous. 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 farther 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 types 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[3], 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 overlying "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

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

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 Bellvue: *Retzia woosteri, Spirifer rockymontanus, Spiriferina octoplicata, Spirigera subtilita, Hemipronites crenistria, Axophyllum rudis* 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 follow: *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.

Such fossiliferous Mississippian pebbles are also found on the plains at Round Butte, north of Wellington, and a few have been found in the lower "Dakota" conglomerate. In southwestern Colorado, Mississippian pebbles are common in the McElmo and "Dakota" conglomerates.

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 probably equivalent to part 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 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.

A re-examination of this material and reconsideration of the whole subject, since the original publication of this report, convinced me that these nodules were derived from the destruction of Mississippian limestones, no remnant of which can now be found exposed. Mr. R. M. Butters, at my request, visited the locality in 1910, and his investigation led him to the same conclusion. This disposes of the problems suggested on pages 161 to 164 of the original publication of this report.

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.

The conglomerate itself with its fossiliferous pebbles derived from destruction of Mississippian strata in northern Colorado, suggests a probable widespread unconformity between the Mississippian and Pennsylvanian of Colorado.

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 then 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 Carboniferous, but its occurrence at this horizon points strongly to the Pennsylvanian age of the Fountain beds near Manitou."

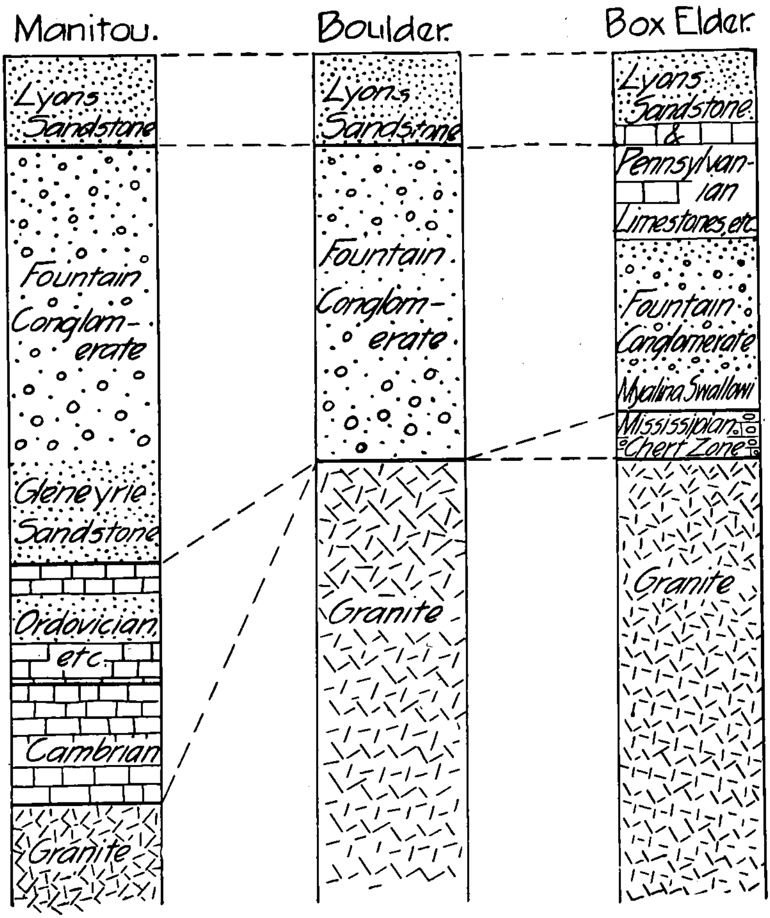

Fig. 6. Generalized geologic columns from granite to Lyons sandstone at Box Elder, Boulder and Manitou.

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 strata supposed to be 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 Gleneyrie, 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 strata thus referred to the lower 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 I 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, 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. Of this I am not so certain. From Boulder to the Cache la Poudre these two formations are sharply differentiated, and neither contains any impor-

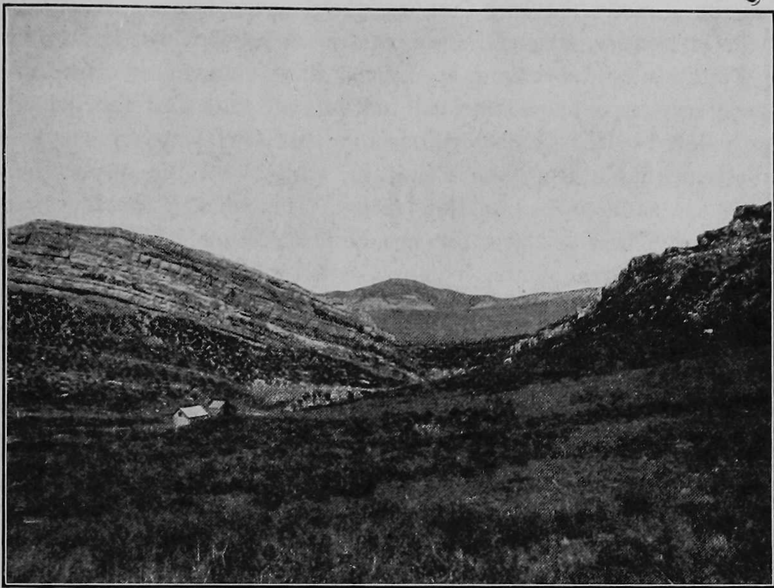

Fig. 7. Looking east through Owl Canyon. The ridge in the foreground is crowned by Pennsylvania limestones, with Fountain conglomerates at the base.

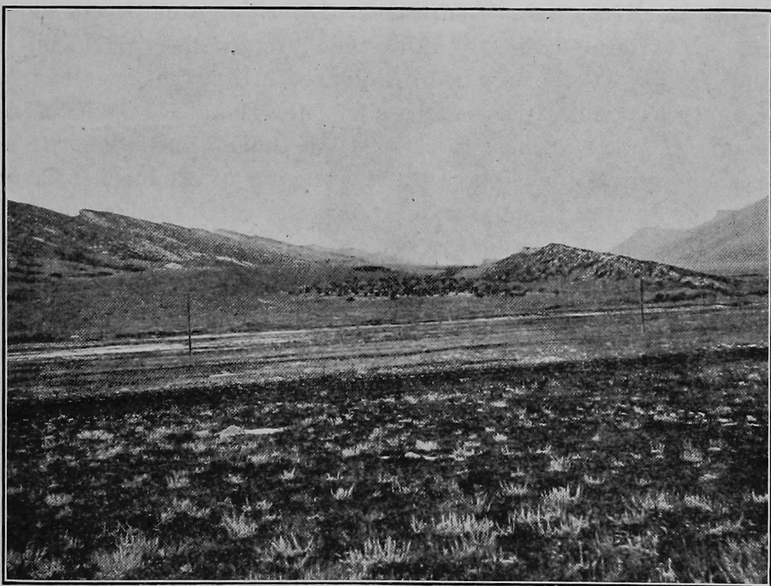

Fig. 8. Ridge making, cross-bedded sandstone in the lower part of the Lykins formation, south of Owl Canyon, looking north, with Carboniferous limestone ridge on the left, and Dakota-Morrison escarpment showing dimly on the extreme right.

tant 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 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.[4] 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 Fourmile 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 characteristics 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,

[4]This is quite contrary to Butter's interpretation, based upon work done since the publication of this report. (Colo. Geol. Surv., Bull. 5, pp. 68-70, 83-84.)

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 lith-

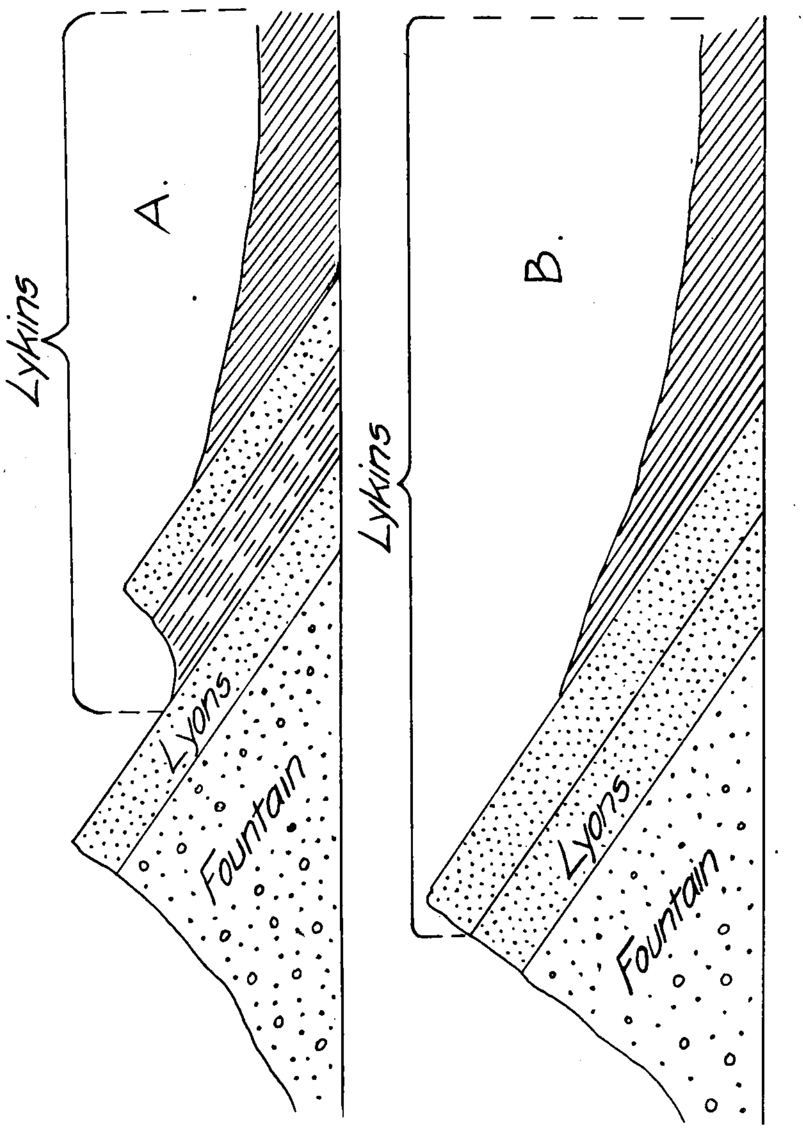

Fig. 9. A. East-West section, showing ridge of cross-bedded sandstone in the Lykins formation west of Fort Collins. B, showing apparently the same sandstone crowning the Lyons escarpment north of the Little Thompson.

ologically 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 Lykins and making the former the crest of the escarpment, almost covering the latter. (See Fig. 9.) 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.[5]

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 Beloden, 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.*

[5]Since the foregoing was published, Butters has worked in this region, and in his report (Colo. Geol. Surv., Bull. 5, pp. 68-70, 83-84), he correlates this upper cross-bedded sandstone underlaid by red shales with Fenneman's Lyons sandstone, describes the lower sandstones as the Ingleside formation, and says that the latter "plays out just north of Lyons."

*Since this was published Butters has found, 200 to 300 feet above the base of the Lykins, several well-known Pennsylvanian fossils, besides some new ones, and on the strength of the fossils Girty has tentatively correlated the lower Lykins with the Rico formation of Southwestern Colorado, sometimes designated as Permo-Carboniferous. (Butters, Colo. Geol. Surv., Bull. 5, pp. 84-85; Girty, Annals N. Y. Acad. Sci., XXII., pp. 1-8, 1912.)

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, including yellowish sandstones, follows 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 farther south (9, p. 82).

In the Box Elder District above the characteristic soft, deep-red shales and sandstones of the Lykins is a harder, massive sandstone, 100 feet or more in thickness, pink in the lower half, grading through yellowish to creamy-white above, which probably includes the beds referred to the Sundance by Darton. It is discussed by Butters in pages 70 and 71 of his report. It has a tendency to form cliffs, in places weathering into rounded forms, especially southward. It occurs at least as far south as Loveland, but is absent in the Boulder District, where the Morrison rests directly upon deep-red Lykins sandstones. Its absence at Boulder may represent a not easily detected unconformity.

JURASSIC OR CRETACEOUS

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 or part of 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 strong conglomerate at the base of the "Dakota" along the foothills, resting upon the finer sediments of the Morrison suggests an unconformity at the top of the Morrison also. This idea is emphasized by a recent discovery east of Arkins, where Professor P. G. Worcester found a 60-foot conglomerate overlaid by several feet of variegated shales such as are usually found in the Morrison. The shales disappear within a mile to the northward, bringing the conglomerate into contact with the supposed basal sandstone of the Dakota in a steep cliff. This vicinity deserves a more careful examination than we have been able to give it.

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.

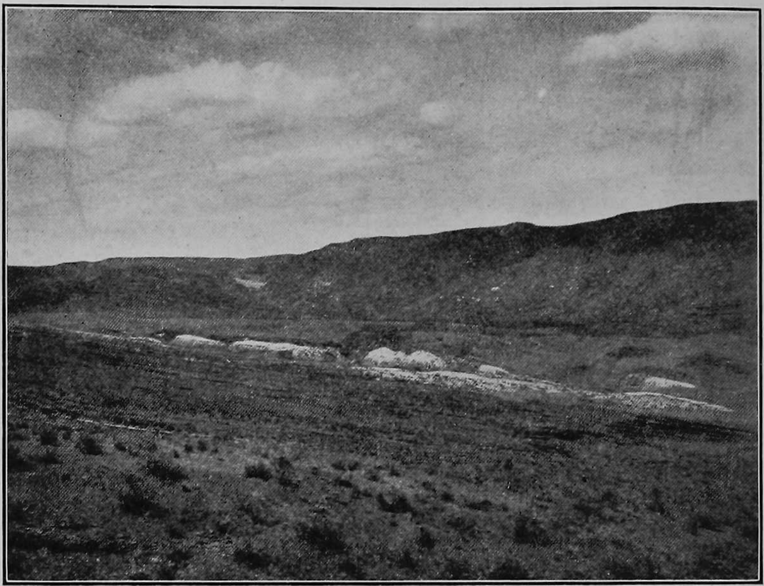

Fig. 10. Gypsum beds in the Lykins formation, southeast of Box Elder post-office, looking northeast.

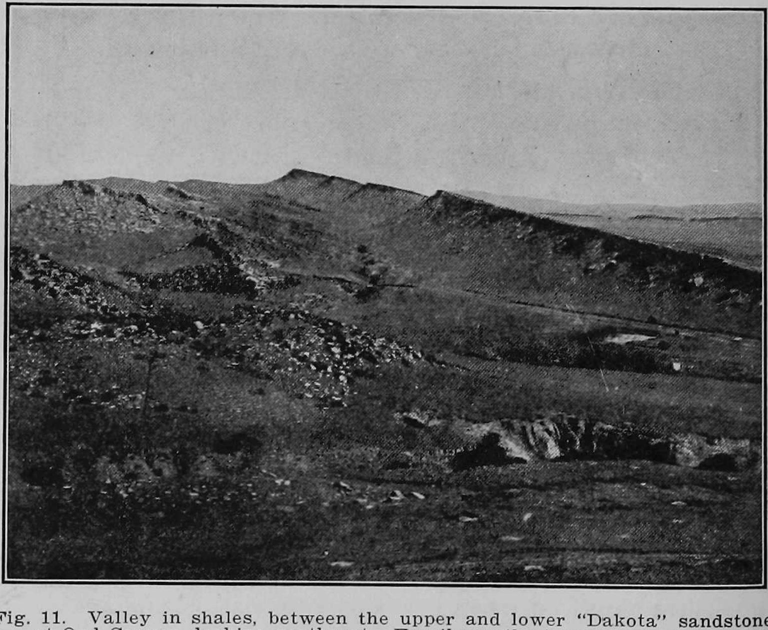

Fig. 11. Valley in shales, between the upper and lower "Dakota" sandstone, at Owl Canyon, looking northeast. Fossils on the inner slope of the right hand ridge.

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 Darton, 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 hog-back 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 at certain horizons 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 vertebrae.

In 1920 we found marine algae (Halymenites) in the upper sandstone at the mouth of Little Thompson canyon and ten miles north of Boulder. This genus also occurs in the Pugnellus (Upper Benton) sandstone in Huerfano Park, in the sandstone at the top of the Benton at Trilby and in the upper Fox Hills sandstone at many Eastern Colorado localities, almost invariably associated with marine invertebrates.

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 southward, but we have found in it no organic remains except casts of supposed worm borings and seaweeds (*Halymenites*). 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, the attached value of 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 principal *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 (23, pp. 99-104; 24, pp. 149-152; 26, pp. 184-192).

Laramie Formation.[6]—This formation, consisting of sandstones 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

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

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.

QUARTERNARY

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.[7] 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

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

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

Clay.—Fire clay is found in the "Dakota" and Laramie. The former has been used extensively at Golden. West of Fort 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 Fort 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 probably 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 probably 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 perhaps continued through Lykins time, though probably parts of these formations are subaerial (Vail, 36-A). During Morrison and perhaps part of Lyons, Lykins and "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 nearest 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 set 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.

It is sometimes assumed that the Cretaceous and pre-Cretaceous formations of Eastern Colorado once extended across what is now the Continental Divide into Middle and North Parks (see Lee, Geologic Story of the Rocky Mountain National Park, 1917, p. 16, fig. 2). Grave difficulties stand in the way of accepting that theory. If true, whence came the coarse material composing the "Dakota" conglomerates and the much coarser material of the Fountain? Other pertinent questions are unanswered. Subsidence at a rate not equal to the rate of deposition, perhaps proceeded even during non-marine epochs, so that the subsequent marine beds are not marked off by distinct angular unconformities.

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 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. 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 it is now known to be Pennsylvanian.

The lower part of the Lykins is considered late Pennsylvanian or Permian.

No evidence has been found bearing upon the age of the upper part of the Lykins formation 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 lower 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-Cretaceous 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 perhaps 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 fresh-water deposits. Vail (36-A) has discussed the evidence of climatic pulsations and subaerial origin of portions of the Lyons and Lykins formations. 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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INDEX

COLORADO GEOLOGICAL SURVEY
BOULDER

R. D. GEORGE, State Geologist

BULLETIN 20

Preliminary Notes on the Revision of the Geological Map of Eastern Colorado

By
W. C. TOEPELMAN

BOULDER, COLORADO
1924

GEOLOGICAL BOARD

LETTER OF TRANSMITTAL

State Geological Survey,
University of Colorado, October, 1924.

Governor William E. Sweet, Chairman, and Members of the Advisory Board of the State Geological Survey.

Gentlemen: I have the honor to transmit herewith Bulletin of the Colorado Geological Survey.

Very respectfully,

R. D. GEORGE,
State Geologist.

PRELIMINARY NOTES ON THE REVISION OF THE GEOLOGICAL MAP OF EASTERN COLORADO

INTRODUCTION

During the past year there has arisen a great need and demand for a revision of the present geologic map of Colorado. Because of this it has seemed advisable to place in bulletin form a brief synopsis of new information at hand, and to place before the interested public a preliminary map of the eastern part of the state where experience has shown considerable revision to be necessary.

The data upon which the present report and map are based have been derived from many sources. The major portion of the information has been derived from field work done under the supervision of the Colorado Geological Survey. Publications of the United States Geological Survey have been consulted freely and where the areal geology is known to be essentially correct, the results have been incorporated in the present work.

FIELD WORK

The field work of the Colorado Survey has been spread over a considerable period and has been supervised by several workers. The area included between the 103d and 104th meridians and the 37th and 38th parallels was mapped by a party in charge of J. T. Duce. In 1921 a party consisting of A. J. Tieje, J. C. Myers, and A. N. Murray covered an area included in T. 24, 25 and 26 S., R. 53 and 54 W. The remainder of an area included between T. 21 and 26 S., R. 53 and 57 W. was mapped in 1922 by Dr. Horace B. Patton and party. In 1923 a party under the direction of the writer completed the mapping of Crowley and western Otero counties. During the past field season two parties were employed in making a rather rapid study of the areas where revision has been shown to be urgent. One party, under the direction of Mr. J. W. Vanderwilt, covered a considerable area in Baca County, the region from southern Cheyenne County (east of R. 50 W.) north to the state line and from the parallel 40° 30′ to the state line west to the foothills. The second party, under the direction of the writer, mapped the territory from the southern boundary of Lincoln County to the northern line of Morgan County and from R. 50 W. to approximately R. 68 W. A considerable portion of the latter territory, included roughly between the tracks of the Union Pacific and the Chicago, Rock Island and Pacific Railroads, was mapped a number of years ago by G. B. Richardson of the United States Geological Survey and has not been studied again. As noted below, however, some additional study of an area east of the town of Kiowa is contemplated in an effort to determine the existence of beds of Raton age.

GEOLOGY

In the course of the work outlined above, the following formations have been studied in more or less detail:

Tertiary:		
Miocene-Pliocene ?	Arikaree, Ogallala, Nussbaum, Mapped as a unit	125 feet
Oligocene	White River	0-140 feet
Eocene	Arapahoe?	?
Cretaceous:		
	Laramie	0-400 feet
Montana group	Fox Hills	400-700 feet
	Pierre	2000-5000 feet
Colorado group	Niobrara	700 feet
	Benton	390 feet
Dakota group	Dakota	100 feet
	Purgatoire	160 feet
Jurassic:		
Morrison formation		150-270 feet
Permian-Pennsylvanian	"Red Beds"	365 feet

Only a brief summary of the lithologic character of the beds can be given in this paper, the detailed description being reserved for a later and more complete publication. For more detailed descriptions of the formations of the foothills of north central Colorado and the Cretaceous of the northeastern part of the state, the reader is referred to Bulletin 19 of the Colorado Geological Survey by Prof. J. Henderson.

DESCRIPTION OF FORMATIONS

PALEOZOIC

Permian-Pennsylvanian: The oldest formations exposed in eastern Colorado outcrop along the Purgatoire River and Chaquaqua Creek in T. 28, 29, 30 S., R. 56, 57 and 58 W., and consist almost exclusively of red beds. J. T. Duce in an unpublished manuscript described two distinct members at the junction of Chaquaqua Creek with the Purgatoire River, the Chaquaqua member below and the Red Canyon member above. The Chaquaqua is described as being 122 feet in thickness and consisting of brick red to purplish sandstone and red to maroon colored sandy shale and shale. The Red Canyon member consists of 240 feet of maroon sandstone, oolitic in structure and probably of eolian origin. Above this member Duce describes 60-65 feet of gypsum, gypsiferous clays, and grey sandy shale transitional to the Morrison. Part of this zone should perhaps be included in the Morrison formation.

JURASSIC?

Morrison formation: Following the past practice of the Colorado Geological Survey, the Morrison is here considered as Jurassic, though there is as good evidence for placing it in the Cretaceous. The formation occurs at the surface, east of the foothills, only in the valleys and canyons of the upper portions of the Purgatoire River and Rule Creek drainage systems in southeastern Otero, northeastern Las Animas, and southwestern Bent Counties. Lithologically, the Morrison is an extremely variable formation, sections from nearby areas often showing few to no similarities either in character of beds or color. In the outcrop area in southern Colorado, the formation consists chiefly of rather brightly colored shales and sandstones with intercalated thin limestones and a basal conglomerate. Greens, reds, purples, and chocolate brown are the predominant colors. The sands are, in general, but poorly indurated. Gypsum is found near the base in most places and, according to Duce, is always overlain by beds containing abundant chalcedony nodules. Bones of dinosaurs are usually present. Though least important in the makeup of the formation, the limestones are the most resistant members and give origin to most of the topographic features in the region of outcrop. In thickness, the Morrison is said to vary from 150 to 270 feet.

CRETACEOUS SYSTEM

DAKOTA GROUP

The Dakota group, consisting of the Purgatoire formation and Dakota sandstone, occurs at the surface in eastern Colorado in an area south and slightly north of the Arkansas River and in the foothills region. In the latter, the Dakota group is not generally separated into distinct units with separate names, but the same tri-partite arrangement as described below has been recognized in most places.

Purgatoire formation: The lower member of the Dakota group is composed of 160 feet or more of white and yellow sandstone with some 15 to 30 feet of grey shale and flaggy quartzitic sandstone at the top. The lower 100 feet consists of massive, coarse grained, rather soft white sandstone. This is overlain by 30 to 40 feet of yellowish sandstone grading up into the shale and quartzite series noted above. Marine fossils are reported in limited numbers from the yellow sandstone and from the shale series. The shale member here undoubtedly corresponds to that which separates the two sands in the Dakota formation in the foothills, and is probably to be correlated with the Fuson shale of the Black Hills region.

According to Duce, the Purgatoire thickens westward into the Apishapa quadrangle, where 220 feet are reported by Stose in the Apishapa Folio of the United States Geological Survey. Patton, in his work on the Otero County sections, found the top of the Purgatoire sandstone to be marked by a distinct ledge formed by a bed, five to six feet thick, more resistant than the underlying sands.

Dakota sandstone: The true Dakota in southern Colorado is made up of approximately 100 feet of hard, thick to thin bedded, light grey to buff, locally white, quartzitic sandstone. It is usually finer in grain and much more firmly cemeted than the underlying Purgatoire. Locally the color may become dark brown. Duce reports that the Dakota yields considerable fossil wood and imperfect leaves in places, whereas only marine invertebrates occur in the lower member. In the foothills region, marine fossils have been found in the formation in several places.

The two formations in the Dakota group are the most important members of the geologic column from an economic standpoint. In the Arkansas Valley and elsewhere in eastern Colorado, the group is the source of artesian water. Both members yield water, the Purgatoire being the "second Dakota", the Dakota the "first Dakota sand" of well drillers. In north central Colorado, the Dakota group forms the reservoir for the oil and gas in the Ft. Collins region. It is the opinion of the writer, Prof. Henderson, and others that the the so-called Muddy sand of the oil geologist is the true Dakota as described in the type area in South Dakota and that the lower member of the group is the equivalent of the Purgatoire of the Arkansas Valley and the Lakota-Fuson of the Black Hills region in Wyoming and South Dakota.

COLORADO GROUP

Benton Subgroup: The Benton formation is divided into three members, the Graneros shale below, the Greenhorn limestone and the Carlile shale above. Because of the limited areas covered by the thinner members, and the difficulty in showing each separately on a small scale map, the three units are mapped together here. The following description, however, gives the chief characteristics of each member.

Graneros shale: The Graneros shale is a body of 200 to 210 feet of medium to dark grey bluish shale. The central portion is dark grey to black, the lower and upper portions are distinctly lighter in color. Some forty feet below the top occur several thin beds of grey, platy, sandy limestone, the thickest bed being about a foot thick. Some 85 feet above the base is a three-foot bed of Bentonite. Crystals of selenite gypsum are common near the base. The Graneros weathers easily and except when protected by the overlying Greenhorn limestone, does not often appear in outcrops. Because of the limited areas where the shale has been mapped separately, its surface distribution is included with that of the entire group on the accompanying map. In general it occurs only in the Arkansas Valley and its tributaries to the south in Otero, Bent and Prowers counties.

Greenhorn limestone: Overlying the Graneros is a series of alternating bluish grey limestones and darker grey shales, fifty to sixty feet thick. The limestone layers vary from three to twelve inches in thickness and comprise about one-third of the total thickness of the formation. They are fairly hard and break into angular blocks as a result of thickly crowded vertical joints. The limy layers are much more resistant than the intervening shales and tend to form benches along valley sides.

The exact limits of the formation are often difficult to determine because of the gradation into the overlying and underlying shales. The largest outcrop areas occur on the south side of the Arkansas River from just south of La Junta eastward to Las Animas, in Bent County. A narrower strip occurs north of the river along most of the area of Benton outcrop and also on the valley sides of the tributaries to the Arkansas from the south in Bent and Prowers Counties.

Carlile shale: The upper division of the Benton group consists of 125 to 225 feet of shales, medium grey in color in the upper and lower portions and greyish black in the middle. About 20 to 30 feet below the top the shale becomes slightly sandy and contains numerous large roundish concretions measuring from two to five or six feet in diameter. The top of the Carlile in the Arkansas Valley is a greyish crystalline limestone weathering to a rusty brown color and measuring from two to fifteen feet in thickness. It is very fossiliferous, the fossils consisting mainly of small oyster shells, (*Ostrea lugubris*), and casts or impressions of strongly ribbed, coiled ammonites, (*Prionocyclus wyomingensis*). This top limestone is, perhaps, the most resistant rock in the Arkansas Valley from Apishapa Creek eastward and it forms most of the pronounced buttes, benches, and escarpments in the region south of the Arkansas River.

This member has been described as a sandstone by Darton, Fisher and Stose in the region embraced in the Nepesta and Apishapa Quadrangles. Patton and the writer, however, have found it to be a distinct limestone in Otero and Bent counties, and the writer finds that the limy nature continues for some distance west into the Apishapa Quadrangle. Sand is introduced even in the region south of La Junta, but at no place studied as far west as R. 61 W. can the rock be called a sandstone. There is little doubt that the rock becomes more sandy and thicker westward and in the foothills region north into Wyoming, the top of the Carlile is distinctly a sandstone.

The Carlile appears at the surface in eastern Colorado chiefly south of the Arkansas River from the foothills to the state line. The larger streams, as the Purgatoire and Rule Creek, have cut through it and removed the formation from a large area north of the Mesa de Maya in Las Animas, southeastern Otero and southwestern Bent counties. From the Apishapa River east, the Carlile forms the bottom of valleys and arroyos and the lower portion of escarpments capped by the Timpas limestone. The formation occurs on the flats of the Arkansas Valley about La Junta where it extends slightly north of the river along Horse and Adobe Creeks.

Niobrara subgroup: The Niobrara consists of two distinct members in eastern Colorado, the Timpas limestone, averaging 200 feet thick, and the Apishapa shale, 500 feet thick above. The two members are mapped as a unit, since separate mapping has been completed only over rather limited areas. The formation occurs at the surface in southern Colorado over a broad area south of the Arkansas River east into Otero County, whence it swings north in a broad band through northern Otero, southern Crowley, most of Kiowa and most of eastern Cheyenne Counties. In the latter two counties, the Tertiary covers large areas and hides the Niobrara. In Kiowa County, it seems probable that most of the surface before Tertiary times had Niobrara as the chief exposed rock. A small area occurs on Black Wolf Creek in Yuma County south of Wray.

Timpas limestone: Although the name Timpas limestone has been applied to the entire thickness of the lower member, only the lower fifty feet can be properly designated as limestone. This consists of soft, whitish limestone of very compact texture in layers from a few inches to several feet thick. The layers are separated by thin films or one or two inch bands of dark grey shales. The rock weathers into thin, rough slabs and chips with the cleavage planes parallel to the bedding. Large individual shells of *Inoceramus deformis* occur in most places. The surface of these shells is usually well covered with the masses of *Ostrea congesta.* The contact of this limestone member with the Carlile is usually sharply defined, but east of La Junta Patton reports it difficult to separate the Timpas and Carlile limestones, due to the fact that the latter becomes lighter in color and seems to grade into the former.

The basal limestone passes gradually into some 150 feet of limy shale, prevailingly light grey in color, but locally dark grey and even almost black at the top. Intercalated with the shales at different horizons are thin beds of limestone similar to that at the base. At the top of the member occur thicker white to yellowish limestones, which split readily into thin layers and leaves. Fossils similar to those in the basal limestone also occur in the higher horizons.

Apishapa shale: Conformably overlying the Timpas are some 500 feet of highly calcareous shales called the Apishapa shale. The lower 50 to 75 feet are dark bluish grey in color. These are followed by shales of similar color that weather into papery flakes. The central portion is much lighter and distinctly more sandy in character; the upper is much darker. Locally, the shales develop into impure limestones a foot or more thick. Upon exposure, the Apishapa weathers into a pronounced light yellow color, which in itself is often enough to identify the formation.

The shale is characterized from top to bottom, both in the unoxidized dark parts and the weathered portions, by an abundance of minute whitish specks. They are usually visible to the unaided eye and are easily seen with a lens in all specimens taken. With dilute hydrochloric acid, the shale effervesces freely and the tiny white spots disappear. They would appear, therefore, to be calcite. This was verified by Patton after an examination of thin sections under the microscope.

Fossils occur sparingly throughout the formation. *Ostrea congesta* upon an undetermined large species of *Inoceramus* is most abundant, but fish scales, shark's teeth, fragmentary skeletons of fish and a few other forms occur.

No sharp line of demarcation between the Pierre and Apishapa has been found. Over most of the Arkansas Valley the contact is covered by recent sands and alluvium and the lines drawn upon the map are only approximately correct.

MONTANA GROUP

Pierre formation: The Pierre shales outcrop over considerable areas in Crowley and Lincoln Counties in the drainage basins of the larger streams, notably in the Horse Creek-Pond Creek basin in Crowley and southern Lincoln Counties, in the Sand Arroyo of Lincoln and Cheyenne Counties and along the Big Sandy Creek from the vicinity of Hugo south and east into Cheyenne County. In these areas, the complete thickness of the formation is exposed, but limited outcrops preclude the possibility of measuring the thickness with any degree of accuracy. In central Morgan, northeastern Adams and western Washington Counties, occur several hundred feet of beds which are here referred to the upper Pierre or, better, to the so-called "Transition series" between the Pierre and Fox Hills.

In the southern outcrop area noted above, the total thickness of the formation probably does not exceed 2200 feet and may be considerably less in places. An indefinite three-fold division has been noted by several workers, but detailed investigation shows that any attempt to subdivide the formation is fruitless. The lower 400-600 feet consist of dark grey to black shale, with much gypsum and some thin limestone lenses and concretions near the top. The lower beds are practically barren of fossils and contain little calcium carbonate except in concretionary forms. The upper part of this lower series is much stained by iron, and passes into a middle zone with abundant limonite concretions. Because of the abundance of iron concretions, the weathered outcrops of the middle 600 feet present a distinct yellow brown or rusty appearance and this is called the "Rusty Zone" by Darton and others. Lime concretions and fossils are rare in the zone. The remaining portion, some 1000 feet in thickness, is characterized by an abundance of limestone lenses which, because of greater resistance to weathering, give rise to numerous tepee buttes, particularly in the lower few hundred feet of the zone. These buttes contain an abundance of fossils, notably *Lucina occidentalis*, *Baculites ovatus*, *Scaphites nodosus* and *Inoceramus barabini*. The shales of the zone are predominantly dark grey in color, with a few bands of light grey, and others almost black color.

The question of thickness of the Pierre in various places in eastern Colorado could not be settled during the present field work. In the foothills region Henderson, Fenneman and others report thicknesses of from 4000 to 7000 feet at a maximum in sections from near Pueblo north to the Wyoming line. To the east the formation is undoubtedly much thinner, but the amount of thinning is open to question. All lines of evidence from well logs indicate a maximum of from 1800 to 2200 near Ordway, 2000 feet near Akron, about 2000 feet near Sterling, and, according to verbal reports, 2500 feet in western Nebraska near the state line. No additional proof of eastward thinning was secured. There can be no question of the thinning eastward from Pueblo into Crowley and Cheyenne Counties, but similar thinning in the region to the north up to the South Platte Valley is problematical.

Though an attempt has been made to separate the Pierre and Fox Hills in the mapping, the work of the past summer has served only to emphasize to the writer the utter impossibility of establishing a boundary that is not open to severe question. Between the typical upper Pierre shales and the arenaceous shales of the Fox Hills, as recognized in Colorado, are several hundred feet of transitional shales containing a mixture of Pierre and Fox Hills faunas, but which are lithologically inseparable from either formation. It is beds of this nature that are mapped in southern Morgan, northeastern Arapahoe and western Washington Counties as Pierre, but except that *Inoceramus fibrosus* and allied forms occur in abundance there is no basis for the line of contact as shown other than topography. To the writer, the simplest procedure seems to be to limit the use of the term Fox Hills to the upper sandstone, the Milliken, where it is typically developed, and to group the underlying shales and sandy shales with the Pierre under the term Montana Group.

Fox Hills: This upper division of the Montana group occurs at the surface over considerable portions of Elbert, Arapahoe, Adams, and Washington Counties between R. 53 and 58 W., (except that an area of Pierre will be shown from the South Platte south to the middle of T. 3 S. in R. 54, 55, and 56 W.). Outcrops of Fox Hills occur also on both sides of the South Platte from eastern Morgan County west to Greeley. In the valley proper a heavy mantle of dune sand and alluvium hides the formation.

The character of the Fox Hills is sufficiently well known so that no detailed description need be given here. Near the foothills the transitional beds from the Pierre are overlain by from 800 to 1000 feet of sediments becoming progressively more sandy toward the top which is marked by the Milliken sandstone of Henderson. Overlying the Milliken sandstone near Windsor and Milliken, (Wild Cat Mound), is a thin series of sandy shales transitional to the Laramie which may or may not be part of the Fox Hills.

East of Greeley the nature of the formation is notably different. Except in one or two places north of Weldon, (T. 6 N., R. 59 W.), the Milliken cannot be recognized and the entire thickness consists of alternating greyish, arenaceous shale, yellow brown to white sandstone, usually in thin beds, and sandy purple brown concretionary limestone. The thickness assigned, not more than 400 to 500 feet, depends entirely upon the thickness of the transitional shales included with the Fox Hills at the base, and the plane where the Fox Hills-Laramie contact is placed. The latter, however, can be located within rather narrow limits in most places. The outstanding characteristic of the Fox Hills east of R. 65 W. is the great abundance of purplish brown concretions of limestone and the decidedly lower proportion of sand contained in the formation. In the easternmost exposures studied, in the vicinity of Brush, the formation is distinctly a shale with some sand and suggests the possibility that under the Tertiary to the east the formation would entirely lose its identity and be inseparable from the Pierre except on a strictly faunal basis. Faunal studies are as yet very incomplete, but the faunas also seem to suggest that in eastern Colorado the Fox Hills does not exist as a separate member of the Mountain Group.

LARAMIE

The Laramie coal-bearing formation is exposed over most of the surface west of R. 58 W. from a point a few miles south of the Chicago, Rock Island and Pacific Railroad in Elbert County, north to T. 1 N., whence it swings west along the South Platte Valley. North of the river, the formation again covers a broad area from R. 58 W. to a line of cliffs, extending northwest from a point about six miles north of Greeley through R. 66, 67, 68 W. almost to the Wyoming line.

Lithologically, it is rather difficult in some places to separate the base of the Laramie from the Fox Hills. As indicated above, in the vicinity of Windsor and Wildcat Mound a thin series of shales is transitional from the Milliken sandstone to the basal sandstone of the Laramie. Along the eastern margin of the outcrop, the shale series was not seen and the white sandstone of the Laramie rests directly upon Fox Hills sands and shales. The characteristic white sandstone of the foothills region forms the base of the Laramie in the region here mapped and is overlain by several hundred feet of dark carbonaceous shales, thin iron stained sands, lignitic shale and discontinuous coal seams, with numerous thin beds made up almost exclusively of shells of *Ostrea glabra* and *Anomia micronema* in some places and various species of *Corbicula* in others. These shell beds occur at no definite horizons and cannot be used for key beds except over very limited areas.

In thickness the beds vary from slightly over 100 feet on Crow Creek to some 300 feet near Briggsdale, in Weld County, and to 400 feet or slightly more in the region south of the South Platte Valley. Thicknesses of 1800 or more are reported in Bijou Creek drainage area by White, but it is wholly probable that there were included in this section a series of beds that are now known to contain an abundance of Raton plants. This region has not been studied in detail as yet, but it is hoped that additional information will soon be available. Suffice to say here that limited collections made by Cockerell and Hubbard of the University of Colorado, and identified by Miss Grace Sandhouse, have brought to light a flora having distinct affinities with the Raton in an area mapped as Laramie.

TERTIARY

Sedimentary beds of Tertiary age cover extensive areas of eastern Colorado. Except that they cover the older formations and serve as a source of domestic and stock waters, the rocks are of little economic importance. But little time was devoted to them except to determine the contact with the earlier horizons. The oldest Tertiary seen in the field is of Eocene age, the latest, the "Nussbaum," is probably Pliocene.

EOCENE

Arapahoe formation: The present geologic map of Colorado shows a broad area of Arapahoe beds in the vicinity of Brighton, in Adams County, and extending northward in a broad tongue to T. 3 N., R. 62 W., in south central Weld County. During the past field season a very hurried reconnaissance of the area was made. Outcrops are exceedingly few and poor, and, as a result, no great change has been made in the mapping. The northern part of the area is heavily mantled with recent dune sand. The limited exposures consist of light ash-grey clays and fine to coarse sands with abundant unidentifiable plant fragments. No trace of conglomerate was discovered in the region studied, but as noted above, only a very hurried trip was made and it is quite probable that future study will show the need of revision in this region.

Denver-Dawson-Raton?: The present map shows a considerable area of Eocene beds south and east of the city of Denver. This area was covered in detail by G. G. Richardson during a study of coal deposits for the United States Geological Survey and it is assumed that the results of his work are essentially correct. No new information has been brought to light except in the Bijou Valley east of Kiowa, where, as noted above in the discussion of the Laramie, it seems probable that a series of beds below the basal conglomerate of the Dawson as generally recognized may be Raton. A detailed study of the question is contemplated in the near future and the final edition of the geologic map will incorporate any changes found necessary.

OLIGOCENE

White River: The White River formation outcrops over rather narrow areas from a point about two miles north of the south line of T. 4 S. and the line between R. 53 and 54 W., north and east through western Washington County and thence northeast through southeastern Logan County to approximately the place where the South Platte leaves the county. Thence it covers an irregular band through northern Logan and Weld counties almost to the foothills. A few outliers, too small to be mapped, occur just north of the Morgan County line and about Briggsdale.

Lithologically, the formation consists chiefly of white and vari-colored clays, marls, sands, with locally a conglomerate at the base. In some places, notably some fifteen miles east and slightly south of Brush, numerous coarse, highly cross-bedded channel sandstones are found in the lower portion. These sandstones are very firmly cemented and resistant, with the result that numerous slight escarpments are capped by them. The major portion of the formation, however, consists of easily eroded partially consolidated clay, sandy clay, and marl, the so-called chalks of the region about Pawnee Buttes and westward. The beds are often highly colored with pinks, reds, and yellows as the dominant shades. Upon erosion, the formation tends to form badlands as in the type region in South Dakota, though upon a much smaller scale. Due to the great unconformity between the White River and older beds, the thickness varies greatly from place to place; the maximum may be as much as 150 feet, the minimum as little as five or ten feet.

MIOCENE PLIOCENE?

The most extensive exposures of Tertiary deposits in eastern Colorado are those variously called Nussbaum, Arikaree, and Ogallala and assigned with some doubt to the Miocene and Pliocene epochs. No good basis for the separation of the units has been found and the same symbol is here used for the entire series. The term Nussbaum should probably be limited to the beds in the area between the Arkansas River and Big Sandy Creek; the Arikaree to the deposits along the Arikaree River; and the Ogallala to the more northerly exposures. On the whole, the Nussbaum is perhaps the coarsest in texture, but texture is at best a most unsafe guide in separating the several units.

The Miocene-Pliocene deposits cover the major portion of the surface east of a line trending in general in a northeasterly direction from almost the Arkansas River some 10 miles east of Pueblo to the Nebraska line in the center of R. 45 W. near Julesburg. Big Sandy Creek has cut entirely through the Tertiary along its whole course and exposed Cretaceous beds. The larger creeks flowing into the Arkansas from the north have also cut their valleys through the Tertiary for long distances. North of the Big Sandy valley only the larger streams have succeeded in cutting valleys to the Cretaceous, and these only near the eastern border of the state. Outliers occur at widely scattered places over much of the eastern part of the state.

The Nussbaum-Ogallala-Arikaree consist essentially of sands, sandy clays and conglomerates all partially or entirely uncemented. The coarser beds are as a rule near the base and are characterized by a great abundance of undecomposed pink orthoclase feldspar debris, varying in size from minute fragments to bits nearly an inch long. Associated are well rounded to angular pebbles of quartz and igneous materials often several inches in diameter. The sands are much finer and usually are very poorly cemented, so that enormous quantities are easily dislodged and scattered widely by winds. Because of incomplete sections no general thickness can be assigned, but it is known to vary from practically nothing, near the contacts with older formations, to several hundred feet in the vicinity of the Arikaree River. It is probable that sudden variations in thickness occur because of the great unconformity below, and because of the manner of deposition as stream debris. There seems to be little reason to doubt that most of the material was laid down by running water, as evidenced by its heterogeneity of material and its peculiar bedding from place to place.

QUATERNARY

Though no attempt has been made to map as separate units the Pleistocene and Recent sediments, it would be well to outline in a general way the distribution of the more important areas covered by the deposits.

Alluvium: Along the Arkansas and South Platte Rivers extensive deposits of stream alluvium cover all earlier beds. These vary in width from a few hundred yards to several miles and serve as a source for many of the sands to be noted below. Other less important alluvial deposits occur along the smaller streams, particularly Big Sandy, Rush and Horse Creeks, tributary to the Arkansas.

Eolian sands: Eolian sands cover large areas about the two major streams and also near the boundaries of the Miocene-Pliocene formations. The most extensive areas of sand dunes occur north of the 40th Parallel to approximately 40° 30′ north and from R. 52 W. to the vicinity of Brighton and Greeley. Though these sands are not continuous, they commonly hide the bed rock in critical areas and many of the indefinite contacts in the South Platte basin are due to sand cover. The thickness of the cover varies from a few inches to fifty feet or more. Typical sand dune topography is developed in most of this region.

Other less extensive deposits of eolian sands occur between Rush and Big Sandy Creeks in eastern Lincoln and western Cheyenne Counties. These are probably derived chiefly from Tertiary beds and hide the contact between the Tertiary and Pierre. Sands of similar origin occur in patches in southern Lincoln and Crowley Counties on and near the Nussbaum. Between the Missouri Pacific R. R. and the Arkansas River in southwestern Crowley County a large sandy area, without dunes, covers the Pierre-Niobrara contact. South of the Arkansas, though sands occur, they are less important.

Terrace deposits: Several levels of terrace gravels occur along both the Platte and the Arkansas Rivers. These are mentioned only because some of the higher deposits have previously been confused with Tertiary formations. They are, on the whole, distinctly coarser than the Tertiary gravels and less widespread in distribution.

Consolidated gravels: At widely separated places in northern and eastern Colorado, there exist thoroughly consolidated gravels and conglomerates, whose age is the subject of considerable discussion. These contain many small boulders of igneous and metamorphic rock, some pebbles of sediments found in the foothills region, and in most places large masses of silicified wood. The best known exposures on the plains are on an escarpment in T. 9-10 N., R. 67 W., at the top of Wild Cat Mound, in T. 4 N., R. 67 W., and at Point of Rocks, T. 6 N., R. 62 W. Others of similar appearance occur near the Morgan County line in Weld and Morgan Counties to the east. The preponderance of evidence to date indicates Pleistocene age for these deposits, but additional data is needed to settle the question.

AREAL DISTRIBUTION

The accompanying map incorporates all of the information that has come to light in the past decade concerning the areal distribution of the sedimentary rocks of eastern Colorado. In some places, notably south of the Arkansas River, recent field studies have shown the present edition of the Geologic Map of Colorado to be essentially correct. Such areas will be discussed only in a most general way in the following pages. Where numerous changes have been made, more detailed discussions will be given.

Upon the map, suitable letters have been used to differentiate the several formations. As noted at the beginning of the report, the map is not to be regarded in any way as a finished product, and some slight revisions of small areas may still be necessary before the final complete revision of the whole state map is issued.

PALEOZOIC

Pennsylvanian-Permian: The red beds of late Paleozoic age occur at the surface at several places in southern Colorado. The area shown about the Chaquaqua Reservoir, in Las Animas County, on the present map has been found to be approximately correct, though a trifle too large. The limits of the formation are found in the southern half of T. 28 S., R. 55 and 56 W., T. 29 S., R. 54 to 57 W., T. 30 S., R. 55 to 57 W., in the north central part of T. 31 S., R. 56 W. and the northeast corner of T. 31 S., R. 58 W. Except near the junction of Chaquaqua Creek with the Purgatoire River, the formation occurs only in narrow outcrops along the stream bottoms. A second outcrop covers a small area in T. 34 and 35 S., R. 55 and 56 W. Another small area of red beds is found in T. 35 S., R. 50 W.

The area of red beds shown in T. 28 S., R. 52 W., on the existing map was not found by Duce and is omitted here.

JURASSIC? SYSTEM

Morrison formation: As was the case with the red beds outcrops but little revision of the distribution of the Morrison has been found necessary. Such changes as have been made are of minor importance and need not be discussed in detail. The formation outcrops broadly about the headwaters of Rule Creek and the lower portion of Chaquaqua Creek in T. 26 S., R. 52 to 54 W., T. 28 S., R. 51 to 56 W., T. 29 S., R. 51 to 54 W. In T. 29 to 32 S., R. 55 to 58 W., the outcrops are confined to narrow bands below younger formation along the stream courses. In T. 33, 34, 35 S., R. 50 W., Duce has described a small area of Morrison, not shown on previous maps.

CRETACEOUS SYSTEM

DAKOTA GROUP

The lower formation of the Dakota group, the Purgatoire, occurs as a narrow band all around the Morrison outcrop area as outlined above. In but few places is the band as much as a mile wide and then only for short distances. In actual surface area covered, the Purgatoire is the least important formation to be discussed in this paper. On the accompanying map, the Purgatoire is included with the Dakota because of the fact that its outcrop area is too limited to be shown separately on such a small scale. The final edition will, however, map the formation as a separate unit.

The Dakota sandstone comes to the surface over extensive areas in southeastern Colorado from the Arkansas Valley south to the state line. It is probably present below the Tertiary over most of Baca County.

Between the 103d and 104th meridians and from T. 30 S. to the New Mexico line, the Dakota is at the surface in all places not mentioned in the descriptions given above, except where it is covered by Tertiary basalt in parts of T. 33 to 35 S., R. 51 to 56 W., and by the Nussbaum sediments in parts of T. 33 and 32 S., R. 50 and 51 W. North of T. 30 S. the surface has been more thoroughly dissected by streams and the outcrops are less continuous. Likewise the regional dip is in a northerly direction and younger formations begin to cover the Dakota near the Arkansas River. West of the Purgatoire River, the formation is at the surface in an irregular band from the north line of T. 33 S., R. 60 W., northeast to T. 26 S., R. 53 W., from which place it occurs on both sides of the stream to the city of Las Animas. A rather large inlier occurs in T. 27 and 28 S., R. 57 and 58 W. East of the Purgatoire, Dakota sandstone outcrops broadly to the 103d meridian from T. 27 S., to the south side of T. 22 S. just north of the city of Las Animas and thence east to a point a few miles east of Lamar. This represents the most northerly exposure of the formation in the plains region of the state. Between the Purgatoire and Rule Creek, a large outlier of Benton covers the divide in T. 23 to 25 S., R. 51 to 52 W. Outliers of Dakota, separated only slightly from the main outcrops, occur in T. 27 to 29 S., R. 54 to 55 W., and in the northwestern part of T. 28 S., R. 51 W.

East of meridian 103° west, no recent studies of the geology have been made north of Baca County. In the latter, Vanderwilt reports that only slight changes are required in the distribution of the Dakota. The chief change has been to make the outcrops along Horse and Bear Creeks and Sand Arroyo much narrower than on the 1913 map.

COLORADO GROUP

Benton subgroup: As was the case with the preceding formations, the Benton group of the Cretaceous is exposed only in southeastern Colorado. From T. 29 S., R. 58 W., northeast to Las Animas, the formations are found west of the Purgatoire, paralleling the stream as a band varying from three to perhaps ten miles wide. The contact with the Dakota on the east is a fairly regular line, that with Niobrara on the west is exceedingly irregular and sinuous. Isolated patches of Niobrara cover the Benton formations in several places. From about five miles west of La Junta to the 103d meridian, Benton occurs on both sides of the Arkansas. The northern boundary swings northeast along the river to T. 22 S., R. 53 W., whence it continues east along the north line of the township. The southern boundary is again irregular, the formation usually occurring below the Timpas limestone in stream valleys only. Directly south of La Junta it is found as a strip a mile or more wide through the center of R. 55 W. south into T. 26 S. Another small strip is found along the north edge of the Tertiary basalt in T. 33 and 34 S., R. 54 to 56 W. On the whole, however, no serious errors have been found in the contacts as shown on the existing map.

Niobrara subgroup: Because of the great difficulty in definitely establishing the contact between the two members of the Niobrara group, the Timpas limestone and Apishapa shale are mapped together. In general it may be said that the Timpas outcrops over less territory and is found south and east of the Apishapa. New data on the distribution of Niobrara is confined to a region between the east boundaries of the Apishapa and Nepesta quandrangles in Otero and Crowley Counties and the 103rd meridian in Bent and Kiowa Counties. It is known that considerable revision of the Geologic Map is needed in Cheyenne, Kiowa, Bent and Prowers Counties but no opportunity for field study has yet occurred.

The Niobrara-Benton contact enters the accompanying map in the north part of T. 26 S., R. 60 W., continues southeast to the north half of T. 27 S., R. 59 W., crosses the Santa Fe tracks on the west line of T. 26 S., R. 57 W., thence swings south to T. 28 S. in the same range and then northeast roughly parallel to the Santa Fe Railroad to the middle of the east line of T. 24 S., R. 54 W. From this point, the location of the contact is outlined above in the discussion of the Benton formation. The contact with the Pierre as it is shown here is open to some question, as it lies almost entirely in the irrigated section north of the Arkansas River. It enters the map just south of the Arkansas River in the middle of T. 22 S., R. 59 W., and trends slightly north of east to the Crowley-Kiowa County line in T. 20 S., R. 55 W. Here the boundary turns rather abruptly north through the west half of R. 54 W. to the middle of T. 18 N.; thence it again turns east and south to the Missouri Pacific right of way in R. 52 W. Over the whole extent of this northern boundary, no outcrop showing the actual contact has been found. In the irrigated area east and west of Ordway, a heavy mantle of recent dune sand covers all bed rock and the position of the boundary has been computed from dips measured in two or three places. It is the writer's belief, however, that the contact is as nearly correct as it is possible to make it without reliable sub-surface data.

Beds of Niobrara age have recently been reported by several workers in the central part of T. 2 S., R. 43 W., south of Wray, in Yuma County. The outlines of the outcrops have not been definitely determined, but it is unlikely that the area of Niobrara exposed is more than a few square miles. A narrow band is also found immediately above the Benton and below Tertiary basalt in T. 33 and 34 S., R. 55 and 56 W., in southern Las Animas County.

MONTANA GROUP

Because of the practical impossibility of definitely establishing a dividing plane between the Pierre and Fox Hills members of the Montana group, the letters Kp (Pierre) and Kf (Fox Hills) are inserted in areas where it is reasonably certain that faunas show the presence of the formation indicated, but the contacts are only approximate. The writer wishes again to call attention to the desirability of discarding the use of the term Fox Hills in the plains region of Colorado. Neither lithology nor faunas warrant a separation of the Montana group, and as indicated by Hayden and many others, had the beds been studied first in the mountain region, it is highly probable no distinction between Pierre and Fox Hills would have been made.

Pierre shale: Except in the vicinity of Colorado Springs, and in Cheyenne County east of R. 50 W., the boundaries of the Pierre exposures have been revised over all of eastern Colorado. The location of the contact with the Niobrara has been discussed above. The location of the boundary between the Pierre and overlying formations has been changed considerably from previous maps in many places and Pierre shale has been found exposed in places where older maps indicated younger formations.

In practically all of Crowley and Lincoln Counties, the Pierre is limited above by the Tertiary Nussbaum formation. The contact enters the map about the middle of the south line of T. 21 S., R. 59 W., where the Nussbaum forms a sharp cliff along the Missouri Pacific Railroad. It swings almost immediately north through the east half of the range and except for a few minor changes conforms to the old geologic map. In Crowley County, the only alterations found necessary are in T. 19 S., R. 58 W., and T. 17, 18, 19, 20 S., R. 56 and 55 W. In the former location, it is found that the Nussbaum occurs only in the township mentioned, whereas the former map shows the formation to extend into T. 18 S., R. 58 W. In the second area mentioned, it is found that the long arm of Tertiary extending south from the main outcrop area is much narrower than formerly shown, and instead of being an arm is really an elongate outlier occupying the divide between Horse Creek and Sand Arroyo. A smaller outlier occurs in the east half of T. 18 S., R. 55 W. The Pierre, therefore, extends somewhat farther north in this area than previously mapped.

In western Lincoln County, (T. 12 to 17 S., R. 55 to 59 W.), Pierre shale occurs only in the deeper valleys of Horse and Rush Creeks and their tributaries. The chief revision found necessary was to extend the Pierre from one to ten miles farther up stream along some of the tributary valleys. In eastern Lincoln County, the distribution of the Pierre is very different from that indicated on the 1913 edition of the geologic map. South of T. 15 S., only a few minor corrections have been noted and these can be neglected here. Beginning at about the middle of the east line of T. 14 S., R. 54 W., the Pierre-Nussbaum contact extends through the east half of the range to about Section 25, T. 12 S., thence southeast to the south third of T. 13 S., R. 53 W., and again north and west parallel to and some two to three miles west of the Big Sandy Creek to the southwest corner of T. 10 S., R. 55 W., where the Pierre gives way to Fox Hills. East of this line and south of the Big Sandy, Pierre is found over all the surface to R. 50 W., except for an area in the south half of T. 14 S., R. 51 and 52 W., and the north half of T. 15 S., R. 51 W., where it is covered by Tertiary beds. A large portion of this area is covered by dune sand, but sufficient outcrops occur to allow the location of contacts with reasonable exactness.

North of the Big Sandy, the Pierre has been found to extend considerably farther north and east than previously thought. From about the middle of T. 9 S., R. 55 W., the Pierre-Nussbaum contact extends west and south into T. 10 S., R. 52 W., and then northeast to the middle of the east line of T. 8 S., R. 50 W., northeast of Flagler, where it crosses the South Fork of the Republican and trends back on the south side of the stream to the west side of T. 11 S., R. 52 W. From this point, the contact trends southeast to the southeast corner of T. 13 S., R. 51 W. Three small outliers referred, with some question, to the Nussbaum occur in T. 13 S., R. 52 W. North of the south line of Kit Carson County and east of R. 52 W., no Pierre occurs at the surface, except narrow bands in the valley of the Arikaree River in T. 3 S., R. 43 W., and T. 1 and 2 S., R. 41 and 42 W., and on both sides of the Chicago, Burlington and Quincy Railroad immediately east of Wray in T. 1 and 2 N., R. 41 and 42 W. The formation is also reported from several localities on the South Fork of the Republican River in southeastern Yuma and northeastern Kit Carson counties.

During the past summer, an hitherto unmapped area of Pierre shale was found in southeastern Morgan, northeastern Adams and southwestern Washington Counties. Only the upper few hundred feet of the formation are exposed and, because there is a complete gradation faunally and lithologically into the Fox Hills as recognized in Colorado, no boundary line could be determined. Upon the accompanying map, the writer has shown by a broken line the probable extent of the Pierre in the region. Similar beds are reported by Vanderwilt along Pawnee and Clear Creeks in Logan County. Outcrops in all places are few and unsatisfactory, and it is probable that considerable change will be found necessary as more detailed work is done. Because of this uncertainty, no effort to discuss the boundaries will be made here.

Fox Hills formation: Beds of Fox Hills age outcrop much more extensively over eastern Colorado than indicated on previous maps. The most southern exposures studied in recent field work occur below the Nussbaum on the headwaters of Horse Creek in T. 13 S., R. 58 and 59 W., in southwestern Lincoln County. About Limon the Fox Hills occurs in the valley of Big Sandy Creek in T. 8, 9, 10 S., R. 55 to 58 W. It is covered by Tertiary beds both on the north and south. North from T. 7 S. the formation covers a broad triangular area from the divide between the Bijou and Badger Creek drainage basins in R. 58 W. to the Tertiary-Fox Hills boundary discussed in the following paragraph.

Tertiary-Fox Hills boundary: This boundary marks the eastern limit of Fox Hills exposures in the state and differs only in details from the Laramie-Tertiary contact shown on the existing map. Beginning at the southwest corner of T. 7 S., R. 57 W., the Miocene beds (Nussbaum-Arikaree) overlie the Fox Hills east of a line trending northeast to the southeastern part of T. 4 S., R. 54 W., where the White River formation of Oligocene age is introduced below the younger Tertiary. From this place on, the contact trends north in R. 54 W. to T. 2 N. and then slightly northeast to the south line of T. 11 N., R. 48 W., in Logan County. The contact parallels the South Platte in a southwesterly direction to the middle of T. 9 N., R. 52 W., and thence turns northwest through the east half of T. 11 N.,

R. 55 W. From the latter point the formation occurs only in the bottoms of the valleys of Horse Tail Creek and its tributaries in T. 9 and 10 N., R. 53, 54, 55 W. Beginning at approximately the northeast corner of T. 8 N., R. 53 W., the Fox Hills-White River boundary trends in general to the west but is very irregular about the headwaters of the tributaries of Pawnee Creek in T. 8, 9, 10 N., R. 53 to 58 W. From the middle of the north line of T. 8 N., R. 57 W., the line extends through the north half of the township to the west corner of R. 58 W., where the Fox Hills gives way to the non-marine Laramie formation.

Outliers of White River rest upon Fox Hills beds in the north half of T. 8 N., R. 53 W., in a small area in the east half of T. 10 N., R. 54 W., and in a large mass only slightly separated from the main outcrop body in T. 7 and 8 N., R. 55 to 58 W. Numerous patches of what may be White River, but too small to map, occur near the north line of Morgan County. Included here are several outcrops of consolidated gravel, the age of which is doubtful.

Laramie-Fox Hills boundary: It has long been known that the Laramie was much less extensive than shown on early maps of eastern Colorado. The contact between it and the Fox Hills first emerges from below Nussbaum beds in the middle of T. 10 S., R. 58 W., and continues in a northerly direction through the Range to T. 1 N., where it begins to turn west. In Range 58 West the contact is practically on the crest of the Bijou-Badger Creek divide. Coal beds occur in the western half of the range throughout the entire extent noted above, but except in parts of T. 8 and 9 S., the eastern half is some 200 feet lower topographically and outcrops yield marine Fox Hills-Pierre fossils in most places.

From the 40th parallel in R. 58 W. the contact is covered by dune sand. The boundary as here located is quite indefinite and has been determined largely on the basis of topography and a few scattered outcrops. As drawn the contact runs northwest into T. 5 N., R. 54 W., and thence southwest to the edge of the map in the middle of T. 2 N., R. 68 W.

North of the South Platte River, the Laramie is likewise much less extensive as the surface rock than formerly thought. The contact with the Fox Hills enters the present map on the south side of T. 11 N., R. 68 W., and continues smoothly southeast to the south side of T. 6 N., R. 64 W., some three miles north of Greeley. From this point to the middle of the east line of T. 6 N., R. 62 W., the surface is again heavily mantled with sand and alluvium and the boundary has been placed on the basis of topography. From the latter point the contact is exposed irregularly in the north half of T. 6 N. through R. 59, 60, and 61 W. From the southeast corner of T. 5 N., R. 58 W., the contact is again hidden over considerable distances but is known to extend northeast until it disappears below the White River in T. 8 N., R. 58 W. Northeast the Laramie is found only in the valleys of the major streams in T. 9 and 10 N., R. 58 W. Outliers of Laramie occur in T. 5 and 6 N., R. 61 W., and west of Greeley in T. 5 N., R. 66 and 67 W.

Laramie-Tertiary boundary: Except an area east of Brighton where it is thought beds of Arapahoe age exist, the Laramie comes into contact with the Tertiary only in Weld County, and for short distances in eastern Elbert

County. In the latter region the contact has been traced only from the middle of T. 10 S., R. 58 W. to west line of T. 11 S., R. 59 W. A small finger of Tertiary projects over the Laramie for a short distance in the southwest corner of T. 7 S., R. 57 W. In Weld County the Laramie first appears in contact with the White River in the northwest corner of T. 8 N., R. 5 W. Thence it trends westward through the north half of the township to the middle of R. 61 W., where it turns slightly northwest to the northwest corner of T. 11 N., R. 66 W., and then west to the border of the map. Small outliers of White River rest upon the Laramie in the middle of T. 7 N., R. 59 W., in the north half of T. 8 N., R. 62 W., on the line between R. 62 and 63 in T. 9 N., and in the southeast quarter of T. 9 N., R. 63 W.

Outcrops of the Laramie reported north and east of Sterling in Logan County were not seen in the course of the past season's field work and are not included on the map.

EOCENE

Arapahoe formation: The Arapahoe area in southern Weld and northern Adams Counties is left approximately as on the 1913 map. No data were found to justify any but minor alterations.

OLIGOGENE-MIOCENE-PLIOCENE?

The contacts between the later Teritary deposits and the Cretaceous formations have been sufficiently discussed above. There remains, therefore, only to mention the White River-Miocene-Pliocene (?) contact. The White River first appears below what are probably Arikaree sands in T. 4 S., R. 54 W. The contact then follows in almost the same direction as the Fox Hills-White River boundary northeast through western Washington County, southeastern Logan County, and on into Sedgwick County to T. 11 N., R. 45 W., where it crosses the South Platte and continues north to the state line in T. 12 N. The latest Tertiary beds almost immediately again reenter the state in the east half of T. 12 N., R. 46 W. and the contact between them and the White River trends in general westerly direction through T. 12 N. to the middle of R. 48 W. It then drops down in T. 11 N. and continues through it, chiefly in the north half, to the west line of R. 53 W., where it again enters T. 12 N. to R. 56 W. Thence the contact turns north through the west half of the range to the Wyoming line. The boundary once more enters Colorado just west of the east line of T. 12 N., 64 W., continues west in the south half of T. 12 N. and the north third of T. 11 N. to R. 68 W., where it leaves the map. Outliers, too small to map separately, occur in various places all along the contact as outlined above.

ACKNOWLEDGMENTS

The writer wishes to take the opportunity to acknowledge briefly the assistance and advice so freely given by Prof. Junius Henderson of the University of Colorado, Prof. R. D. George, State Geologist, Mr. Harry A. Aurand of Denver and the members of the United States Geological Survey under the direction of Dr. Kirtley F. Mather. Numerous others have aided materially in the course of the field work and in the preparation of this report. In connection with the latter acknowledgement is made of the aid of J. W. Vanderwilt, Elton Johnson, and H. A. Hoffmeister of the Colorado Survey staff.

The following publications have been used and consulted to some extent in the preparation of this paper. Specific credit will be given in the final report.

Bull. 19, Colorado Geological Survey.

Apishapa Folio No. 186—U. S. G. S.

Nepesta Folio No. 135—U. S. G. S.

Prof. Papers No. 32 and 52—U. S. G. S.

COLORADO GEOLOGICAL SURVEY
BOULDER
R. D. GEORGE, State Geologist

BULLETIN 21

THE GEOLOGY
OF THE
WARD REGION, BOULDER COUNTY, COLORADO

BY
P. G. WORCESTER

EAMES BROS.
STATE PRINTERS FOR COLORADO
DENVER, COLORADO

GEOLOGICAL BOARD

LETTER OF TRANSMITTAL

State Geological Survey,
University of Colorado, November 22, 1920.

Governor Oliver H. Shoup, Chairman, and Members of the Advisory Board of the State Geological Survey.

Gentlemen: I have the honor to transmit herewith Bulletin 21 of the Colorado Geological Survey.

Very respectfully,

R. D. George,
State Geologist.

CONTENTS

ILLUSTRATIONS

The Geology of the Ward Region, Boulder County, Colorado

CHAPTER I

INTRODUCTION

PURPOSE OF THE REPORT

The area covered by this report lies north of the "Main Tungsten Area" of Boulder County and west of the "Sugarloaf District," which have been described, respectively, by R. D. George in the first annual report of the Colorado Geological Survey, and in a thesis by R. D. Crawford.

It is planned by Professor George, who is head of the Department of Geology at the University of Colorado, and also State Geologist, to have other areas mapped and described, until eventually it will be possible to make a complete report in monograph or bulletin form on the Geology of Boulder County, Colorado.

FIELD WORK

In 1906 Mr. B. H. Jackson began a survey of this region, but after partially mapping the areal geology of four square miles east of Ward he gave up the work.

In the fall of 1909 the writer started to prepare a topographic map of an area of about nine square miles, that lies mainly west and south of Ward, but which includes the town of Ward and the adjacent mining communities, Frances, Puzzler, Bloomerville and Sunnyside. This map was completed in 1911. In 1913 the topography of this area was mapped by the United States Geological Survey, and it is included in the Longs Peak Quadrangle map published in 1915. The map, west of 105° 30′, as it appears in this report is, however, entirely the work of the writer.

The geologic work was carried along with the topographic mapping during 1910 and 1911, and the areal geology was nearly finished in the spring of 1911. The economic geology could not be satisfactorily worked out during this period because so few mines were unwatered. This report has been delayed for several years on account of the writer's desire to make a thorough study of the underground geology. He hoped that from time to time old mines would be reopened or new ones developed, and he has taken advantage of such conditions whenever they have come to his attention. It has been impossible, however, to make a complete study of the mines of the district, and this report is therefore presented with the understanding that it represents an attempt to cover in detail only the areal geology. The notes on the economic geology are fragmentary and at best are unsatisfactory.

OFFICE AND LABORATORY WORK

The office work has included the preparation of the maps and the report as it is herewith presented. The laboratory work included examination of about 200 thin sections of igneous rocks; the fire assaying of many samples of ore; and the qualitative analysis of a large number of minerals.

HISTORY OF THE REGION

In the early sixties when the mining industry in Colorado was in its infancy the western half of Boulder County was divided into many small mining communities, each of which was a more or less independent governmental unit having local rules and regulations to control mining, prospecting and other affairs of a public nature. These units were called "districts," and most of them were named for the largest, and, in many cases the only settlement in the community. The term "district" persists in the records of mining claims and in other literature at the present time, although its former significance has long since disappeared. It is to be hoped that gradually the use of the names of the various districts will be discontinued, for whatever value such a classification once may have had, it certainly results only in confusion when used now.

The Ward "district" was one of the first to be located, and it has been always one of the very important mining localities of Boulder County.

The region described in this report includes not only the Ward "district," but parts of the Grand Island and Gold Hill districts which adjoin it respectively on the south and east.

It has been exceedingly difficult to get reliable data regarding the production and the early development of the region. The mint reports and other official publications give only incomplete data. It has not been possible to procure complete sampler or smelter returns from the ores produced in the district. Many mines have changed ownership several times and records have been lost. Dates and estimates of production kept in a man's head for forty or fifty years are generally subject to correction when compared with records in black and white. While many of the old settlers in the district have furnished considerable first hand information, and while all available records have been consulted, it must be understood that the following statements present only an approximate outline of the development of the district.

The first gold was discovered in 1861 by Calvin Ward. This discovery was made on the hillside north of Lefthand creek, just east of Indiana gulch, in what is known as the Ward Lode. The following year John Deardorf discovered the Columbia vein, and this discovery led to the establishment of the town of Ward. In 1863 a wagon road was extended up Lefthand creek from Boulder to Ward. The Nelson mine was located about the same time as the Columbia and the Chathem, Gold Queen, Stoughton, Baxter, Columbia No. 5, B. and M. and several others were discovered before 1870. Then came the Colorado, Morning Star, Utica, Modoc, Humboldt, Celestial, Grandview, Dolly Varden and many others. More recently still the Copper Glance, Golden Chest, Ward Rose, White Raven, Lois, Milwaukee, Ruby and dozens of other mines have been developed.

In Hollister's "Mines of Colorado," page 266, the statement is made that the first mill built in the district was put up in Indiana gulch in the autumn of 1861, by Davidson and Breath, and that the mill ran from time to time until 1865, when it was sold. This statement is challenged by others who say that the Niwot mill, which was built in 1865, was the first mill in the district.

The machinery for the Niwot mill, which had 50 stamps, was hauled across the plains from Kansas City in ox carts. The stamps weighed 650 pounds each. Timbers for the construction of the mill were obtained from a saw mill on Lefthand creek, about one-half a mile away. Hollister states (page 268) that the Niwot mill ran about a month before it was burned down. Mr. John Rice of Ward says that the mill burned to the ground on the day the first run was to be made. At any rate the mill burned. It was immediately reconstructed and it ran steadily for many years. Mr. Israel Benson who worked in the mill told the writer that it cleared up $2,500 a day for many months.

Since the days of the old Niwot mill many mills have been built in the hope of perfecting a suitable process for the economical treatment of low grade sulphide ores, and nearly as many processes, as there are mills, have been introduced, but none of them have been entirely successful.

Mining has been carried on more or less spasmodically ever since the first discovery of gold was made. The drop in the price of silver in 1893 had little effect on the production of the district, but litigation, poor management, an unfortunate tendency on the part of a few individuals to promote fake mining companies, and to raise money to develop properties of doubtful value, combined with the inability to successfully treat the low-grade sulphide ores, have kept the district from the development it otherwise would have had. In the United States Mint report for 1898, this reference to Boulder County is found: "A spirit looking to the development of mines for sale rather than for profit in working the same, it is alleged, served somewhat to minimize the county's production. The county is bountifully supplied with new and old process mills. In many instances the erection of mills antedated the discovery of the contiguous mining properties." While this statement may or may not be true of the Ward district, it is significant in that it illustrates certain tendencies which have been of too common occurrence in this county. It is reassuring, however, to note that this old spirit is largely a thing of the past, and that the work now being done is carried on in a legitimate fashion, which argues well for the future development of the Ward district and the adjoining regions.

PREVIOUS SURVEYS

The Hayden survey made topographic maps and geologic reports that covered the area under consideration, but the work of this survey was strictly reconnaissance in nature, and as the development of the region was in its infancy at the time the survey was made no important additions to the geology of the region can be procured from this report.

This area was also covered in a general way by the King survey of the 40th parallel, but only incidental mention is made of this district.

Several individuals have studied certain dikes within the area; and the results of their study have been printed in the *Proceedings of the Colorado Scientific Society*. Reference to these reports will be made in the bibliography and in the discussions of the igneous rocks.

No other attempts have been made, so far as the writer knows, to map or describe in a serious way the general geology of this region.

ACKNOWLEDGMENTS

To Professor R. D. George, who made the work possible, and who has given his advice freely and fully when it has been sought, the writer's sincere thanks and appreciation are extended.

Professor R. D. Crawford has made many valuable suggestions and criticisms pertaining to the microscopic determination of the igneous rocks, and his kindly interest is gratefully acknowledged.

Messrs. Roy M. Butters and Howard H. Barker made fire assays of many samples of gold and silver ore, under the direction of Professor Crawford. Messrs. Donald C. Kemp and Ross L. Heaton made 27 microscopic examinations of rocks of this district under the supervision of Professor Crawford, and their notes have been in part used in the descriptions of the following rocks: Quartz monzonite porphyry, latite porphyry, diorite porphyry, monzonite porphyry and andesite porphyry. To all of these men the writer is deeply indebted.

Many mine owners and operators have been called upon in one way or another for information, or for permission to study the underground workings, and all have responded readily to such requests.

The topography of the eastern two-thirds of the area was taken from the Boulder Quadrangle topographic sheet that was published by the United State Geological Survey in 1904. The culture of this map has been modified by the writer to show the changes that had taken place since that map was made. The rest of the topography of the area included in this report has recently been mapped by the United States Geological Survey, and it has been published as part of the Longs Peak Quadrangle sheet, but the topography of the western third of the region embraced in this report is entirely the work of the writer.

The areal gology of approximately four square miles, including the section in which Burnt Mountain is situated, the two sections east thereof and one west, was mapped by Mr. B. H. Jackson. His map and notes are incorporated in this report.

As is hereby acknowledged, the writer has had considerable assistance and has received valuable advice in the preparation of this report, but he accepts full responsibility for the conclusions expressed herein.

CHAPTER II

GEOGRAPHY AND TOPOGRAPHY

LOCATION

The region here described is situated in the western part of Boulder County. Ward, the most important town, is about 15 miles northwest of Boulder. Other settlements in the area are: Frances, Bloomerville, Puzzler, Sunnyside, Sunset and Copper Rock, all of which, with the exception of Sunnyside were on the Denver, Boulder and Western Railroad.

Ward is 19 miles by wagon road and 27 miles by railroad from Boulder. For many years, during the summer months, a combination passenger and freight train was run from Boulder to Ward. The train service was more or less irregular, but usually there were at least two trains a week, and when there was much mining activity, or when the tourist season resulted in heavy traffic, there were daily trains. During the winter, the train service to Ward was usually suspended on account of light traffic, heavy snows and deep drifts. If there was freight enough to warrant it, however, the road was kept open.

In 1919, the railroad was abandoned and the equipment sold to a wrecking company. As this report is being written the rails are being pulled up. Daily automobile stages now run between Boulder and Ward, and there is irregular automobile service from Boulder to the other mining camps in the district.

Because of its location, near the continental divide, its beautiful and picturesque scenery, its pure water, fine summer climate, and well-stocked trout lakes and streams, the Ward region has gained considerable well-deserved recognition as a summer resort. In this respect its fame has been increased because of the automobile roads that run; one, north from Ward, through Peaceful valley and Allen's Park, to Estes Park; and another from Ward to Glacier Lake, Lakewood, Nederland and Boulder. These roads afford most delightful drives that should be taken by all visitors of this region.

RELIEF AND TOPOGRAPHY

The whole area included in this report is of high relief. The lowest elevation is near Copper Rock on Fourmile creek, where the altitude is 7,400 feet. The highest place in the district is the summit of a hill directly west of Ward, where the altitude above the sea is 10,400 feet. This difference in elevation of 3,000 feet within a distance of six miles indicates the general character of the relief of the entire district.

The canyons of Fourmile and Lefthand creeks are steep-walled and deep. A narrow circle separates them except at the west where the streams head on the steep east facing slopes of Bald Mountain. The northern portion of the district, beyond Spring Gulch and near Gold Lake is the only part of the area that has not been deeply eroded by streams. This region, which is a highland of rather low relief, is part of the old uplifted peneplain that once extended eastward from the continental divide to the crest of the foot-hills which lie at the western border of the great plains. Remnants of this peneplain are found farther south within the area, but they are not nearly so conspicuous as in the vicinity of Gold Lake.

VULCANISM

There has been a great amount of volcanic activity in the district, and Sunset might be considered almost the center of such disturbances. Great dikes and stocks of felsite, latite and monzonite were formed in the gneisses and schists, and these intrusions, because of their great resistance to erosion, form the crests of many ridges or summits of hills that now stand conspicuously above the general level of the surrounding country. Burnt, Bald and Sugarloaf mountains are good examples of such erosion remnants.

GLACIATION

Glaciers were important agents in producing the present topography of the northwest portion of the Ward district. In California Gulch, above the old railroad bridge and in the Duck Lake region there are great moraines, some of which are 50 feet or more high. These moraines unite near the Lois mine and extend westward toward Redrock Lake. Other glacial deposits are irregularly distributed south and west of Ward, but most of them are outside the district under discussion.

All the hills near the west side of the area have been rounded off and the projections on the sides of hills and valleys have been removed by glacial erosion.

DRAINAGE AND WATER SUPPLY

All the larger valleys have been cut to grade with the exception of their heads. The two main creeks, Fourmile and Lefthand, are throughout their lower courses highly overloaded, because very much more material has been carried in from the sides of these valleys by small tributaries than the large streams of lower gradient can carry away. Hundreds of alluvial fans or cones fringe the main streams. In many places the valleys have been filled clear across to depths of not less than 40 or 50 feet with materials brought in by tributary streams.

Fourmile and Lefthand creeks have a strong flow of water during all but the summer months. At this time the flow is much reduced, but the creeks very seldom dry up. Usually there is water enough available for the concentrating mills that may be running.

RESERVOIR AND POWER SITES

There are several good power sites within or west of the area. One good natural site is on Fourmile creek, between Sunset and Sunnyside. At present there are no hydroelectric plants in this region.

LAKES

Gold Lake is the only lake in the whole district. The basin is largely, if not entirely artificial, but it is situated in an exceptionally favorable natural location. The lake is used as a reservoir to store water for irrigation purposes. Some of the water from South St. Vrain creek is diverted to Gold Lake, by the Lefthand ditch. Water released from the lake flows into Lefthand creek and is taken out by canals near the plains.

CLIMATE

The situation of this region, on the east slope of the continental divide, at an average elevation of about 8,500 feet insures cool summers and relatively cold winters.

The Weather Bureau records do not give complete data regarding the temperature and precipitation, winds, etc., of the region, but a volunteer station at Frances furnishes fairly typical data, and a summary of the temperature and precipitation records from this station for 1917 is given here.

Elevation, 9,300 feet. Length of temperature record, 13 years. Annual mean temperature, 38°F. Highest temperature, 79°F. June 29, and on subsequent dates. Lowest temperature, —15° Jan. 16.

Precipitation, length of record, 12 years. Total precipitation for 1917, 23.38 inches, which was 0.8 inches below normal. Greatest monthly precipitation 5.06 inches in May. Least monthly precipitation, 0.39 inches in June. Total amount of snowfall, 241.3

inches. Number of rainy days, 147. Number of clear days, 102. Number of partly cloudy days, 217.

Frances is near the northwest corner of the area and considerably higher than the average elevation of the region. The precipitation decreases and the temperature increases rapidly with decreased altitude and distance east. An idea of these changes can be obtained by comparing part of the summary given above with one taken from the records of the Boulder station for the same year, 1917.

Boulder elevation, 5,347. Length of temperature record 22 years. Annual mean temperature, 51°F. Highest temperature, 99°, June 29. Lowest temperature, –11°, Jan. 22. Total precipitation for the year 13.99, which is 4.15 inches less than normal. Total snowfall, 75.0 inches. Number of rainy days, 57. Number of clear days, 173. Number of partly cloudy days, 104.

The western side of the area has climatic conditions, indicated by the summary of the Frances records, while the climate of the eastern part of the region is intermediate between that of Frances and Boulder. The summer climate is delightful. It is warm in the sun during the day, but there is almost always a breeze, and it is always cool at night. In the winter, the snowfall is heavy, and there are strong winds which are particularly bad during the fall and early winter.

The altitude is too high and the nights are too cool for extensive agriculture, even if the topography and soil were favorable, but garden vegetables and grasses grow very well.

SOIL

The soil over the greater part of the area is thin and lacks fertility, although grasses and forests grow fairly extensively on most of the north and east slopes.

On the moraines, in some valley bottoms, and where the monzonites and latites have been thoroughly disintegrated, the soil is much richer than elsewhere and it seems to be of a very good quality.

In many places, rock in place comes clear to the surface of the ground, and there is neither soil nor mantle rock present.

VEGETATION AND TIMBER

The vegetation over much of the region, as is indicated by the preceding paragraphs, is scanty. Where the slopes are sufficiently gentle to allow the accumulation of soil, grasses grow well, and such slopes are grazed by cattle or sheep.

Good timber is scarce. There is considerable between Sunset and Sunnyside, and quite a good deal of pine is scattered over some of the higher slopes, but there is not enough to supply the demand in case of extensive mining operations. There is not enough to make large scale lumbering worth while, although there is sufficient timber to supply the present local demand.

Some rather large areas should be re-forested, in order to prevent, or at least reduce, the dangers of soil removal in times of flood. Most of the timber on the ground now is pine, although spruce and aspen are of common occurrence.

INDUSTRIES

Mining and grazing are the chief industries.

MINING

The mining will be discussed more in detail later on, but it should be stated that ever since the first prospectors entered the district, mining has been the most important industry. It is responsible for the building of the Denver, Boulder and Western railroad, for the location of the town of Ward, and for most of the cultural development of the area. At one time when the production of the region immediately about Ward was at its height, more than 2,100 people got their mail at the Ward post office, and other settlements and towns were at one time or another very prosperous. At present the mining industry is at low ebb. Most of the best ground has been worked out down through the zone of secondary enrichment. The ore now available, while large in amount, is of low grade, and it offers many obstacles to successful economical treatment. When an efficient, economical method for treating the low-grade sulphide ores has been devised, it is safe to say that mining and milling will again come into their own, in this region.

GRAZING

Cattle, sheep and horses graze in this region during the summer, and horses run out all winter long in the vicinity of Gold Lake, where the grass is heavy and where there is reasonably good protection from the cold winds.

The grass seems to be exceptionally good for sheep and cattle, and both do splendidly on the summer range. Since nearly all of the region is within the boundaries of the Colorado National Forest Reserve, the number of animals allowed to graze is limited, and the preservation of the grasses on the range is thus assured.

CHAPTER III

GENERAL GEOLOGY

OUTLINE OF THE AREAL GEOLOGY

All of the rocks of this region, except the alluvial and glacial deposits, are either igneous or metamorphic. There are no unmetamorphosed sediments nearer than the foothills formations that lie several miles to the east.

Pre-Cambrian schists, gneisses, granites and quartz diorites constitute about two-thirds of the out-cropping rocks of the area. Small batholiths, stocks and dikes of acidic, and intermediate Tertiary (?) intrusives cover most of the rest of the area. There are a few small intrusions of basic rocks.

ALLUVIUM

Nearly everywhere along the creeks there are small deposits of alluvium. These deposits are increasing in amount at present, because of the inability of the larger streams to carry away the material that is brought in by small tributaries, or carried in by slides, slope wash, etc. Most of the debris left along the stream beds is very coarse.

In the heads of some of the valleys there are patches of alluvium, large enough, and rich enough, to be valuable for agriculture. These are shown on the geologic map by the symbol Qal.

MORAINES

In the northwest corner of the area there are large glacial deposits. The glaciers came from the west and brought great amounts of debris of all sizes from large boulders to fine rock flour. The deposits are left in well-developed lateral moraines which are found near Duck Lake and in California Gulch southwest of Ward; and in ground moraines of irregular form and surface relief that occur west of Ward.

The moraines are typical, both as to form and composition, but, as has happened in most of the mountainous mining regions of Colorado, their origin has not been recognized by the prospector, and in the Ward region there has been a good deal of useless prospecting in the glacial debris. Claims have been located, shafts sunk and tunnels driven because of the finding of indications of mineralization in the moraines. Of course, the mineralized boulders may have been carried several miles by glaciers.

Some perfectly legitimate prospecting may have been done in the morains if outcropping veins have been followed up to the edges of the glacial deposits, but there is little evidence that this has happened in the region near Ward. Most of the prospect holes, so far, located in the moraines have been of the "hit or miss" variety and it is probably unnecessary to say that so far they have without exception "missed" the veins.

SCHISTS

The highly metamorphosed gneisses and schists have not been mapped separately in the Ward district. To do so would require a large amount of detailed work that would be out of harmony with the purpose of the report. Intense folding and crumpling have made the relationships between the two groups most complex, and in many places it is impossible to determine where one leaves off and the other begins.

Structure.—The structure of the gneiss and schist series is complicated, and no single group of measurements can be accepted as of average value in determining the dip and strike of the schistose layers. In general the dips are high, ranging from 40° to 63°, with 45° as perhaps the nearest approach to an average reading. The direction of dip is generally northeast.

GRANITE AND QUARTZ DIORITE GNEISS

Closely associated with the schists are many masses of granite, and quartz diorite gneiss. The rocks exhibit all stages of metamorphism from the slightly metamorphosed condition to completely banded and highly crumpled gneisses. In some cases the degrees of metamorphism are regarded as indications of the relative ages of the rocks, the more highly metamorphosed ones being, supposedly, the older.

Since the granites and quartz diorites occur, usually, in masses of small extent and since, in many cases, it is impossible to entirely differentiate them from the older schists, they have been mapped with the pre-Cambrian metamorphics, although they may be, in part, of more recent age.

GRANITES

In the central and northern parts of the Ward district there are granites which are possibly much younger than the rocks just described. These granites are comparatively little metamorphosed. But it is not unusual to find small masses of gneiss or schist enclosed in the granite, as if caught up when the granite was intruded into the older rocks.

The borders of the granite areas are not as distinct, in all cases, as the boundaries on the map might lead one to believe. In many places the exact contact is indistinct and irregular and the boundary lines are, therefore, more or less arbitrarily drawn.

PEGMATITE

Pegmatite dikes are found scattered all over the areas occupied by the metamorphic rocks and the granite and quartz diorites. That they are of various ages, some very old, is shown by the variable amount of alteration in dikes of different regions. In the gneiss and schist areas some of the dikes have been broken apart, and moulded into elongated lens-shaped masses by the forces that altered the country rocks. Other dikes in the same areas show little or no evidence of metamorphism.

Most of the dikes are small, with widths varying in different dikes from a few inches to two or three feet, and with lengths of from a few feet to several hundred yards. Since most of them are so small and unimportant they have not been shown on the geologic map.

TERTIARY (?) INTRUSIONS

There are a great many Tertiary intrusions in the Ward district, and they occupy in the aggregate a rather large area. One monzonite porphyry batholith has an area of more than two square miles. Another trachyte intrusion has a surface exposure of more than one square mile. These with ten other smaller intrusions have a total combined area of about seven square miles. In addition to these, there are more than 130 dikes which vary greatly in width and length.

All of the larger intrusions, in whatever form they may be, are important factors in the development of the topography of the region. Nearly every prominent peak or sharp ridge is made up of intrusive rock which is more resistant to erosion than the surrounding country rock. Burnt and Bald mountains, and Sugarloaf Mountain that lies just east of Bald Mountain, although outside of the area covered by this report, are good examples of the effects of the intrusions on the topography.

Composition.—With the exception of a small number of basic dikes, the intrusives of this region represent a very complex acidic and intermediate series of rocks. In several instances there are well-represented transitions from the rocks near the center of a small batholith outward to the border. A full study of these rocks would be a very interesting piece of work for a petrographer, but it would require several hundred thin sections and a very large amount of time. As the work now stands more than 200 thin sections were examined under the microscope and many interesting results were obtained, but the petrographic work could have been greatly enlarged upon if it had seemed desirable to do so.

The preponderance of acidic and intermediate rocks over the basic intrusions is very noticeable. The only representatives of the latter are two small masses of olivine basalt and five small dikes of diabase.

Age.—So far as the field evidence goes there is no way of determining the general age of the intrusions. They are referred, however, to the Tertiary period, because this was the time when the great volcanic disturbances were most extensive in the Front Range region.[1]

[1]Cross, W., U. S. Geol. Survey Monograph 27, p. 312, 1896. Richardson, G. B., U. S. Geol. Survey Geol. Atlas, Castle Rock folio (No. 198), pp. 10 and 13, 1915.

CHAPTER IV

GENERAL GEOLOGY—Continued

PRE-CAMBRIAN GNEISS, SCHIST AND GRANITE

THE IDAHO SPRINGS FORMATION

There are four important varieties of schist in the Ward district; namely, garnetiferous quartz-mica schist, sillimanite schist, quartz-mica schist and hornblende schist. All probably are phases of the Idaho Springs formation.[1]

Name.—This term was first used by Ball to designate "a series of interbedded metamorphic rocks, presumably of sedimentary origin, which are typically exposed in the vicinity of Idaho Springs," Colorado. The same name has been used by Bastin[2] and Hill in describing rocks of the same characteristics that occur in parts of Gilpin, Clear Creek and Boulder counties.

Age.—The Idaho Springs formation is believed to be of pre-Cambrian age, and its highly metamorphosed condition led Bastin[3] to regard it "as much older than the slightly metamorphosed pre-Cambrian quartzites of certain parts of the (Front) range, which have been provisionally classed by Van Hise[4] and others as Algonkian.

Extent.—This formation covers approximately the south half and part of the east portion of the area of the Ward district. It is not entirely continuous but is nearly so. It undoubtedly extends all the way along from Ward to Idaho Springs, east of the crest of the Front Range. The width of the formation is very variable, in the Ward district it ranges from less than 1 to more than 6 miles.

GARNETIFEROUS QUARTZ-MICA SCHIST

This is the most common schist in the region. It occurs extensively along the south side of the district, and is somewhat less abundant in the other parts of the metamorphic area.

Composition.—Quartz, biotite and garnet are the important constituent minerals. The garnets range in diameter from 2 mm. to 10 mm., and they make up very varying amounts of the whole rock. Most of them are badly fractured, and in many cases they have been changed by movements into more or less lens-shaped aggregates. Quartz makes up roughly from one-third to one-half of the whole rock. It is much more abundant in the schists of the

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[1]Ball, S. H., General geology [of the Georgetown quadrangle, Colo.]: U. S. Geol. Survey Prof. Paper 63, p. 37, 1908.

[2]Bastin, E. S., and Hill, J. M., Economic geology of Gilpin County and adjacent parts of Clear Creek and Boulder counties, Colorado: U. S. Geol. Survey, Prof. Paper 94, p. 26, 1917.

[3]Bastin, E. S., and Hill, J. M., op. cit., p. 30.

[4]Van Hise, C. R., and Leith, C. K., Pre-Cambrian Geology of North America: U. S. Geol. Survey Bull. 360, p. 827, 1909.

northeastern part of the district than in those of the southwest part. It is colorless, or white because of fracturing. Biotite is next in importance to the quartz. Where there are few or no garnets present the biotite is likely to be fresh, but where it is associated with garnets, it is usually altered. Chlorite and iron oxides are the common alteration products. Sillimanite appears, in many cases, as small fibrous looking crystals, which weather white. These crystals add to the readiness with which the rock cleaves. Orthoclase or microcline are subordinate constituents.

Associations.—This schist grades so gradually into gneissoid granite that it is in many places quite impossible to tell where one rock ends and the other begins.

It is also closely associated with the other schists hereafter described.

SILLIMANITE SCHIST

The chief differences between this schist and the one just described are in the larger amounts of sillimanite, and the smaller amounts of quartz present, in the sillimanite schist.

Composition.—Muscovite is an important constituent of the sillimanite schist, and orthoclase is more abundant than in the garnetiferous quartz-mica schist. Sillimanite, while probably subordinate in amount to the quartz, is by far the most conspicuous mineral in the rock. It occurs as radiating feathery appearing crystals or fibrous grains. Its color is grayish brown when fresh, but grayish white when weathered, and since most of the surface rocks are weathered the effect of the sillimanite is to give the schist, in which it occurs, a white or gray appearance. The sillimanite seems to have been formed, largely, along shearing planes in the schist. Garnet may or may not be present, but if present, it is always in a subordinate amount. Biotite occurs in small amounts.

Occurrence.—Sillimanite schist is found in the Idaho Springs formation, chiefly south and east of Sunset and near Sunnyside.

QUARTZ-MICA SCHIST

In several local areas, but particularly in the northeastern part of the district, there is a quartz-mica schist which is markedly different from all the other schists in the area.

Composition.—It is a fine even grained rock, made up of flakes of biotite and grains of quartz, each mineral grain being about 2 mm. in diameter.

Structure.—Foliation is not so pronounced in this rock as in the other schists, although the flat surfaces of the biotite flakes are in a roughly parallel position. The mica grains are considerably mixed with the quartz, and the result is a peculiar "pepper and salt" effect in the color and general appearance of the rock.

Occurrence.—This rock is not of wide spread occurrence, and it is only regarded as a peculiar and interesting, but relatively unimportant member of the metamorphic complex.

HORNBLENDE SCHIST

This is the least common of all the schists in the Ward district, but it is found in several localities, and is particularly noticeable near Gold Lake, south of the Morning Star mine in Spring Gulch, and in the Ruby mine at Sunnyside. It is very heavy and tough. The color is black or dark gray.

Composition.—It is composed almost entirely of hornblende with only very small amounts of feldspar and quartz. South of the Morning Star mine, the schist has more quartz, and is coarser than are most of the other rocks that have been included under the same name. When weathered the color usually becomes green.

Structure.—The hornblende occurs in stout interlocking prismatic grains, and as a result of this occurrence the schist is rarely well foliated. It does not break much more readily in one direction than in another.

Origin.—It is possible that this schist is of igneous, rather than sedimentary origin, and if so, it does not properly belong with the Idaho Springs formation. The foliation planes of the hornblende schist do not correspond in attitude with those of the other schists. Furthermore, much of the hornblende schist seems to occur in small masses in the granite. It is possible that the rock represents small ancient intrusions of hornblende diorite or gabbro that have since their formation been much metamorphosed.

GRANITIC GNEISS

Occurrence.—Granite gneiss or gneissoid granite, as it might equally well be called, is the most abundant rock in the Ward district. It occurs in practically every part of the area where schists are found, and it is also found, although much less abundantly, in the areas that have been mapped as granite. In neither case has it been differentiated from the other rocks on the map.

In the schist areas the gneiss is likely to grade almost insensibly into schist. In the granite areas the boundaries are in most places fairly distinct.

With the possible exception of hornblende schist, the gneiss is unquestionably younger than the schists with which it associates. It is certainly older than the granites, and is probably about the same age as the quartz diorite gneiss which will be described later.

Structure.—There is a great difference in the development of the gneissic structure in the different rocks of the area. When the rocks are fine and even textured, and when they contain biotite, the banding is usually uniform and well developed. In the gneisses which have very small amounts of biotite the gneissic structure is indistinct. In those rocks that have a very large amount of biotite, that mineral is likely to be found segregated more or less completely into lenses which interlock rather loosely with lenses of quartz and feldspar. These lenses average about an inch in thickness. They are two or three times as long and wide as they are thick. This peculiar segregated structure of the minerals leads to a rather mottled or blotched appearance of the rock.

Composition.—The gneissoid granites contain about 50 per cent of feldspar, mainly microcline, 25 per cent of quartz and about the same amount of biotite. Minor minerals are sillimanite, which occurs in considerable quantities in some of the rocks, magnetite and acid plagioclase. Microcline, the most abundant feldspar, is usually white or flesh colored, and it occurs in grains as much as 20 millimeters in length. More often, however, the grains are much smaller.

QUARTZ DIORITE GNEISS

Occurrence.—This rock is believed to be only a phase of metamorphosed granite, and the occurrence is essentially the same as that of the granite gneiss. All of the quartz diorite gneiss outcrops, however, have a small surface area. The most typical example of this rock is found near the Giles mill at the junction of Peck and Spring gulches.

Composition.—The chief differences between the quartz diorite gneiss and the granite gneiss are in the composition of the plagioclase feldspars and in the amount of quartz present in the two rocks. The typical quartz diorite gneiss has much less quartz and much more plagioclase, but there are all gradations from one rock to the other.

Biotite makes up fully 25 per cent of all the quartz diorites. It may occur in even larger amounts. Microcline and an intermediate sodic-calcic feldspar, probably labradorite, are present in varying amounts, but together they constitute about 50 per cent of the rock. Quartz, which is usually glassy, is the next most important mineral. Sillimanite and magnetite may occur in small amounts. The latter is found only in microscopic grains, and it is probably an alteration product from biotite.

When weathered the feldspars kaolinize, the biotite disintegrates, forming chlorite, iron oxides and epidote, and the rock soon becomes streaked with iron rust.

Structure and Color.—Most of the quartz diorite gneiss is rather perfectly and uniformly banded, due to the presence of so much biotite and to the even and rather fine texture of the rock. The prevailing color of the rock is dark gray. Most of the biotite is fresh, and its luster is bright. The feldspars are predominantly blue-gray when fresh and white when weathered. The whole rock, because of its color and structure, presents a most striking and attractive appearance.

GRANITE

Occurrence.—Except possibly for the Tertiary intrusions the granites are the most widespread and important rocks in the northern half of the Ward region. They occur mainly in stocks and bosses throughout the area, the smaller intrusions being in the southern half and the larger ones farther north.

Varieties.—There are four more or less easily recognized varieties of granite in this region. The first is a medium to coarse textured somewhat porphyritic biotite granite, which probably corresponds to the Silver Plume granite[1] described by Ball from the Georgetown Quadrangle.

The second variety is a much finer textured rock rich in biotite. The third is a very coarse grained or porphyritic massive granite composed chiefly of quartz and feldspar, and the fourth is pegmatite, which occurs in dozens of dikes and veins cutting all rocks older than the Tertiary intrusives.

Age.—As is stated in the preceding chapter, the age of the granites is, for lack of better evidence, regarded as pre-Cambrian. In general they appear to be much younger than the gneisses and schists, but in some cases it is difficult to separate the granites from the gneisses. The varying degrees of metamorphism of these granites that are on the borderline, suggest that they are of more than one age, but there is no other evidence available on this point.

COARSE-TEXTURED BIOTITE GRANITE

This is by far the most common of the granites mentioned above. It occurs in practically all of the granite areas and is the typical massive granite of the region.

Description.—The color is usually light gray or pale pink, the latter color predominating. Porphyritic texture is very common. The phenocrysts are chiefly microcline.

[1]Spurr, J. E., Garrey, G. H., and Ball, S. H., Geology of the Georgetown Quadrangle, Colo., U. S. Geol. Survey Prof. Paper 63, pp. 58-60, 1908.

Composition.—The minerals present consist chiefly of microcline, orthoclase, biotite, considerable quartz and a small amount of acid plagioclase. Accessory minerals are occasional grains of hornblende and apatite in very small amounts. Pyrite is of very common occurrence near quartz veins of which there are many cutting the granite.

The rock is fine textured with most of the grains averaging less than 3 mm. in diameter. However, some of the feldspars are 10 or 15 mm. in length.

The color is usually dark gray. The biotite is rather evenly distributed through the rock, and it presents a distinct granular appearance. The rock is seldom found fresh, but is streaked or stained with iron due to rapid weathering.

FINE GRAINED BIOTITE GRANITE

This granite is much less important, and more restricted in occurrence than the one just described. It occurs almost entirely in small masses in the schist and gneiss areas, and probably represents small intrusions in those rocks. It is in some places, but not everywhere, gneissoid.

Composition.—Biotite constitutes about one-tenth of the rock. Quartz occurs in somewhat larger amounts, and microcline is the most abundant mineral of all. The usual accessory minerals occur in small amounts.

PORPHYRITIC GRANITE

This rock, which occurs most extensively in the northern part of the area, between Lefthand creek and Spring Gulch and north of Peck Gulch is quite likely a phase of the coarse biotite granite described above. It is composed almost entirely of quartz and microcline, both of which occur in rather large grains. The microcline grains are in many cases an inch or more long and give the rock a distinctly porphyritic appearance.

The color of the microcline is white or pale pink. The quartz is colorless, the general color of the rock is a light pink or gray.

Composition.—Iron oxides, both hematite and limonite, are found sparingly between the grains of quartz and feldspar. Biotite, hornblende and muscovite are almost never found.

PEGMATITE

There are a great many pegmatite dikes and veins that cut the gneiss, schist and granite in all parts of the area. The dikes vary greatly in length, width and importance. The largest one is the great Livingston dike which is in the northeast corner of the area. It is between 200 and 300 feet in width.

The larger dikes are, without exception, very coarse grained. The small ones vary in texture from an aplite to a medium textured pegmatite. Some have local masses of graphic granite.

Composition.—Microcline, orthoclase, quartz, muscovite and biotite are the most important minerals and are named in the order of their importance. Muscovite does not occur anywhere within the area in large enough amounts to be of commercial value. Muscovite and biotite do not occur in the same dikes. In many cases massive quartz and feldspar are the only important minerals present.

On the whole these dikes are remarkably free from the accessory minerals that so often occur in pegmatite. Pyrite and fluorite are the only such minerals that are found in any considerable quantity. The former is of widespread occurrence. The latter occurs in small amounts in two dikes east of Ward.

Age.—Although many of the dikes cut the metamorphic rocks they show little or no evidence of metamorphism. It is probable, however, that some of the small gneissoid granites in the schist and gneiss areas, particularly those gneissoid granites that are poor in mica, were once dikes of pegmatite which have been so thoroughly metamorphosed as to nearly destroy their identity. The borders of such masses are so mingled with the country rock that their exact limits are in doubt, but in general these masses are lens shaped, or roughly rounded.

Effect on Topography.—The larger dikes of pegmatite form the backbones of ridges, in which they occur, and they are always important factors in the development of the topography.

Many of the larger dikes have great amounts of massive quartz in the center. This is scattered over the ground as the dike weathers, and because of resistance to chemical weathering it soon forms a protective covering over the dike and its immediate surroundings. In course of time the area so covered is left in the form of a ridge or hill by the agents that wear down the land surface.

Origin.—There are believed to be two modes of origin of the pegmatite. Some of the large dikes are evidently intrusions, and very old ones, for they are cut by Tertiary intrusions. The small veins and dikes, which are in most cases very irregular in width and length, are the result of solution and recrystallization along ancient joints and in fracture planes of the country rock. These are much more commonly found in the granite than in the gneiss and schist areas.

CHAPTER V

GENERAL GEOLOGY—Continued

TERTIARY (?) IGNEOUS ROCKS

GENERAL RELATIONS AND OCCURRENCE

There are more than 130 separate intrusions within a surface area of 22 square miles in the Ward region. These are divided into 14 varieties of rocks, most of which are acidic or intermediate in composition and aphanitic or porphyritic in texture.

Forms.—The forms of the intrusions are: Dikes which vary greatly in width and which range from a few feet to more than two miles in length, and stocks which are very irregular in outline and cover areas that differ in size from a few square yards up to more than two square miles.

The largest stock is monzonite porphyry. It extends from Fourmile creek between Sunset and Copper Rock northeast and north to Lefthand creek and on to include Burnt Mountain, which lies north of Spring Gulch. This stock is very irregular in outline as is indicated by the geologic map. Most of the others are more nearly circular in form.

Origin.—The forms of the intrusions suggest that they spring from a common magma. That this magma is monzonitic in composition is indicated by the following facts: First, there are no dikes cutting any of the stocks and practically none that cut other dikes. Second, nearly all of the stocks are monzonite porphyry, and where they occur there are few monzonite dikes near, but many others of slightly different composition radiate out from the regions of the stocks indicating magmatic differentiation and intrusion. Third, in the region west of the monzonite stocks there are many quartz monzonite dikes. It seems entirely probable, therefore, that at least the monzonite, latite, diorite, andesite and dacite intrusions, as well as the few basalts and diabases may have sprung from a common magma, and since some of the felsites are dacitic and latitic in composition, and others which are true rhyolites are in direct contact with monzonite stocks, it is probable that they too may have come, through magmatic differentiation, from the monzonitic magma.

Age.—As is stated in Chapter III, these rocks are regarded as of Tertiary age. The references given at the end of the third chapter may be supplemented by the following to indicate the age of similar rocks farther south[1] and east.[2]

Fenneman noted the fact that intrusions cut Pennsylvanian and Upper Cretaceous sediments near Boulder, and it is now known that some of these intrusions are almost identical with those in the Ward region.

Cross[3] has stated that the andesitic dikes from volcanic rocks of the Front Range first appear in the Denver formation, which is of early Tertiary age. The volcanic rocks of the Ward region are similar in composition, and it is believed of the same age as those referred to by Cross west of Denver. Hence, they are probably of early Tertiary age.

Descriptions.—The following descriptions will give the main facts concerning the composition, texture and occurrence of the Tertiary (?) igneous rocks of the region. Detailed exhaustive microscopic descriptions have with one exception been avoided.

The general order of the descriptions is based on the percentage of silica in the rocks. It is theoretical only, however, and depends entirely on microscopic determinations, for no chemical analyses have been made.

FELSITE

Name.—The term felsite is used to include a large number of light colored fine-grained or partly glassy rocks, which consist chiefly of potash feldspar and quartz, with small amounts of biotite or hornblende.

Occurrence.—Twenty-six dikes have been mapped as felsite. They are found chiefly in and near Ward and on the east side of the area.

One felsite dike is a mile or more long. Most of them are only a few hundred feet long and less than 100 feet wide.

Composition and Color.—Most of the rocks are nearly white when fresh. After weathering the colors are gray, greenish gray and white. Dendrites and concentric rings of brown iron oxides are of common occurrence in the weathered rock. Kaolin is an important end product in the weathering.

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[1]Bastin, E. S., and Hill, James M., Economic Geology of Gilpin County and adjacent parts of Clear Creek and Boulder counties, Colorado. U. S. Geol. Survey Prof. Paper 94, 1919.

[2]Fenneman, N. M. Geology of the Boulder District, Colorado: U. S. Geol. Survey Bull. 265, pp. 35-40, 1905.

[3]Cross, Whitman, Geology of the Denver Basin in Colo.; U. S. Geol. Survey Mon 27, pp. 34-209, 1896.

Often a platy parting is found in the rock due probably to peculiarities in cooling.

The important minerals are: Orthoclase and microcline, a good deal of quartz and small amounts of biotite or hornblende. Plagioclase feldspar is found in some of the specimens and the felsites, grade, therefore, into dacites and quartz latites. Pyrite and iron oxides occur in varying amounts. Many important ore deposits occur on the borders of felsite dikes.

Texture.—Most of the felsites are very dense and fine grained. In many specimens there is much glass, which indicates very rapid cooling. Usually those of the whitest color are the finest grained, while those that have greenish gray colors are coarser.

Phenocrysts of biotite are quite common. Occasional quartz crystals are found. Orthoclase also occurs as phenocrysts in some of the dikes. Muscovite is found in distinguishable grains in some cases. Few of the phenocrysts are large and none of the felsites is extremely porphyritic. They are to be classed, therefore, as partially glassy and very fine grained, or as medium grained aphanitic rocks with occasional small phenocrysts.

QUARTZ MONZONITE PORPHYRY

Name.—The name quartz monzonite porphyry is here applied to a large number of rocks which are composed of about equal amounts of orthoclase and plagioclase, a smaller amount of quartz, either biotite or hornblende and small amounts of accessory, or secondary minerals, and which have phenocrysts occupying at least as large space as the groundmass.

Occurrence.—There are five prominent types or varieties of this rock, four of which are found near important mines. It has seemed best to give to each variety the name of the mine or region where it is typically exposed and to describe each separately.

The following varieties will, therefore, be described in order:

Modoc quartz monzonite porphyry.

Utica quartz monzonite porphyry.

Brainerd quartz monzonite porphyry.

White Raven quartz monzonite porphyry.

Mt. Alto quartz monzonite porphyry.

MODOC QUARTZ MONZONITE PORPHYRY

Occurrence.—This rock occurs in a single dike, which is found in the Modoc mine about half a mile due north of Ward. The dike extends east for about a mile. It is found just north of the Telegraph mine buildings and along the north side of Spring Gulch. The dike varies from 20 to nearly 100 feet in width. It does not make a prominent ridge, but weathers, in most places, as fast as the country rock.

Texture.—The texture of this rock is even and fine grained with many white feldspar and greenish black hornblende phenocrysts. A few phenocrysts of quartz are also present. The feldspar crystals are, as a rule, not more than 4 millimeters long and half as wide. The most common size is about 2 millimeters in diameter. Hornblende grains occur up to 5 millimeters in length, but most of them are not half so long, and they are very narrow.

Color.—Fresh specimens are hard to get. When weathered the color is a greenish gray, due to the alteration of the ferromagnesian minerals. The white feldspars kaolinize and turn slightly yellow. Green or yellowish green epidote also appears. The effects of weathering are to give the rock a greenish gray tone and also to emphasize its granular texture.

Composition.—A study of thin sections gives the following mineral constituents: Orthoclase and albite, in about equal amounts; biotite, quartz, hornblende, epidote, zoisite, sericite and kaolin. The last four named are secondary minerals, which are alteration products of first four, except quartz. Apatite and magnetite also occur as accessory minerals.

The feldspars occur both as phenocrysts and in the groundmass. In most of the specimens studied the phenocrysts were so kaolinized that their outlines were indistinct. Quartz makes up about one-tenth of the groundmass. It rarely occurs in phenocrysts. Biotite and hornblende have been much altered and little of this is left. Apatite is quite plentiful. Magnetite is found in small amounts in both euhedral and subhedral grains. Epidote and zoisite occur in medium sized subhedrons, and as jagged shreds in the groundmass. Sericite occurs in thin plates on some of the feldspar phenocrysts.

UTICA QUARTZ MONZONITE PORPHYRY

Occurrence.—There is also only one dike of this rock. It extends for about half a mile southeasterly from the Utica mine, and is 30 or 40 feet wide.

Texture.—At first glance this rock appears to be of fine, even grained texture. The phenocrysts are small and harmonize so well with the color of the groundmass that they are not at all conspicuous.

Color.—The color of fresh specimens is gray. When weathered it is a rusty or mottled gray. There is much fresh biotite present, which, with the white feldspar and gray groundmass gives a "pepper and salt" appearance to the rock. The biotite grains are particularly prominent in weathered specimens.

Composition.—In hand specimens, biotite and orthoclase are the only minerals that can be identified. Under the microscope orthoclase, plagioclase, biotite and quartz are the principal minerals. The first two occur in nearly equal amounts. Quartz is found sparingly as small phenocrysts and abundantly in the groundmass. An occasional grain of hornblende is seen. The feldspars are much kaolinized. Magnetite occurs as small interstitial grains.

BRAINERD QUARTZ MONZONITE PORPHYRY

Occurrence.—There are two large dikes of this rock on the north side of the valley near the mouth of the Brainerd tunnel which is on Lefthand Creek about a mile east of Ward. Another dike occurs farther north in Tuscarara Gulch.

Texture.—The texture is rather coarsely granular. Biotite, hornblende and orthoclase can be distinguished in the hand specimen. Feldspar crystals up to 5 or 6 millimeters in diameter occur in abundance and give the rock a somewhat porphyritic appearance. Biotite crystals in perfect hexagonal form are plentiful.

Color.—This rock has a very attractive soft gray color, which in some cases has a slightly pink tone, due to the large number of orthoclase phenocrysts. The general appearance is much like that of a very fine, even grained quartz poor light gray granite. When weathered the color is brownish gray.

Composition.—In the hand specimen, feldspars often more or less kaolinized, bright biotite crystals and fine needle-like grains of hornblende are easily recognized.

In thin sections, orthoclase, plagioclase, quartz, hornblende, biotite, apatite and iron ore are seen. Plagioclase with low extinction angles is rather more abundant than orthoclase. Biotite occurs in larger amounts than hornblende. Quartz is seldom phenocrystic, but there is much in the groundmass. Apatite and iron ore are found only in very small amounts.

So far as the writer could learn no important ore bodies are located on dikes of this rock.

WHITE RAVEN QUARTZ MONZONITE PORPHYRY

Occurrence.—There are 22 dikes of this rock in the Ward region. Nearly all of them are found between Sunset and Sunnyside and northward in a belt less than two miles wide to Ward. There are more dikes of this rock near Puzzler and in the lower part of California Gulch than in any other part of the area.

Most of the dikes are small, but three are each a mile or more in length, and several are more than 100 feet in average width.

Economic Conditions.—In many places the contacts of this porphyry and the country rocks are highly mineralized. The White Raven mine, Black Jack, Cross, Graybird and Philadelphia, all in California Gulch, and many other small properties in that region undoubtedly owe their silver, gold and other mineral deposits to the intrusion of this rock.

Texture and Color.—In all places where it was examined the rock was a typical porphyry. It is often called "bird's-eye porphyry" by the miners of the districts in which it occurs.

White plagioclase feldspar makes prominent phenocrysts, which are in sharp contrast to the gray or greenish gray fine-grained groundmass. In some cases the groundmass is partly glassy and very dense, and the color is decidedly green.

Composition.—Specimens from the same dikes and from different dikes vary considerably in composition. Phenocrysts of quartz are found in the rock of one part of a dike while they may be entirely absent from another part. Where it is abundant, there is on the average one good sized grain of quartz for each square centimeter of surface area. In most specimens examined, however, there was much less. A lime-soda plagioclase feldspar makes up practically all of the other phenocrysts. Multiple twinning can be seen with the unaided eye in many of these grains. The large feldspars have been much kaolinized.

Microscopic examination shows that the mineral constituents are: Orthoclase, plagioclase and quartz; the secondary minerals, epidote, chlorite, kaolinite and sericite; and the accessories, apatite, magnetite and pyrite. The exact determination of the plagioclase feldspars in this section is impossible on account of the kaolinite and sericite that have formed on the parent feldspar grains. However, chips broken from the freshest phenocrysts and placed upon the stage of the microscope and measured for the maximum extinction angles from the trace of the albite twinning indicate that the plagioclase is andesine. Ferromagnesian minerals, probably mostly hornblende, have been largely or entirely replaced by chlorite, epidote and zoisite. The greenish color of much of the rock is due to the abundance of chlorite. Quartz is present both as phenocrysts and in the groundmass. In the latter condition it encloses many minute orthoclase crystals. Apatite is quite abundant. It occurs as minute needle-like crystals. Magnetite appears as small grains, and it also surrounds those minerals which have been formed through the alteration of the ferromagnesian minerals. Pyrite anhedrons, small but rather plentiful, occur with chlorite.

MOUNT ALTO QUARTZ MONZONITE PORPHYRY

Occurrence.—This rock is found in a single dike about one-fourth of a mile north of Mt. Alto Park, and about one mile east of Gold Hill Station.

It is of no economic importance as far as is known, but it is an extremely interesting rock to the petrographer on account of its similarity to the great stock of monzonite porphyry that lies a short distance to the north.

Texture.—The texture is coarsely porphyritic. Single crystals of orthoclase two inches long are not uncommon and there are many from one-half inch to one inch in length. Quartz is also phenocrystic, although there is more in the groundmass.

Color.—The color is prevailingly gray or brownish gray, although the white or pale flesh-colored orthoclase phenocrysts may give slightly different shades. Much fresh biotite in the groundmass, and as small phenocrysts combined with the quartz and feldspar, both of which are commonly quite fresh, give the rock a speckled appearance.

Composition.—The minerals just named in the preceding paragraph are the only ones that can be recognized without the aid of a microscope.

A detailed microscopic examination of thin sections from this rock was made by Mr. Donald C. Kemp, and his description, slightly modified by the writer follows:

In the thin-sections of this rock, examination under the microscope discloses titanite, magnetite, apatite, hornblende, biotite, feldspar and quartz; also chlorite and a carbonate.

The titanite occurs as anhedrons and euhedrons. The latter are of two types: (a) Long lath-shaped crystals, which in some cases show twinning, and (b) minute grains, having a rhombic outline. It is fairly plentiful in the rock, equalling if not exceeding the quartz grains in amount. The largest crystals occur with magnetite; many of these contain inclusions of apatite. Magnetite is plentifully scattered throughout the section, and occurs, (a) as comparatively large anhedral masses 0.5

mm. or less in diameter, generally in patches or groups, (b) as smaller euhedrons sparsely distributed, and (c) as minute, pepper-like sprinklings, or "reaction-rims" surrounding biotite and hornblende. These minerals also enclose magnetite grains. Minute crystals of apatite, both in slender needlelike forms, and in short stout prisms are found as inclusions in most of the larger titanite crystals.

Hornblende, which originally occurred as small, well-developed phenocrysts has been almost completely replaced. Of the mineral itself but one or two small fragments were noted in the slide. The crystal cavities however, have been refilled by magnetite, chlorite, and a carbonate, probably of magnesium and calcium. The borders of these pseudomorphs as a rule are surrounded by rims of secondary magnetite. Biotite, sparsely distributed, appears as medium-sized flakes, all of which contain inclusions. These are, for the most part magnetite, with one exception, viz., that of a relatively large, rounded feldspar grain. An instance was noted also, where a feldspar phenocryst included a partially chloritized biotite flake. These relationships indicate that the crystallization of biotite and feldspar was in part at least, synchronous. In general the biotite shows less alteration than does the hornblende, although the outlines of the flakes are ragged, indicating that alteration has set in.

The feldspars are orthoclase and plagioclase. The former occurs as large ragged euhedrons and subhedrons which show fracturing. The surfaces as a whole appear fresh, but along the fracture-lines sericitic material appears, and slight kaolinization has developed. Inclusions of magnetite are common, and in one case, above mentioned, a tablet of biotite appears. The orthoclase except in one instance, is not twinned. In this case, however, the trace of the twinning plane is parallel to the trace of the principal cleavage. The cleavage remains in the position on both sides of this trace. This is a characteristic of Manebach types. Phenocrysts of about half the size of those just described, and of more regular outline are common. Kaolinization is quite noticeable in the centers of these. Plagioclase, in well distributed small and medium-sized phenocrysts; and in large localized patches composed of interlocked lath-shaped grains, occurs about equally with the orthoclase. Twinning after the Carlsbad, albite, and Manebach laws is common, and sometimes all three systems appear in the same mass. In general, however, the first two only occur. Kaolinization in the plagioclase has not developed to the extent shown in the orthoclase. Extinction angles, in sections normal to the albite twinning, measured from the trace of the twinning plane, vary from 8° or 9° to as high as 17° in one or two cases. No very satisfactory determination of the feldspar could be made in this slide, because of the manner in which most of the crystals are cut. But where Carlsbad twinning is present there is a sharp contrast in interference colors between crossed nicols, in the 45° position. This evidence, together with that of the extinction angles, places the plagioclase in the andesine group; and the zonal banding shows a gradation in composition from the borders toward the centers of the crystals; the centers being more basic. Quartz occurs in small rounded grains few in number, and scattered. These all show resorption. The phenocrystic quartz content would probably be less than 3 per cent of the entire rock.

The ground-mass, which constitutes about half of the rock, is composed of much altered orthoclase, and possibly quartz in micropoikilitic texture.

QUARTZ LATITE PORPHYRY

Name.—Quartz latite porphyry is the term applied to rocks of the same composition as quartz monzonite porphyry, but whose groundmass is largely glassy.

Occurrence.—It is interesting to note that two of the three quartz latite porphyries of the region are found on the borders of quartz monzonite porphyry dikes, while the third is very closely associated, if not actually connected, with its granular equivalent.

The first of these rocks occurs in the White Raven mine near the contact of the large quartz monzonite porphyry dike and the granite country rock. The rocks are mapped together with the name of the latter porphyry.

Another quartz latite porphyry is found on the borders of the Brainerd quartz monzonite porphyry in Tuscarora Gulch. It is also mapped as quartz monzonite porphyry.

About one mile east of Sunnyside, on the north side of Fourmile Creek, there are three dikes close together, and all of the same rock. The eastern one of the three can be traced almost to the large branching quartz monzonite porphyry dike which is found slightly farther east and northeast. There is every reason to believe that they are all parts of the same intrusion. The three dikes have, however, been shown on the map under their proper names.

Texture.—All of the rocks are distinctly porphyritic. Few phenocrysts are more than 5 millimeters in diameter. In the hand specimens, the groundmass in all cases appears very dense. Under the microscope it is found to be almost entirely glassy, but it includes some very small feldspar grains. The groundmass and phenocrysts occupy nearly equal areas.

Color.—The two rocks first mentioned above under "occurrence" are gray. Those east of Sunnyside are a very light brown, and are much streaked with iron rust.

Composition.—In so far as the composition can be determined it agrees almost exactly with that of the White Raven and Brainerd quartz monzonite porphyries, with which these rocks are respectively associated. Orthoclase, intermediate plagioclase, quartz and biotite, and the common secondary minerals derived from the alteration of these are the important recognizable minerals. The White Raven quartz latite porphyry is highly impregnated with galena which is silver bearing.

MICA DACITE PORPHYRY

Name.—A fine-grained porphyritic rock, composed of chiefly quartz and plagioclase with subordinate amounts of orthoclase, and one or more of the minerals biotite, hornblende and pyroxene, is called dacite. In the Ward district the rocks of this general composition have biotite in large amounts and are, therefore, mica dacite porphyries.

Occurrence.—There are 11 dikes in the Ward region, and all but one are north of Lefthand creek. One large dike runs north and south from one hill to the other across Lefthand Canyon, just east of Puzzler. The others lie mainly in a belt about one and a half miles wide, from the Lois mine on the west nearly to the east border of the area.

Texture and Color.—There is a rather remarkable similarity in the appearance of the rocks in these dikes. When fresh, the color is gray or greenish gray. The groundmass is very fine grained, and, in some cases from the borders of the dikes, it is glassy. There are many prominent phenocrysts of feldspar, quartz and biotite. Usually the feldspar crystals are rectangular in outline. They are six or eight millimeters in length and two-thirds as broad. In some specimens the quartz phenocrysts are as large and quite as numerous as the feldspars, but in the average specimen they are fewer in number and slightly smaller. In most of the rocks studied much black, very lustrous biotite is present in hexagonal crystals. The freshly broken surface of average specimens shows a rather coarsely porphyritic rock whose phenocrysts are fresh and of glassy luster. These stand out in strong contrast to the dense gray or greenish gray groundmass. When weathered the color is greenish gray, dull gray or brown.

Composition.—The composition, as shown in the hand specimen, is indicated in the preceding paragraph. Many thin sections were studied under the microscope, and the minerals determined are: Plagioclase, quartz, orthoclase, biotite, magnetite, apatite, epidote, sericite, chlorite, kaolinite. In a thin section of the dike rock that runs east from the Lois mine, garnet and zoisite were also found.

Very little orthoclase occurs as phenocrysts, but there is considerable in the groundmass. It is fresh in some specimens and coated with kaolinite or sericite in others. The extinction angles in the plagioclases measured from the trace of albite twinning averaged between 0 and 3½ degrees. Therefore the plagioclase is believed to be a rather basic andesine. Quartz is abundant as phenocrysts and also in the groundmass. In the latter it is micrographic, enclosing minute tablets of feldspar. Biotite is found in larger amounts as phenocrysts, than in the groundmass, but is present in both conditions. Apatite is abundant in long needle-like crystals, and is sparingly present in short prisms. Magnetite is not plentiful. When present it is in euhedral crystals. In the Lois mine dacite there are minute garnets in the groundmass which are apparently dodecahedral in form. They are surrounded with a matrix of epidote and zoisite and are clearly of secondary origin. Epidote, zoisite and chlorite are present in approximately equal amounts. They have been formed through the alteration of feldspars and ferromagnesian minerals. Chlorite gives the groundmass of some rocks its green color. In some sections kaolinite and sericite are abundant. In others they are entirely absent.

In weathering, both biotite and feldspar crystals disintegrate rapidly, leaving little pits, while the quartz stands out prominently as knobs on the surface of the rocks.

TRACHYTE

Name.—Trachyte is the name applied to a fine-grained rock of the general composition of a syenite. It contains chiefly orthoclase feldspar and one or more of the ferromagnesian minerals, biotite, hornblende or augite. The two soda-lime feldspars, albite and oligoclase, are generally present in small amounts, as are of course the common ascessories, titanite and zircon and sometimes quartz in very small amounts.

Occurrence.—This rock is popularly known as the "Sunset trachyte," because of its occurrence in a large stock, and in dikes near that village. The main part of the trachyte stock is on Bald Mountain, about a mile and a half west of Sugarloaf Mountain. The large dikes extend out to the north from the stock. One of them crosses Fourmile Canyon and continues for more than half a mile beyond. Three other dikes of trachyte are found near those already mentioned. Before the railroad between Boulder and Sunset was junked, this rock was shipped in car load lots to Boulder where it was crushed and used to surface streets. Its platy jointing made it very suitable for this purpose.

Description.—It was impossible to secure fresh specimens of trachyte, therefore the appearance of the unweathered rock is not known with certainty. It is probably a light gray rock with pale pink, flesh colored or white phenocrysts of orthoclase. The weathered rock ranges in color from a light brown through buff to red and pinkish gray. Kaolinization is pronounced, and there are numerous pits where there were at some time ferromagnesian minerals. Manganese stains are very common.

Wherever it is found the rock breaks into sharp-edged plates, which are usually not more than two or three inches in thickness. The texture is usually decidedly porphyritic.

The phenocrysts seldom exceed 3 millimeters in diameter. They are chiefly glassy orthoclase, but hornblende, or at least outlines of what is believed to have been hornblende, occurs in small amounts.

Composition.—Orthoclase is the most important primary mineral in the rock. It has been replaced by sericite and kaolinite to a very large extent in the specimens that were examined. A small amount of soda-lime feldspar probably oligoclase is also present. Considerable iron and chlorite are believed to be derived from the decomposition of ferromagnesian minerals, and small amounts of titanite and zircon complete the list of recognizable minerals in the thin sections that were examined.

[1]Breed made both microscopic and chemical analyses of this rock and records apatite, and probably augite in addition to the minerals given above. His chemical analysis is given in the accompanying reference.

There are few, if any, important ore deposits connected with the trachyte intrusions.

MONZONITE PORPHYRY

Name.—Monzonite is the name commonly applied to rocks intermediate in composition between syenite and diorite or between diorite and gabbro, in which orthoclase and plagioclase occur in nearly equal amounts, and in which one or more of the ferromagnesian minerals is present. If much more orthoclase than plagioclase is present the rock inclines toward syenite, if the reverse is true, to a gabbro.

According to this usage, the rocks in the Ward region, which have the mineral composition indicated above, and in which the groundmass is microlitic and the texture distinctly porphyritic, are called monzonite porphyries.

Occurrence.—This rock has the greatest areal distribution of any of the post-Cambrian intrusives in the region. It forms a very large irregular stock which extends from the south side of Fourmile Creek nearly to Gold Lake. It also is found in 18 dikes.

As is stated in the first part of this chapter, it is believed that the monzonite magma is the parent of most of the intrusive rocks of the region, and this opinion will probably be substantiated by a

[1]Breed, R. S., The Sunset Trachyte, from near Sunset, Boulder County, Colorado. Colorado Scientific Society Proceedings vol. 6, pp. 216-230, 1899.

detailed study of the geologic map, on which the relations of the great monzonite stock to the other intrusive rocks is well shown.

Description.—There is a wide variation in the appearance of the rocks classed as monzonite porphyry. Most of them are coarsely porphyritic, with orthoclase and hornblende predominating. Others have fewer and smaller phenocrysts, with hornblende in long slender needles the dominant mineral. Still others are essentially even grained, but have some feldspar phenocrysts which are so small or so nearly the color of the groundmass as to be very inconspicuous.

When fresh the rock is rather dark gray in color, but it weathers rapidly, and the color changes to some shade of brown or greenish gray. The pink, flesh colored or white feldspar crystals, and the black hornblende or biotite relieve the rather monotonous gray or brown that would otherwise be pronounced. The feldspar phenocrysts, however, kaolinize as weathering goes on and turn yellow or brown, and the ferromagnesian minerals also break down so that after prolonged weathering the prevailing color is a light brown, sometimes with green tone, which is characteristic of the monzonite porphyry areas as a whole.

Composition.—Orthoclase and sanadine constitute most of the feldspar phenocrysts. Many orthoclase crystals, perfect in crystal form, or twinned, and more than an inch in length have been found where the monzonite has been disintegrated through the agents of atmospheric weathering. Orthoclase also occurs sparingly in the groundmass. Plagioclase, mostly andesine, is the most important mineral in the groundmass. It also may occur as phenocrysts, which are smaller than the orthoclases. The proportion of orthoclase and plagioclase varies greatly in different parts of the same stock. As a rule plagioclase is found in greater amounts. In some places it is impossible to differentiate between monzonite porphyry and diorite porphyry. Hornblende is the most important ferromagnesian mineral. It occurs both as fine, long needle-like crystals, and as medium sized stout phenocrysts. It is present also in the groundmass. Biotite is rarely phenocrystic, but is present in the groundmass. Epidote invariably accompanies hornblende and biotite. Zircon is found in some sections as inclusions in the hornblende. Titanite is abundant in the groundmass as is magnetite. Sericite, kaolin, chlorite and calcite are plentiful in the thin sections of weathered rocks.

LATITE PORPHYRY

Name.—Latite is a monzonite in composition, but with a groundmass that is largely glassy. Latite porphyry, therefore, is, as the name implies, essentially like the monzonite porphyry just described except that it is finer textured and has much glass in the groundmass.

Occurrence.—There are 9 latite porphyry dikes which are scattered widely over the Ward region. Some are found near Copper Rock, others near Tuscarora Gulch, and others north of Sunnyside, as well as in intermediate areas. Practically all of the latites are mineralized at least on their borders. Pyrite is found in nearly all of these rocks, and the occurrence of more or less gold with the pyrite is not uncommon. Because of the pronounced mineralization, particularly on the borders of latite intrusions and granite, there has been much prospecting in such regions, and every latite dike has been well exposed.

Several masses of latite porphyry are found on the borders of monzonite porphyry dikes or stocks. They have been mapped with the monzonite. Others occur on the borders of diorite porphyry, and have been mapped with the diorite.

Description.—In the whole Ward region no other series of dike rocks, which can be classified under a single group name, exhibits so many variations in color, texture and condition of weathering as do the latite porphyries. No two look alike. In most cases they do not resemble any other rocks in the region, although some are much like andesites, and others might be mistaken for some of the felsites. All have two common characteristics, a dense or glassy matrix and many phenocrysts. Here the similarity ends. Some have many small phenocrysts, others have few and large ones. Gray and brown colors, or tones intermediate between these are most common. In most of the hand-specimens taken from the dikes, the phenocrysts are feldspar. In some, hornblende is prominent, in two biotite is very common, and in one all three minerals are abundant.

Nearly all of the latites are bady weathered. It is probable that where fresh they are of medium gray color, but after weathering the color is likely to be one of those mentioned in the preceding paragraph.

Composition.—The latite porphyries have essentially the same composition as the monzonites just described. Most of them are so badly weathered that it is impossible to determine the original mineral composition. Plagioclase seems to be more abundant in the groundmass than orthoclase, and it is also equally important in phenocrysts. Hornblende was probably the most common ferromagnesian mineral, but in most of the specimens it has been badly altered. Biotite is rare in most of the thin sections examined. In at least two, however, it is abundant as phenocrysts. Epidote, chlorite, kaolinite, magnetite and titanite are of very common occurrence. The green minerals, epidote and chlorite, have much to do with the color of the weathered rocks. Pyrite is very abundant in some of the dikes.

DIORITE PORPHYRY

Name.—This name is given to a rock intermediate in its silica content, which is holocrystalline and porphyritic, and which contains chiefly an intermediate plagioclase feldspar and one or more of the ferromagnesian minerals.

Occurrence.—The diorite porphyry of the Ward region is almost certainly a differentiation product of monzonite. It is found in six different intrusions, two of which are small stocks and the rest are dikes. Two dikes are quite large. The diorite occurs chiefly north and south of Lefthand Creek, one or two miles east and southeast of Ward. One large dike crosses the old Denver, Boulder and Western railroad grade, about one mile northwest of Sugarloaf Mountain. North of Lefthand Canyon and just east of Tuscarora Gulch there is a stock of what should properly be called diorite porphyry. This connects with the monzonite porphyry stock of Burnt Mountain by a narrow neck of the latter rock. Within the borders of the stock are good examples of the closely related rocks, monzonite, latite and diorite porphyry. The prevailing rock is, however, the latter.

Description.—In general appearance the diorite porphyries are much like the monzonites, except that they are somewhat coarser grained. They are all porphyritic. All are brown or gray in color and nearly all show abundant plagioclase and biotite phenocrysts. When weathered the color of the surface of the rocks is brown or reddish, often the latter, due to the liberation of iron oxides. The rock joints and breaks into thin, nearly flat sharp-edged plates which lie in many places on steep hillsides and protect the underlying rocks from rapid disintegration.

Composition.—Under the microscope the following minerals were recognized: Plagioclase, biotite, a little orthoclase, apatite, titanite and calcite. All of the feldspars are badly weathered, but most of them seem to belong to the group basic andesine. Some of them seem to be andesine on the borders and a more basic feldspar probably labradorite in the center.

Phenocrysts make up more than one-half of the average rock. There are apparently two periods of crystallization of the phenocrysts. During the later period more, but smaller, grains were formed.

Biotite is brown in color. It occurs in many irregular grains, almost always bordered by magnetite. In the hand specimens, thick grains of biotite, which happen to be oriented in the right direction, much resemble hornblende when seen on their edge. Apatite is found as long slender grains. It is closely associated with calcite. Titanite is sparingly present. Hornblende is found in small quantities in some specimens. There are no important ore deposits known on the diorite dikes in this region, and there is very little mineralization of the rocks. There are some prospect holes, long since abandoned near the contacts of this rock and granite.

ANDESITE AND ANDESITE PORPHYRY

Name.—Andesite is the name given to fine-grained rocks which have the composition of diorites. Such rocks contain large amounts of intermediate or basic plagioclase feldspar and one or more ferromagnesian minerals, with (usually) smaller amounts of orthoclase and other accessory minerals. The rocks may or may not be porphyritic, but in the Ward region, practically all are.

Occurrence.—All of the andesites in this region occur in dikes. There are no stocks. Fifteen dikes, which include the various varieties of andesite, have been mapped. The most important group of dikes is found south of Copper Rock on the north side of Sugarloaf Mountain. Others are scattered widely over the whole region. Several dikes are half a mile or more in length and from a few feet to more than 100 feet in width, but most of them are smaller.

Many prospect holes have been dug on the borders of the andesite intrusions on account of their extensive mineralization, but so far as could be determined no large and rich bodies of ore have been found.

Description.—Most of the fresh andesites are gray. Some are very dark, others are light. Many are brownish or greenish gray when slightly weathered, due to the liberation of iron or to the formation of epidote or chlorite from the ferromagnesian minerals. Thoroughly weathered surfaces are, in most cases, some shade of brown.

The groundmass of most of the rocks is very fine grained. Grains of feldspar, and biotite, hornblende, or augite often occur in sufficient size to give the rock a distinctly porphyritic appearance. Most of the feldspar outlines are rectangular. When hornblende occurs as phenocrysts it is usually in needle-like grains from one-fourth to one-half an inch in length. Where augite is phenocrystic the grains are usually short and stout. If broken they show rectangular outlines. A large proportion of the biotite grains that are large enough to be regarded as phenocrysts are really very small, possibly averaging 2 millimeters in diameter. Their hexagonal crystal form may be easily seen under a pocket magnifying glass. The rocks containing hornblende or augite phenocrysts are, as a rule, much more weathered than are those which contain biotite.

Some of the andesite porphyries can not be distinguished in the hand specimens from diorite porphyry. In fact the same masses of rock in some cases, are dioritic in the center and andesitic on the borders. Andesites and latites also may look very much alike, and it is impossible to separate them except under the microscope.

Composition.—This has in part been indicated in the preceding paragraphs. All the slides that were studied, showed orthoclase, plagioclase, biotite and titanite. Hornblende was present in nearly all cases, and a pyroxene, which is believed to be augite, was found in several sections. In the weathered specimens the feldspars were more or less kaolinized, and red and black iron ores, epidote, chlorite and calcite occurred in abundance, as alteration products of the ferromagnesian minerals. A little primary quartz is present in some specimens, and there is some which is probably secondary. Most of the titanite is fresh or very little altered. Some large zircon grains were found, and apatite inclusions in feldspar were of frequent occurrence.

There are few orthoclase or microcline phenocrysts, but considerable orthoclase is in the groundmass. Most of the plagioclase is acidic andesine, but some labradorite is present. Many plagioclases show zonal banding and are obviously more basic in the center than on the edges. In some specimens hornblende phenocrysts far exceed the feldspars, but in the majority of cases, feldspars are the most numerous.

OLIVINE BASALT

Name.—Olivine basalt is the name applied to a fine grained rock of the composition of a gabbro. That is, one which contains chiefly a basic feldspar, pyroxene and olivine.

Occurrence.—There are two small bosses of this rock near the Mountain View and White Pine mines in Chipmunk Gulch, about one mile north and a little east of Ward. Neither boss has a surface area of more than a few hundred square feet. No important ore deposits are known to occur here.

Description.—This rock is a very fine textured, dark gray basalt, of high specific gravity. In the hand specimens, many minute lath-shaped grains of gray feldspar, and larger grains of green olivine can be seen. While the texture is, as a rule, fine and even, it varies from place to place, and near the borders of one of the intrusions it is vesicular. The vesicles have been filled with amygdules of secondary white quartz. The rock weathers to a dark brown color. Weathered surfaces are much pitted, and are streaked with red or brown iron oxides. No regular system of jointing could be found.

Composition.—Microscopic study of thin sections shows that basic, undetermined plagioclase is the most abundant mineral present. This feldspar shows no polysynthetic twinning, and as no chemical analysis of the rock was made its composition is not definitely known. Augite and olivine are also present in large amounts. Considerable black iron ore and calcite are found in weathered specimens.

DIABASE

Name.—This rock was named hypersthene diabase by Professor Crawford in his descriptions of the rocks of the Sugarloaf district.[1] Since the publication of his report on that area, Professor Crawford has studied this rock further, under the microscope, and has advised the writer that he has some doubt as to his original identification of the mineral called "hypersthene." He, therefore, believes it better to call the rock simply diabase.

Diabase is the term used to define a basic rock of the composition of the gabbro family, but intermediate in texture between the granitoid (holocrystalline) gabbro and the felsitoid (lens grained) basalt. It has also another textural significance, in that the older lath-shaped feldspars are separated by younger irregular grains of pyroxene. If the pyroxene grains actually enclose the feldspars the texture is called "ophitic."

Occurrence.—There are 5 dikes of this rock, all in the northeast corner of the area. The largest dike is about 60 feet wide and extends northwesterly for more than a mile from the east border of

[1]Crawford, R. D., Geology and Petrography of the Sugarloaf District: University of Colorado Studies. Vol. 6, No. 2, p. 115, 1909.

the region mapped. It is the same dike which cuts through the Sugarloaf district, and its course can be followed for 10 miles or more. This dike is much more resistant to the agents of erosion than the country rock which it cuts, and it, therefore, makes a conspicuous ridge throughout its whole extent in the Ward region.

The other dikes are not so large nor are they so conspicuous, but they are easily recognized, and can be followed by their topographic forms. No important ore bodies have been found on these dikes.

Description.—For a full description, including microscopic analysis of this rock, the reader is referred to Professor Crawford's report[1] mentioned above.

The diabase is heavy, hard and very tough. Fresh pieces can be broken only with difficulty.

The color is black, gray or dark greenish gray. The latter color predominates. When weathered the color is brown or brownish gray.

In the small dikes and along the borders of the large ones the texture is fine grained, but near the center of the large dike it is porphyritic or in some cases entirely holocrystalline. In the course-grained rocks greenish gray feldspar predominates, but a black fibrous looking pyroxene can also be seen. It is evident that the feldspar is responsible for the common greenish-gray color of the rock.

Most of the dikes show highly developed cubical jointing.

Composition.—Under the microscope four important minerals are seen: A basic plagioclase feldspar which shows much polysynthetic and occasional Carlsbad twinning, augite, hypersthene (?) and black iron ore. Calcite and sericite, which are alteration products of the feldspar, quartz, which occurs in small amounts on the borders of some of the pyroxenes, serpentine, which is also an alteration product of the pyroxene and iron oxide, are the important secondary minerals.

Age.—The evidence of the relative ages of this and the other intrusive rocks in the region is not conclusive, for contacts are much obscured in some cases. It is known however that the diabase is younger than the metamorphics, granite and pegmatite. It appears to be younger than one mica dacite and one felsite dike which it intersects. It seems to be older than and cut off by a stock of monzonite porphyry, but it may have come from the monzonite magma through magmatic differentiation.

[1]Op. Cit. pp. 115-118.

CHAPTER VI

ECONOMIC GEOLOGY

ORE DEPOSITS

GENERAL DISCUSSION

When this report was first contemplated the writer expected to make a full examination of the mines of the Ward Region in order that he might study thoroughly the ore deposits. It has been impossible to make such an examination and study on account of the small number of mines that have been in operation at any time since this work was started.

Practically all of the mines that have been opened since 1911 have been studied, however, and the following notes are based in part on specific data procured from such study, and in part on more general information secured from many sources.

GEOGRAPHIC SITUATION

The Ward region is near the northeast end of the great mineralized zone which extends for about 250 miles from Montezuma County in southwestern Colorado, northeastward to the central part of Boulder County. This zone is between 100 and 125 miles wide. It contains practically all of the noted mining regions of the state, among which may be noted, Nederland, Blackhawk, Central City, Georgetown, Empire, Montezuma, Fairplay, Alma, Telluride, Silverton and Rico. Cripple Creek and Silver Cliff and intermediate mining regions lie in a shorter subsidiary belt of the same general trend.

There have been reports prepared by the United States Geological Survey or by the Colorado Geological Survey on nearly all of these areas.

GEOLOGIC CONDITIONS

STRUCTURE

Strike.—With the exception of some of the deposits near Sunset and Copper Rock, nearly all of the ore in the Ward region occurs in veins which strike roughly east and west. In some cases the strike is northwest. The latter is true of veins in California and Puzzler gulches south of Ward.

Dip.—Nearly all of the veins dip at rather high angles to the north. Angles of 60° are not uncommon. Angles of less than 45° are infrequent. Sharp changes in dip are very common.

FORMS OF THE ORE DEPOSITS

Most of the ore deposits are in fissures, and are known as fissure veins. Some deposits are found directly on the contacts of igneous intrusions and country rock and may be classed as contact deposits. It is probable, however, that these are actually fissure veins whose position is dependent upon the formation of fissures subsequent to the intrusions.

In the White Raven mine much of the ore occurs in shoots. In the shoots between the surface and depths of 500 or 600 feet there are many large vugs. Similar shoots of less importance have been encountered in other mines.

Nearly all of the veins are single and straight, without branches or faults. Some, however, are branching.

VEIN FORMATION

County Rock.—The best-developed and richest veins are in granite or gneiss. The Idaho Springs formation seems to have been incompetent to preserve fractures and fissures caused by crustal movements, to the same extent as the granites. The result is that well defined veins in the granites and gneisses often play out in part at least when followed into the schists.

The mineralization in the granite veins is also much greater as a rule than in the highly metamorphosed rocks. This is due, the writer believes, not only to the conditions mentioned in the preceding paragraph, but to the further fact that in the schists because of their structure, conditions would be more favorable for dispersion of mineralized solutions, hence, there would be less likelihood for concentrated deposits.

Relations to Igneous Intrusions.—There is an undoubted relationship between the ore deposits and the Tertiary (?) intrusive rocks. Close questioning of the prospectors who were the first in the district revealed the fact that they "invariably looked for porphyry dikes" when prospecting for new ore bodies. More than half of all of the ore deposits of the whole region are on or near the contacts of dikes.

The richest deposits seem to be closely associated with felsite, dacite, quartz monzonite and latite or quartz latite dikes. These are the ones that were, in all probability, richest in mineralizers at the time of their intrusion.

Origin of the Veins.—That the veins are not all, possibly not the majority, contemporaneous with the intrusions, is shown by the fact that in many cases veins are found within the intrusion, and by the further fact that brecciation in the intrusions and vein filling some distance from the walls has been noted in several instances.

There were, at least, two periods of movement. The first was of large extent and preceded most of the Tertiary vulcanism. The position of the dikes was largely determined by the formation of fissures at this time. The second period of movement with consequent fissuring closely followed the main igneous activity and gave rise to many of the veins that are now found. Because of the limited number of veins that could be examined it is impossible to state whether or not there was a second period of vulcanism following mineralization of the fissures, but it is probable that there was, and that some of the veins have been cut by dikes.

The concentration of the ore deposits near the intrusions, but not necessarily as contact deposits, is probably due to the fact that hot solutions were most abundant and most active near the intrusions, and to the further fact that, in addition to the fissuring caused by crustal movements which preceded igneous activity, there were undoubtedly many fissures in the country rock caused by the intrusions themselves.

Such fractures would be most numerous near the surface of the ground, and would be fewer in number farther down. The land surface at the time of the Tertiary (?) intrusions was much above the present one, hence fissures formed in that way may have largely disappeared through erosion.

The size of the veins is very variable. Some workable deposits are only 6 inches wide. The average width of the veins in the whole region is from 2 to 4 feet. In the Columbia, Niwot, Baxter, Utica, Dew Drop and others, ore bodies from 6 to 8 feet wide are not uncommon. The White Raven vein is 14 feet wide in some places.

Faults that have displaced parts of the veins are not uncommon. The writer has had opportunity to examine faults in the Dew Drop. Newmarket, Humboldt and Nelson, and many others are reported. Nearly all have small displacements, and the faulted ends of veins have been picked up in most cases without much difficulty.

ORES

Gold, silver, lead, copper, zinc, tungsten in the order named are the important ores. Only the first three have been produced, in large quantities, but the others are known to exist in various parts of the region.

GOLD ORES

Occurrence.—Gold has been found in four forms in the Ward region. Some of the first strikes of gold were made in placer deposits. The gold was washed down from the lodes or veins in which it originally occurred and deposited in sand and gravel along the various streams. The placer deposits were never very important and have long ago been worked out. Most of the gold has been found in quartz veins with pyrite or chalcopyrite or both. In such occurrence the gold in the free state is intimately associated with the iron or copper iron sulphide. When it occurs with chalcopyrite the deposits are likely to be richer than in those with pyrite alone. Chalcopyrite usually is less abundant than pyrite, but in some cases it is much more abundant.

Gangue minerals are chiefly quartz, sericite and fluorite. Quartz is invariably present in the large fissure veins. It may be either massive and white or crystalline and colorless. The former variety is much more common except in drusy cavities in veins above the ground water table.

Sericite is of common occurrence in many of the vein walls due to the action of mineralized solutions which filled the veins. This action was undoubtedly effective in widening the original fissures and in increasing to a pronounced degree the size of the mineralized bodies.

Unimportant, but nearly universally present, minerals in most of the larger mines are molybdenite and wolframite. Molybdenite is found sparingly in many veins. It usually occurs as thin black facings which look much like graphite but are blue gray rather than black. In some veins it is present in small flakes.

Wolframite is found in nearly all of the mines of the Ward district. It was not found by the writer in the mines near Sunset. In the Niwot, Newmarket, Humboldt, Nelson and other mines near Ward, and especially in the regions west and south of Gold Lake, it is particularly abundant.

Gold ores also occur with galena and sphalerite ores. Some gold has been mined from veins which contain chiefly galena, silver, and sphalerite. In these veins gold may occur both in its native state and as an alloy with silver. It is not high-grade gold ore, however, and the veins are not mined for their gold content. Only the White Raven mine and others on the same vein and certain others north of Sunnyside have ores of this type.

Calcite and barite are the two most common gangue minerals. Tennantite is present in the White Raven mine in small quantities at depths of approximately 600 to 1,000 feet below the surface of the ground.

Telluride gold ores occur in some mines, particularly those on the east side of the Ward region. Rich telluride ore is reported from the Morning Star mine in Spring Gulch.

ENRICHMENT

Secondary enrichment of the pyritic gold ores above the permanent ground water table and extending slightly below that surface has been of utmost importance in the development of the gold mines of the region, because it is in this oxidized zone that all the rich, "free milling" gold ores have been found.

The oxidized and enriched zone is clearly defined in all the mines which have been started at the surface and which have penetrated well into the ground-water zone. Near the surface the vein minerals are either oxidized or coated with iron oxides. Limonite is the most common mineral. It is rusty yellow or brown in color, and as it has been widely distributed by water, it discolors all substances in and near the veins, with which it comes in contact.

The gangue quartz is stained and loosened by the solution of the associated pyrite. It is often honey combed and is called by the miners "rotten quartz." Drusy cavities lined with small quartz crystals, and stained with iron oxides, are apparently favorable situations for free gold, and it is a well-known fact that from such cavities extremely high values in gold have been taken.

The reasons for the gold enrichment in the pyritic veins are two: First, some of the gold was dissolved and redeposited. Chlorine water is an active solvent of gold, and if the chloride solutions containing gold come in contact with iron (ferrous) sulphate the gold would be precipitated. Ferrous sulphate would undoubtedly be present in large quantities due to the oxidation of pyrite. The source of the chlorine is uncertain. It is, however, present in small amounts in some of the mine waters, and it is assumed that it has been an active chemical agent in the oxidized zone. That enrichment of this sort occurred, is indicated by the large amounts of free gold in certain "bonanzas" found near the surface of the ground. Such rich deposits could not easily be explained by mechanical concentration of the gold through long continued weathering. Solution and redeposition of gold is also indicated by the large size of many flakes and pieces of free gold that have been found in the enriched zone. The writer has seen some such grains that were one-fourth of an inch in diameter. In the veins well below the ground-water level nearly all of the gold is in microscopic grains.

The other process of gold enrichment was undoubtedly a residual one. Through long periods of time the quartz-pyrite veins were subjected to the attack of all the chemical agents in the air and in surface waters. The fractures in the veins at and near the surface of the ground were widened and the chemical activities were thus made to progress through the veins until largely through oxidation and carbonation processes the sulphides and other vein minerals except gold and quartz were removed or greatly altered. Gold would be left as a residuum, and in certain cases would be mechanically concentrated by the movement of solutions through cavities. Naturally, in such cases the gold would be caught and held in pockets and constricted openings of other sorts.

The depth of gold enrichment by the processes just indicated is dependent upon the permanent level of the ground water. Climatic conditions, topography and the texture of, and fractures in the rocks largely control this level. Fluctuations also are caused by mining operations which may drain temporarily or permanently certain regions, but these would be of too recent occurrence to have any important effect on the enrichment of ores. The ground-water table in the Ward region is from 50 to 200 feet below the surface of the ground. It is rarely, however, so deep as 200 feet.

VALUES

Nearly all the valuable gold ores have come from quartz and pyrite, or chalcopyrite veins. The values have varied greatly in different mines. Some very rich pockets of ore have been found in the oxidized portions of the veins and rich solid sulphide ore running from $100.00 to $300.00 a ton was by no means uncommon. The average value of the smelting ore produced in the region up to 1900 was between $60.00 and $70.00 a ton. Milling ore values ran from $10.00 to $15.00 a ton.

Below the ground-water level the values have greatly decreased. There are many thousand tons of ore now blocked out which will run between $6.00 and $12.00 a ton in gold. The average value of this ore is about $10.00 a ton in gold and from $4.00 to $10.00 in copper and silver combined, depending upon the market prices of those metals.

SILVER ORES

Silver is found in some amounts in nearly all of the gold veins. It is particularly abundant in the galena-sphalerite veins, but is usually present in the pyrite veins as well, where it is probably an alloy with the gold.

The proportionate amounts of silver and gold in pyrite veins are indicated by a group of twenty-four assays made from pyrite ores that were taken from all parts of the Ward region. These assays gave an average of .86 ounces of gold and 8.70 ounces of silver per ton of ore, or almost exactly ten times as much silver as gold by weight.

Mineral resources for the years 1910, 1911 and 1912 give a total production for the Ward district of 3,181 ounces of gold and 30,145 ounces of silver, which checks closely the ratio figures given above. This was before the White Raven mine was well developed, and the production was almost entirely from pyrite and chalcopyrite ores.

Mint reports for three representative years, 1887 to 1889 inclusive, when silver was "high," gave the following production values for a group of six mines. The mines were: B. & M., Boston, Colorado, Columbia, Morning Star, Puzzler.

The total values in gold and silver were: Gold, $168,774.80, and silver, $38,395.78.

The silver values, like the gold, are usually greatest in the veins that contain the most chalcopyrite. In the oxidized zone silver values are somewhat lower than in the same veins below the ground water surface. This fact would indicate that the primary silver in the veins is taken into solution to some extent by the chemicals of the air and of surface waters, and is carried away.

The greatest values in silver ore were found in the lead vein of the White Raven and neighboring mines. Since the White Raven was the only mine of this type that was carefully examined by the writer, the discussion of this type of ore will be deferred until the description of that mine is reached.

LEAD ORES

The only lead ore that has been mined in any considerable quantity in the Ward region is from the White Raven mine, therefore the occurrence of this ore will be included in the description of that mine.

Some very good-looking galena, which carries negligible values in gold and silver, was found on a dump (said to be the Gold Drop dump) about three-fourths of a mile northwest of Sunnyside. The shaft was full of water and the vein could not be examined. Considerable quartz and pyrite are on the dump. The country rock is mica schist.

COPPER ORES

Both chalcopyrite and chalcocite are important as ores of copper in the Ward region. Tennantite is found in the White Raven mine associated with galena, but it is not in large enough amounts to be classed as an ore.

Chalcopyrite is the most important copper mineral in this region. It is found in all parts of the area, but is particularly abundant in the mines south and west of Sunset and in the Dew Drop and many other mines near Ward. It is also found at Copper Rock where azurite and malachite have been derived from it through oxidation and carbonation.

From the Sunset region, chalcopyrite has been shipped to smelters, as an ore of copper, in which the gold and silver values have been secondary. Chalcopyrite contains 34.5 per cent copper. Some small shipments of ore from the mines near Sunset have run 20 per cent copper, which indicates the high percentage of chalcopyrite in the veins. Some of these veins are filled almost entirely with massive copper-bearing pyrite which can be mined in the nearly pure state.

The recoverable copper in the gold and silver ores shipped from pyrite and copper-bearing pyrite veins, and taken from below the ground water level averages between 1 per cent and 2 per cent for the whole region.

ZINC ORES

Zinc is not an important ore in the Ward region. It is found in commercial quantities only in the White Raven, Cross and Black Jack mines, all of which are on the same vein. Very little zinc has ever been saved from the White Raven ores. It will be discussed under the description of that mine.

TUNGSTEN ORES

Wolframite is widely scattered through the veins of the Ward district proper. It is not found far south of Ward, which is rather surprising as one would expect to find it in increasing quantities as the Nederland-Lakewood tungsten belt is approached.

Wherever wolframite occurs it is intimately associated with quartz and pyrite, and chalcopyrite is also likely to be present. Although wolframite is found in practically every mine near the town of Ward it has not been mined for the tungsten content from any of these mines except the Nelson. In 1915 and 1916, when the demand for tungsten for war purposes was at its height, certain ore bodies in the Nelson mine were opened with the intention of saving both tungsten and gold values. Wolframite is found in this mine in the 60 and 150-foot levels. A fault with nearly a north strike has cut both of these veins and no tungsten has been found west of it. The wolframite occurs only in pockets, and it is so irregular in amount and so thoroughly intergrown with pyrite that it is not believed to be commercially valuable.

Near Gold Lake there are several tungsten claims. The late Johnnie Knight owned the Connoton claims which are situated about one mile west of Gold Lake.

The Connoton vein is on the contact of mica dacite porphyry and granite. It dips 55° N. 10° W. A drift has been run along the vein for one hundred and fifty feet. Wolframite occurs with quartz and pyrite in the vein, which is from four inches to one foot wide. About ten tons of ore have been shipped from this mine which ran 6 per cent WO_3. It contained so much pyrite, however, that it could not be marketed.

An analysis of the wolframite from this mine[1] follows: WO_3 71.27, FeO 20.01, MnO 7.15, CaO 1.58. This analysis was erroneously reported from "Johnnie Ward's mine, instead of Johnnie Knights'."

During the recent tungsten boom, other properties were developed for wolframite, between Gold Lake and Spring Gulch. The ore and its associated minerals are practically the same as in Johnnie Knights' claims. The properties will be described under mines.

MINING INDUSTRY

GENERAL DISCUSSION

The mining industry in the Ward region has been declining for many years. The decline began with the panic of 1893. While mining has not steadily declined since that date, it is safe

[1]George, R. D., The Main Tungsten Area of Boulder County, Colorado; Colorado Geological Survey, First Report, p. 42, 1908.

to say that it has never recovered from the depression in the price of silver of that time.

About 1899 the annual production of the Ward district alone was $200,000. The annual production for the years 1910 to 1915 inclusive was $41,276 from an average number of nine mines. In 1916 the production was more than $130,000, due largely to the greatly increased output of the White Raven mine, which has been the largest producing mine, from the standpoint of value of the ores, since 1913.

About 1890 more than 2,100 persons got their mail at the Ward post office. At the present time, as this bulletin goes to press, December, 1920, there are not 200 people living in the whole area included in this report.

The decrease in mining in this region may be ascribed to three causes: First: The low price of silver which has affected the industry since 1893. Although the price of silver increased greatly during the war and following its close, mining costs also increased proportionately, and as the price of gold was fixed, it was not profitable to open mines that had long been unused.

Second: As so often happens in declining mining districts, litigation over the ownership of claims has prevented some mines from being worked.

Third, and by far the most important of all: Practically all of the rich pyritic ore deposits have been worked out in the oxidized zone. The ores below the ground-water table are of too low tenure, and the treatment costs are too high to allow profitable mining of the gold and silver ores in pyrite and chalcopyrite veins under existing economic conditions. It is safe to say that with the present fixed value of gold, greatly renewed activity in the mining of the Ward region will appear; only, after improved methods of ore extraction plus lower costs of such concentration and extraction have been developed.

MINES

GENERAL STATEMENT

There are about two hundred mines in this region that have produced some ore. Most of these are very small. It is believed that only about fifty have produced more than $5,000 in gross value during their entire history.

Even had it been possible to personally examine every vein opened by the two hundred odd mines of the region, a description of each mine would be of doubtful value in this report, for in most cases the descriptions would be of necessity largely stereotyped in form and would simply amount to a catalogue of the mines of the region.

As has been stated in the preceding pages, it was not possible to examine most of the mines, because they were not being worked and were full of water. Therefore, for this reason and the one suggested in the last paragraph, no attempt will be made to describe each individual mine. But a list of the most important mines will be given, and the reader will be referred to the Mining Reporter, vol. 40, pp. 18-20, 49-50, 65-66, 78-79, 94-95, 1899, for further information; and to the topographic map which accompanies this report for the locations of the various mines.

Certain mines, concerning which definite data were obtained, and which are representative of certain types of ores or of important localities are hereafter described in considerable detail.

IMPORTANT MINES OF THE WARD REGION

(It has been impossible to get complete data regarding the production of all the mines of this region. Some mines that should be included in this list may have been omitted. Mines that have produced more than $100,000 in combined ore values are starred):

Adit
*Baxter
*B. & M.
*Big Five
Boston
Cardiff
*Celestial
*Celestial Extension
Centennial
Chathem
Colorado
*Columbia
Copper Glance
Dew Drop
Dolly Varden
Forest Queen
Giles
Gold Queen
Gov. Routt
Homestake
Humboldt
Idaho
Innspruck
*Madaline
Maid of Erin
Milwaukee
*Morning and Evening Star
Nelson
Newmarket
Orphan Boy
Pennsylvania
Philadelphia
Puzzler
*Ruby
Skandia
Stoughton
*Sullivan No. 5
Texas
*U. P. Group
*Utica
*Ward Rose
*White Raven
Wirth

DESCRIPTIONS OF MINES

RUBY MINE

Location.—The Ruby mine is situated at Sunnyside on Fourmile Creek, about three miles due west of Sunset. Three claims are owned by the Ruby Mining and Milling Company. They are the Little Annie, Iron Cross and Ruby. All are patented. All have well-defined veins.

Geology.—The country rock is coarse grained gneissoid granite. It has been cut by a dark gray felsite dike which strikes nearly east and west. The dike forms the hanging wall of the Ruby vein. The vein is well defined and has been opened on the 100 and 240 foot levels. It is a typical quartz vein which carries pyrite and chalcopyrite with values in both gold and silver. The strongly mineralized portion of the vein is from six to eighteen inches wide, and from this streak smelting ore is mined which runs from $60.00 to $90.00 a ton. Associated with it is from 2 to 4 feet of mill dirt, which is simply more or less mineralized vein material. This carries values of from $2.00 to $14.00 a ton.

Development.—The development consists of a shaft 274 feet long, drifts on the vein of about 1,000 feet, and stopes between certain drifts, 75 feet high and 200 feet long.

Equipment.—The mine is well equipped with shaft house, steam hoist and all necessary buildings and mining machinery.

A small concentrating mill with stamps, classifiers, Card tables and Frue vanners has been operated to treat the milling ore from the Ruby and the Milwaukee mines. Only the low-grade concentrating ores have been so treated.

Production.—The total production from this mine is said to be $120,000.

WHITE RAVEN MINE

Location.—The White Raven property is situated on the north side of California Gulch at an elevation of 8,800 feet, about three-fourths of a mile south of Ward.

Geology.—The country rock is mainly coarse gray granite, but there is some schist. A large monzonite porphyry dike, in places 50 feet wide and about 1 mile long, cuts the granite and forms the hanging wall of the White Raven vein. The dike strikes nearly east and west and dips at angles between 45 and 80 degrees to the north.

Veins.—The vein was formed after the intrusion of the dike. A fracture roughly parallel to the dike and in most places on the contact between the dike and the country rock was made by earth movements. Brecciation of the dike and country rock was extensively developed, and the fracturing and brecciation of the rock was followed by vein filling.

The vein thickens and thins out between the walls from 2 or 3 feet to 14 feet. Small fractures branch out from the major ones and thus increase the opportunities for mineralization between the main vein walls. The main vein strikes nearly east and west and dips on the average 60° North. Between depths of 400 and 600 feet below the surface the dip flattens to 45°.

Shoots.—Much of the ore and most of the richest ore in the mine occurs in shoots which are roughly cylindrical forms in the vein, of large vertical but small lateral extent. Two ore shoots on the tunnel level run together on the next level, 100 feet below, and this is a rather common condition in other cases. On the fifth level of the mine a very large shoot was found. It was 30 feet wide and at least 200 feet long. Running out from these shoots for some distance on either side the ore in the vein is likely to be very rich.

Vugs.—Vugs or "bug holes," as they are called by the miners, are of very common occurrence in the White Raven mine. Wherever there is much brecciation in the vein vugs occur, and in the ore shoots, especially above the 500-foot level, many vugs into which a man could easily crawl are found. The vugs are almost invariably lined with very rich silver lead ore which occurs as galena crystals covered with wire silver.

Ores.—The ores are lead and silver with a little zinc, copper and gold. Lead occurs as galena, usually in large well-formed crystals. Silver is in two forms. It is included in the galena, probably as native silver, often alloyed with gold, and it is also extensively found in the vugs and upper portions of the vein as coatings on the galena in the form of wire silver. In many places the wires of native silver are so close together that they form a thick net over the underlying galena. The length and the diameter of the wires vary greatly. Many wires half an inch long, and with a diameter larger than a coarse hair have been found.

Zinc is not abundant in the mine, but sphalerite ore has been mined in some of the shoots above the 500-foot level, which ran 30 per cent zinc.

Gray copper, tennantite, is found sparingly in the lower levels of the mine. Scarcely any was found between the surface and the 700-foot level, but between the 700-foot level and the 1,170-foot level it has been found in small amounts scattered through the vein. It is apparently increasing in amount with greater depth.

Gold occurs at all levels. It is alloyed with silver and is intimately associated with galena. It is not an important ore compared with lead or silver. Most of the gold has been found near the surface.

Gangue Minerals.—Calcite and barite are the only two important gangue minerals. Pyrite is present in parts of the vein in well-scattered grains, but it is in too small amounts to be at all important. Calcite is found wherever the vein is mineralized. Barite is most abundant in some large vugs and in cavities where free crystallization of ores and gangue was possible.

Order of Crystallization.—The minerals, galena, primary silver and gold were deposited contemporaneously with calcite. Later more calcite was formed, also some barite, and last of all native silver was deposited. When sphalerite occurs it is with the galena. In some cases the order of formation of the minerals, due to enrichment was evidently lead, silver and gold, calcite, silver, calcite and silver.

Ore Values.—In different levels the values are very different. Practically all of the gold has come from the vein east of the shaft at the tunnel level. The total value of gold recovered has been about $20,000. The highest silver values have been above the seventh level. Much silver lead ore has run 10 to 15 per cent lead and 120 to 180 ounces of silver per ton. Some single 20-ton narrow gauge car loads of ore have netted more than $5,000. With the present 25-ton mill it is stated that it is not uncommon to have clean ups at the end of the day worth $5,000. Zinc ore shipments selected have run 30 per cent metallic zinc, and many selected lots of galena ore have carried as much as 66 per cent lead. The average tenure of shipping ore has been 100 ounces of silver and 10 per cent lead to the ton.

Development.—The White Raven property includes the White Raven, and White Raven Extension claims. The owners of these claims also control the Black Jack, Cross and Gray Bird claims which lie just west of the White Raven claims and which are on the White Raven vein.

Some development work, both by tunnels and shafts, has been done on all of these claims, but most of it has been confined to the White Raven Extension.

On this claim a cross-cut tunnel has been run in 400 feet to cut the vein. At the tunnel level a drift extends 1,000 feet east. A shaft extends up to the surface, and the main shaft which goes down on the vein was begun at this level. The hoist is inside the mine. The tunnel level is about 200 feet below the surface of the ground.

A shaft has been sunk below the tunnel level for a distance of 800 feet measured on the dip of the vein which averages about 60° North. Drifts have been run as follows (the levels are numbered, beginning with the first below the main tunnel):

Level 1	46 feet west from the shaft
Level 2	76 feet west from the shaft
Level 3	54 feet west from the shaft
Level 4	85 feet west from the shaft
Level 5	185 feet west from the shaft
Level 6	246 feet west from the shaft
Level 7	220 feet west from the shaft
Level 8	275 feet west from the shaft
Level 9	275 feet west from the shaft
Level 10	285 feet west from the shaft

All of these have been run out to the apparent limit of the ore bodies, but the vein continues west. In addition, a drift was run 125 feet beyond the ore on the ninth level and drifts were run about 700 feet east of the shaft on the third and sixth levels. The variation of the strongly mineralized portion of the vein is indicated by the amount of drifting to the west at the various levels. On the eighth level a new winze was started which has now been carried down 270 feet measured on the dip.

Equipment.—The White Raven mine has first-class equipment, which consists of the necessary living quarters and mine buildings and a full electric equipment of mining machinery. The hoists are electric and are housed within the mine. The mill will be described in a later section.

Production.—The mine was not extensively developed until 1913. Since that time it has produced about $800,000 worth of ore, chiefly lead and silver. About 1,000 ounces of gold valued at $20,000 has been mined, and the values of zinc and copper have been still smaller.

BIG FIVE MINES

Without attempting to describe the properties in detail, attention is called to the group of mines now owned by the Big Five Mining and Milling Company of Denver.

This company is the largest property owner at the present time in the Ward region. It owns 42 claims, including 8 mill sites. Nearly all of the claims are in a group, which extends from the Columbia vein on Niwot Hill across California Gulch, where the mill and main mine buildings of the Big Five Company are located, on to the south for some distance to include most of the claims in the old mining camp known as Frances. The six Columbia claims and the Queen, Helen C, Gold Crown, Adit, and Dew Drop are some of the important ones in this group.

The Adit tunnel, which starts at the Big Five mill in California Gulch, runs west 4,000 feet to cut the Gold Crown Extension, Dew Drop and intervening veins. It branches at the Helen C claim, and a cross cut extends north 3,000 feet to the Niwot winze on the Columbia vein. Drifts then run 2,000 feet east and 800 feet west on this vein, so that the total development at the Adit tunnel level is nearly 10,000 feet.

In addition to these workings there is a raise from the Adit tunnel to the Dew Drop tunnel level of 300 feet, and the Niwot winze is sunk below the Adit tunnel to a depth of 450 feet on the dip of the vein which is 45° North.

The Dew Drop vein has been opened on its tunnel level for 1,000 feet and some stoping has been done. The ore is a heavy chalcopyrite-quartz gold ore which assays about $10.00 a ton in gold. Very large quantities have been blocked out.

The Niwot shaft is cut by the Adit tunnel at a depth of slightly less than 500 feet. Extending out from the Niwot winze, below the Adit tunnel are drifts as follows:

At 100 feet	east 100 feet
At 200 feet	east and west together 100 feet
At 300 feet	east 150 feet
At 400 feet	east 200 feet and west 100 feet
At 450 feet	east 40 feet and west 60 feet

By means of the Adit tunnel a large amount of ground has been opened and partially developed.

The equipment of this company is complete and modern. The main tunnel is well built and designed to handle a large tonnage from the veins which it cuts.

A 50-ton concentrating mill has at various times been operated by the Big Five Company. It consists of crushers, roll mill and Wilfley tables.

The total production of the properties now owned by the Big Five Company is about $6,000,000. Much of it was obtained from the Niwot and Columbia mines before the present company was organized.

NIWOT AND COLUMBIA MINES

Big Five Mines

It has not been possible to examine these properties in detail, but it would not be proper to prepare a report on the Ward district without some reference to these mines which have been the greatest producers of gold in the entire region.

Location.—The mines are situated near the top of Niwot hill about half a mile west of Ward on the very remarkable Columbia vein which extends eastward from the top of Niwot hill for more than a mile. On this vein are the Niwot, Columbia, Madaline, Sullivan No. 5, Baxter, Boston and Utica mines, all of which have been large producers.

Geology.—The vein is on and near the contact of a white felsite porphyry dike and granite. In places the granite is gneissoid and occasional areas of schist are also found. The vein is large and continuous. In places it is 12 or 14 feet wide. The vein minerals are quartz and pyrite, which carry in the oxidized zone, much free gold and considerable silver. Below the ground-water level the gold is combined with the other vein minerals.

Development.—Part of the development of the Niwot is included in the preceding discussion of the Big Five mines. It has an inclined shaft 950 feet long which reaches a vertical depth of 800 feet. Drifts at regular levels and considerable stoping have thoroughly opened the vein. The Columbia shaft is about 400 feet long on the incline and drifts total about 1,000 feet.

Production.—These two mines have produced nearly half of the values from the whole Ward region. The portions of the vein near the surface are now largely worked out, but there is still much ore at lower depths.

Equipment.—No buildings are left on the Niwot ground, but the winze is worked from the Adit tunnel. There is a shaft house and hoisting machinery at the Columbia mine, but air for drilling, etc., is furnished from the Big Five power house in California Gulch.

NELSON MINE

Location.—This mine is a short distance east of the Newmarket and Humboldt, and near the Colorado and Gold Queen on the hill north of Ward.

History.—It was one of the first mines to be located in the Ward district and it has been worked intermittently ever since, but between 1902 and 1915 little mining was done.

Geology.—The geology of the region is very simple. The rock is mica schist with some gneissoid granite, which probably represents granite intrusions into the schist before the metamorphism. There are Tertiary dike rocks in or very near the mine. The dip of the schistose planes is practically the same as that of the vein, namely 65° to 75° N. 15° E.

The vein is a fissure in the schist. It strikes N. 75° West. The walls are well defined and are ordinarily from 3 to 5 feet apart. The gangue is largely quartz and sericite.

Ore.—The ore is quite typical of that of the Ward region. It is a gold ore, in pyrite. Chalcopyrite and wolframite are irregularly associated with the pyrite. Wolframite is largely confined to the east end of the vein on the 60 and 150-foot levels. Practically no tungsten has been found below the 150-foot level.

The gold ore occurs largely in pockets in the vein. The mineralized portion of the vein entirely pinches out in some places and widens to 18 or 20 inches in other places.

Faults.—A fault, which strikes nearly north and south and dips at a high angle to the east, cuts all the veins a short distance west of the shaft. The west end of the vein has been moved to the north eight feet horizontally by the fault. Practically all gold and silver and tungsten values disappear west of the fault, which indicate that the fault preceded ore formation, and that the mineralized solutions were diverted by the fault plane.

Production.—Ore values of about $75,000 in gold and silver have been produced altogether. More than half of this amount came from pockets near the surface of the ground, for this mine, like most of the others in the Ward region, has produced more and richer ores from the oxidized zone than below the ground-water level. All of the ore mined has been smelting ore which, when well sorted, ran from $20.00 to $80.00 a ton in gold. The small size, and the irregularities of the vein, together with the low gold content below the ground-water level do not make this mine an attractive proposition for future development.

Development.—The development is as follows: One inclined shaft 450 feet long on the dip of the vein. Drifts on the vein at 60, 150, 250 and 450 feet. Total drifting 800 feet. A small amount of stoping above the 150-foot level.

Equipment.—The Nelson is equipped with a good shaft house and shop, and a steam hoist, with the regular necessary mining tools and other machinery.

MORNING AND EVENING STAR MINE

(This statement is based upon notes kindly furnished by R. D. George, who examined the mine in 1911.)

Location.—The property consists of three claims, The Morning Star, Evening Star and Emelina, which are situated in Spring Gulch about one mile east of Ward.

Geology.—The rock in the vicinity of the mine is mainly gneiss and granite. Some blocks of schist are encountered but they are not large in proportion to the whole volume of the country rock along the veins. Felsite porphyry dikes are found in the mine.

Veins.—There is no obvious relationship between the veins and the felsite porphyry dikes of the region, although in some places veins follow or cut the dikes. The veins are strong and continuous. The walls stand up well and need comparatively little timbering. Two well-defined veins are found, namely, the Morning Star and the Evening Star. The Emelina is a faulted portion of the Morning Star vein. Several subordinate veins have been encountered. The strike of the veins is nearly east and west.

Ore.—The usual quartz veins of the Ward region, which carry pyrite and some chalcopyrite with gold values, are typical of this mine. The smelting ore shipped from these veins has been of high grade.

In addition to the ordinary sulphide ore, on the 300-foot level, a rich body of telluride, native gold and sulphide ore was struck. Some of this ore ran 54 ounces to the ton.

The ore is more continuous and much less "pockety" in this mine than in many others, and the reserves are believed to be large.

Development.—The total amount of development done, in shafts, tunnels and drifts is about 6,000 feet. There are two shafts, one 300 feet and the other 210 feet deep. Continuous stopes of considerable length from the 200-foot level to the surface indicate the continuity of the ore bodies.

Production.—The total production of this mine is about $600,000. Smelting ore values run up to $90.00 a ton. Mill dirt carries values of from $3.50 to $14.00.

Equipment.—The mine is equipped with fairly modern machinery, including a hoist good for 500 feet, three boilers, one 100, one 50 and one 30 horse-power, two engines of 30 and 15 horse-power respectively, and a Norfolk compressor.

There is a 10-stamp concentrating mill on the property, which is equipped with amalgamation plates, Blake Crusher, 2 Wilfley tables and one Frue vanner.

ALASKA (BRAINERD) TUNNEL

The portal of this tunnel is at Camp Talcott, on Lefthand Creek, about one and one-third miles southeast of Ward.

On account of the large amount of water in the mines on Utica hill, and because of the strong possibility of cutting valuable veins, it was decided to start a tunnel on Lefthand Creek, which would, when completed, drain the mining region east of Ward.

The linear distance from the tunnel site to the center of Utica hill is about 3,200 feet. The vertical difference in elevation is almost exactly 1,000 feet. The tunnel has been driven about 2,500 feet and is, therefore, still 700 feet from its goal. Shafts were sunk on Utica hill more rapidly than was expected and the B. and M., the deepest mine in the region, is now not more than 200 feet above the tunnel level.

No important veins were encountered, and because of this fact, and due to the decline of mining in the Ward region, work on the tunnel was long ago discontinued.

NATIONAL TUNGSTEN COMPANY CLAIMS

Location.—About half way from Gold Lake, south to Spring Gulch, a group of claims has been developed for their wolframite content. The claims are: Midnight, Last Chance, Jumbo, Jumbo Extension, Pugh, Josephine, Annie S., Jay Bird, and a mill site at the foot of the hill in Spring Gulch.

Geology.—The rocks in the region are granite, and mica dacite porphyry dikes. The dikes seem to have no relationship to the occurrence of the tungsten.

When the claims were visited two veins had been prospected. Wolframite occurred in both, in small amounts. The veins are fissures in the granite. Quartz is the important gangue. Pyrite is not abundant.

The width of the veins varies from 1 to 3 feet. The tungstic oxide content of samples taken across the veins in different places ranges from 2 to 10 per cent. A small concentrating mill with electric power and equipped with crushers, a ball mill, jigs, Wilfley and Card tables was erected to handle the ores, but so far as can be learned little ore was actually treated, due to the decline in the price of tungsten soon after the mill was completed.

CONCENTRATION AND EXTRACTION OF ORES

HISTORICAL OUTLINE

The processes and problems of ore treatment have become increasingly complicated and difficult as greater depths in the mines have been reached, and as costs of labor, transportation and supplies have increased.

In the early 60's and for a number of years thereafter nearly all of the ore produced in the Ward region, was free milling in nature. That is, it came from veins near the surface of the ground, in which most of the sulphides had been oxidized, and the gold was left in a free state in cavities of the veins. All that was necessary, then, in order to save the gold was to break up the ore by stamps which weighed from 650 to 1,000 pounds each, wash the powdered material over amalgamation plates, and the quicksilver caught the gold.

When the veins were mined to a greater depth, massive sulphide ores were encountered. These ores could not be concentrated and the gold obtained by the simple stamp mill, amalgamation method. But with the introduction of smelting methods, it became a common practice to sort the ore and send high-grade sulphides to smelters which were operating at Blackhawk and Denver. This method is still in use.

However, only the ores of relatively high value could stand the mining, transportation and smelter charges and yield a profit. Much valuable ore of lower grade was wasted. It could be only thrown out on the dump, or left in the stopes of the mines. To make greater savings, therefore, concentrating mills were developed. At first stamps were used to break up the ore and gangue minerals, but modern processes have discarded stamps and substituted jaw crushers, and roll mills, or in some cases ball mills. After being crushed the ore is broken up in one of these type of mills. Then it is carried by water over Wilfley and Card tables, and in most cases, Frue vanners, or some other form of blanket tables or "rag plants."

After the crushed material leaves the roll or ball mills or stamps as the case may be, the processes of concentration are based on the fact that the sulphide minerals that carried the precious metals, and also those metals in the free state have a much higher specific gravity than quartz and the rock-making minerals of the country rock. Therefore, when the ore is properly crushed so as to separate it from its gangue and the crushed material is passed over properly constructed and operated tables, the ore and the other minerals are separated.

Jigs are now being employed in some mills. They take some of the classified material that comes from the crushers, and other material that has passed through coarse rolls or ball mills.

Concentrates made by these gravity processes on jigs, tables and vanners are shipped to the smelters as are the high-grade ores.

Later, cyanide plants were introduced. Smelting charges were high, as were transportation costs. It became known that cyanide solutions would dissolve gold, and therefore, in some cases, in conjunction with the gravity processes just described, and in some cases independently, cyanidation treatment was used. This, too, however, is not inexpensive, and difficulties are involved in properly agitating the ore in the solutions so that all the gold may be attacked and eventually dissolved by the cyanide solution.

These processes with many modifications have been tried in the Ward region. None have solved the problem of extracting at a profit, the values from the solid sulphide ores mined well down below the ground-water surface, when such values have been less than $18.00 or $20.00 to the ton of ore.

There are thousands and probably millions of tons of sulphide ore in the Ward region which carry values in gold and silver of from $6.00 to $15.00 to the ton. Eventually they will be mined and milled at a profit.

LIST OF MILLS

The following list includes all the mills that are known to the writer to have been operated in the Ward region. Only one, the White Raven, is at present in operation, and it is the only one that will be described in detail. Those starred are now dismantled.

Name	Location	Type of Ore	Process
Bean Brothers	Spring Gulch	Tungsten	Roasting
*B. & M.	Utica Hill	Gold-sulphide ore	Concentration
Big Five	California Gulch	"	"
Conqueror	Foot of Ward Hill	"	Concentration, Amalgamation
*Giles	Mouth Peck Gulch	"	"
Golden Slipper	Puzzler	"	Cyanidation
*Humboldt	North of Ward ½ Mi.	"	Concentration
Lois	West of Ward 1 Mi.	"	"
Lulu B (Utica Hill)	Utica Hill	"	Cyanidation
Modoc	Duck Lake	"	Concentration
Morning and Evening Star	Spring Gulch	"	"
New Market	Ward	"	"
*Niwot	Niwot Hill	"	Free milling (Amalgamation)
National Tungsten Company	Spring Gulch	Tungsten	Concentration
Ruby	Sunnyside	Gold-sulphide ore	Amalgamation
*Stoughton	Ward	"	"
*Telegraph	North of Ward 1 Mi.	"	Concentration
*Utica	Ward	"	"
White Raven	California Gulch	Lead-silver	Concentration and Flotation

WHITE RAVEN MILL

The only mill at present operating in the Ward region is the White Raven.

This mill was completed and put into operation in September, 1919, and has been running ever since with (until August, 1920) two shifts a day.

The mill is a combined mechanical concentration and flotation plant. Its capacity is 25 tons of ore a day. It was built primarily in order that the dump might be milled, but since the railroad between Boulder and Ward has been junked it has been, and will in the future be used to concentrate all but the richest ore that is mined.

The milling methods are simple but effective. The ore is crushed by a Blake jaw crusher, elevated and classified. Everything less than one-fourth of an inch in diameter goes to a Richards jig, over that size to the large Improved Standard Roll mill. From the rolls the coarse ore goes to the jig and the fine to a Wilfley table. Overflows from the jig and seconds from the Wilfley go to a fine Standard roll, then to a Card table. The overflows from the Wilfley and Card tables go to a Barr flotation cell in which practically all of the remaining values are recovered.

Nearly all of the fine wire silver is caught on the Wilfley table. There are only small amounts of gold and zinc and only traces of copper in the ore. Pyrite is absent, and the concentration problems are, therefore, not difficult.

Two men on a shift run the mill. The cost is $2.00 a ton. It is stated that over 95 per cent of the assay values of the ore are saved.

The jig concentrates, and those from the tables and flotation cells are dried and shipped by truck to Boulder, where they are sampled separately and sold.

PRODUCTION

It has been impossible to get accurate figures of the production of the mines of the whole Ward region.

The U. S. mint reports and the U. S. Geological Survey Mineral Resources, give Boulder County production for certain years by districts. Nearly all of the Ward region is included in the Ward district, but the mines near Sunset are included in the Sugarloaf district.

According to the reports mentioned in the preceding paragraph, Boulder County produced in the years 1885 to 1903 inclusive, gold and silver valued at $8,321,418, and the Ward region produced slightly less than 24 per cent of this amount, or almost exactly $2,000,000.00.

Between 1904 and 1915, inclusive, Boulder County produced, according to Mineral Resources, $2,906,184 in gold, silver, lead and copper. Of this amount the Ward district produced almost exactly 20 per cent, or $581,236.

Since 1915 the production of the Ward region has been approximately $600,000. This gives a total production since 1885 (disregarding lead and copper before 1904) of $3,181,236, for all the mines in this region. Definite figures of production before that year are lacking, but probably greater mineral values were produced before than have been produced since that date.

Another set of estimates has been made from all available sources but largely by a group of men who have been long connected with the mining industry in the Ward region. Some data have been taken from the Mining Reporter for 1899. Nearly all the estimates were checked by at least two men and they are believed to be reliable.

The total ore value of the 30 largest producers in the region has been thus estimated at $7,799,000. No mine whose estimated production is less than $5,000 has been included in this list. There are a larger number of small mines that have produced some ore and the total value of all the ore produced in the Ward region up to the present time is conservatively estimated to be $9,000,000. By many this is regarded as 25 per cent too low.

FUTURE PRODUCTION

The future production of the Ward region is most uncertain, but it is the writer's opinion that this region is by no means "worked out."

PYRITE ORES

It is known that great bodies of low-grade sulphide ores are blocked out in the Dew Drop, Columbia, Utica, B. & M., Stoughton and many other mines, whose veins are both large and continuous. The total amount of such ore is not known, but it probably runs into the millions of tons.

ORE WITH DEPTH

Some doubt has been expressed by various miners and prospectors as to the continuance of the ore bodies with increasing depths below the surface of the ground. It is, of course, evident that enriched ore bodies of the nature of those in this region will disappear with depth, but there is nothing in the geology of the region to indicate that the primary minerals of gold, silver, lead and copper may not be found at much greater depths than have yet been reached.

MORE PROSPECTING

More prospecting should be done along the monzonite porphyry dikes, especially those that are near the foot of Saw Mill hill and in California Gulch, for it is very probable that other ore deposits, similar to those of the White Raven mine exist, and may be found by careful prospecting.

BETTER METHODS OF CONCENTRATING ORE

Until improved methods of concentrating the low-grade gold and silver ores are devised these mines must remain closed, but such methods certainly will be eventually developed. Flotation already seems to be pointing the way toward the desired processes of concentration. If it proves to be as successful as imperfectly completed experiments would indicate that it may be, it will do much to solve the present problems, and this or some other process will bring the Ward region into a new period of production and prosperity.

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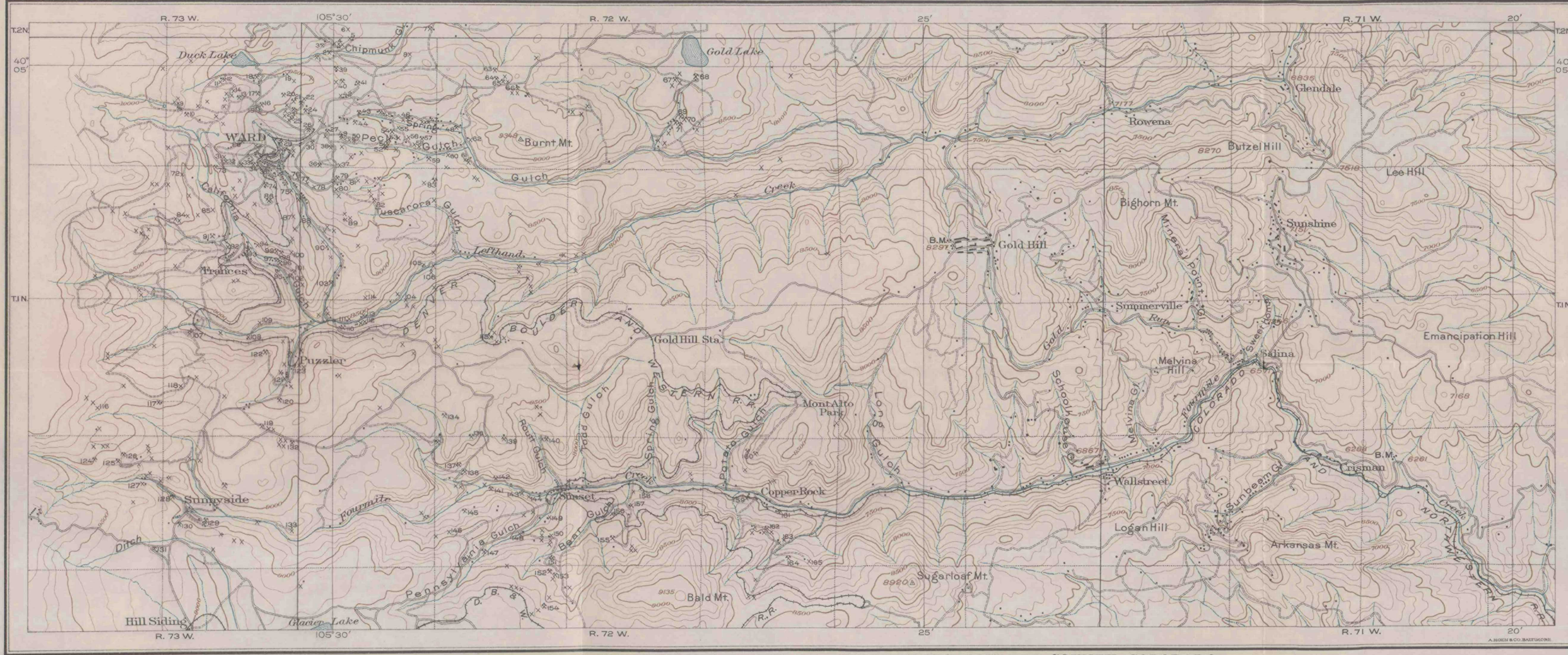
INDEX



TOPOGRAPHIC MAP OF WARD, SUGARLOAF, AND NEAR-BY REGIONS, BOULDER COUNTY, COLORADO

Scale $\frac{1}{62500}$ or approximately $1\frac{1}{4}$ inches to 1 mile

1 ½ 0 1 2 Miles

1 ½ 0 1 2 3 Kilometers

Contour interval 100 feet

Datum is mean sea level

Topography east of 150°30' by U. S. Geological Survey and originally published on the scale of 1:62500
Surveyed in 1902

Topography west of 105°30' by P. G. Worcester
Surveyed in 1910-11

The culture of the U. S. Geological Survey map of the west two-thirds of R. 72 W. has been modified by P. G. Worcester

MINES

1 Sound Currency
2 Sound Currency
3 White Pine
4 Diagonal
5 Mountain View
6 Mountain View
7 Orinoco
8 Bertha
9 Lois
10 Sunny View
11 Cardiff
12 Gold Coin
13 Boulder County
14 Lake Shore
15 Pride of Ward
16 Gold Crystal
17 Humboldt Ext.
18 Modoc
19 Honest John
20 Grand View Sh.
21 Texas Sh.
22 Texas Tun.
23 Grand View Tun.
24 Humboldt
25 Comstock
26 New Market
27 Golden Queen
28 Stoughton
29 American
30 Bluebird
31 Niwot
32 Madeline
33 Columbia
34 Sullivan (No. 5)
35 Baxter
36 B. and M.
37 Oldenburg
38 Colorado
39 Pride of the West
40 Red Cloud
41 Forest Queen
42 Telegraph
43 Telephone
44 Kansas City
45 Celestial
46 Celestial Ext.
47 Morning Star
48 Emilina
49 Chatham
50 Nelson
51 Lake City
52 Denver
53 Jolly Tar
54 Silver Dollar
55 George Washington
56 Calambia
57 Innspruck
58 Norwegian
59 Scharnitz
60 Giles
61 Little Giant
62
63 Mountain Queen
64 Camera
65 Klondike
66 Connoton
67 Sulphide
68 Plymouth Rock
69 Last Chance Tun.
70 Last Chance Sh.
71 Midnight Tun.
72 Nimbus
73 Baltimore
74 U. P. Sh.
75 U. P. Tun.
76 Boston
77 Utica (Lower)
78 Utica (Upper)
79 Lulu B.
80 Oklahoma
81 Superior
82 Idaho
83 Polar Star
84 High Line
85 Gold Chief
86 Gold King
87
88
89
90 Tarbox
91 Dew Drop
92 New California
93 Adit
94 Cornicopia
95 Philadelphia
96 Cross Tun.
97 Cross Sh.
98 Gray Bird
99 Black Jack
100 Village Bell
101 White Raven
102 White Raven Ext.
103 Empire No. 3
104 Moltke
105 Brainard Tun.
106 Bismark
107 Bloomer Tun.
108 Parole
109 Golden Slipper
110 Yellow Aster
111 Col. Dick
112 Leviathan Group
113 Northwestern
114 Ward
115 Holt
116 Gold Drop
117 Copper King
118 Red Lion
119 Ward Rose Sh.
120 Ward Rose Tun.
121 Johannsburg
122 Protection
123 Puzzler
124 Emma Daniels
125 Milwaukee
126 Atlantic
127 Pennsylvania Gr.
128 Silent Friend
129 Ruby
130 Morning Glory
131 Black Diamond
132 Homestake
133 Cumberland
134
135 Moonlight
136 Star
137 Bluebell Sh.
138 Bluebell Tun.
139 Scandia
140 Gov. Routt
141 Centennial Tun.
142 Copper Glance
143 Continental
144
145 Centennial Sh.
146 Mammoth
147 Dolly Varden
148 Bismark
149 Free Coinage Tun.
150 Free Coinage Sh.
151 Canton Tun.
152 Canton Sh.
153 Golden Chest
154 Culebra
155 Lee S. Sh.
156 Lee S. Tun.
157 Meadow Lark Sh.
158 Meadow Lark Tun.
159 Shelton Tun.
160 Don D.
161 Orphan Boy
162 Orphan Boy
163
164 Sunrise
165 McDermit

COLORADO GEOLOGICAL SURVEY
BOULDER
R. D. GEORGE, State Geologist

BULLETIN 22

MINERAL DEPOSITS OF THE WESTERN SLOPE

BY
H. A. AURAND

EAMES BROS.
STATE PRINTERS FOR COLORADO
DENVER, COLORADO

GEOLOGICAL BOARD

LETTER OF TRANSMITTAL

State Geological Survey,
University of Colorado, October 28, 1920.

Governor Oliver H. Shoup, Chairman, and Members of the Advisory Board of the State Geological Survey.

Gentlemen: I have the honor to transmit herewith Bulletin 22 of the Colorado Geological Survey.

Very respectfully,

R. D. George,
State Geologist.

CONTENTS

ILLUSTRATIONS

INTRODUCTION

The office of the State Geologist has been in almost constant communication with individuals seeking information concerning the location, occurrence, and possibilities of mineral deposits on the "Western Slope" of Colorado.

This bulletin was prepared with a view of furnishing the public with information concerning the location of these deposits. It is not exhaustive in its location of the various deposits, nor is the bibliography which accompanies the bulletin exhaustive as to the sources of information concerning the deposits.

The "Western Slope" is divided by natural barriers into three distinct districts; the Southwestern, the Western, and the Northwestern parts of the State. These barriers have so seriously impeded transportation facilities as to limit the areas which may be served by the various railroads.

The three districts are practically isolated from each other as far as railroad transportation is concerned, while the Southwestern and Northwestern parts are at times isolated from the "Eastern Slope," through heavy snows blockading the railroads on the Continental divide.

The general effect of these barriers is to not only impede transportation, but to increase the costs of transportation between the "Western and Eastern Slopes."

The question of a complete survey of the various resources cannot be taken up in a publication of this kind, while a complete bibliography of the resources would have to be published as a separate bulletin.

ACKNOWLEDGMENTS

It would be almost impossible for the writer to acknowledge the many sources from which the material incorporated in this bulletin has been gathered.

The writer feels, however, that he is deeply indebted to R. D. George for his many helpful comments, and for the advice given during the preparation of this bulletin.

Many publications have been drawn upon in seeking material, and while individual acknowledgments could not always be made, the bibliography will undoubtedly indicate the main sources from which the information was obtained.

As the literature on the mineral deposits of Colorado is scattered so widely, the various publications of the United States Geological Survey, the Colorado Geological Survey, the Colorado Bureau of Mines, and the reports of the State Coal Inspector, were used extensively.

A large amount of helpful material was also obtained from articles printed in well-known scientific publications, and from various publications of the University of Colorado and the Colorado School of Mines.

Bulletins of the Colorado Geological Survey on the Molybdenum deposits of Colorado, by P. G. Worcester; the Manganese deposits of Colorado, by G. A. Muilenburg; the Fluorspar deposits of Colorado, by H. A. Aurand, were drawn on freely for information concerning the location of deposits of those minerals.

In many instances the material taken from various publications is quoted literally, in others it is a summary or digest of the original articles or reports. In other cases a few sentences or paragraphs only are used. For the sake of convenience, most of the matter is incorporated into this report without the use of quotation marks or special acknowledgment.

CHAPTER I

MINERAL DEPOSITS

OF

NORTHWESTERN COLORADO

BARITE

GRAND COUNTY

Barite is reported as occurring on the Vasquez River,[1] a left branch of the Frazer River, in Grand County. No attempt has been made to ship barite from this locality.

BUILDING STONE

ROUTT COUNTY

Sandstone.—A creamy-white to pink sandstone has been quarried at Steamboat Springs. The stone was used locally for building purposes.

CLAYS

NORTHWESTERN COLORADO

In this district, there are abundant outcroppings of the Mancos formation. The shales of this formation should prove valuable in the manufacture of ordinary brick, pressed brick, soft mud brick, and coarse earthenware. Certain horizons near the base of the Mancos formation furnish clays suitable for the manufacture of either light flesh-tinted or red pressed bricks.

The Dakota and Mesaverde formations contain numerous lenticular beds of fire clay. Intelligent prospecting will doubtless lead to the discovery of a large amount of fire clay.

[1]Smith, J. Alden, Report of Colorado State Geologist for 1881-1882; p. 131, 1883.

COAL

JACKSON COUNTY

The coal beds of North Park are contained in the Coalmont formation, which is of late Cretaceous or early Tertiary age. The coal beds of greatest importance outcrop between the Michigan and Canadian rivers, and in the Coalmont district in the southwestern part of the field.

Thinner beds of relatively small extent and apparently isolated are found in the Monahan and Mitchell mines. Two other localities, one on Colorado Creek below the Clover ranch, and the other near Arapahoe Pass show relatively thin beds of small extent.

The coal of the district has been classed as sub-bituminous.

It has been estimated by Beekly[2] that the amount of coal recoverable under present mining conditions is 1,152,000,000 short tons.

During 1918, two mines in the district produced 84,504 tons of coal.

YAMPA COAL FIELD

The Yampa coal field covers an irregular area of about 1,200 square miles, lying along the center of the Yampa (Bear) River valley. The area lies west of the Park Range and north of the White River Plateau and Axial basin. The field is roughly triangular in outline, its corners being, approximately, at Lay post office, Sand Mountain, and a few miles north of Yampa.

The important coal measures of the field are found in the Mesaverde formation. The coal seams fall into three groups, each ranging through a vertical distance of from 200 to 400 feet, the several groups being separated by from 500 to 1,000 feet of barren sandstone and shale.

Like most coal fields of Colorado the Yampa field contains coals ranging from lignite to anthracite. The coals for the most part are bituminous. Some lignite is found in the Laramie formation northwest of Hayden and Craig.

Anthracite coal is found in the northern part of the district, around Pilot Knob and Wolf Mountain. The anthracite area is possibly 25 square miles in extent, with a known area of 10 square miles.

[2]Beekly, A. L., Geology and Coal Resources of North Park, Colorado: U. S. Geol. Survey Bull. 596, 1915.

During 1918, 19 mines were operated in the Yampa coal field, in Routt County.

The total output of the district during 1918 was 962,691 tons, as compared with 1,057,686 tons mined in 1917.

It seems almost certain that with more adequate transportation facilities the Yampa coal field will become an important factor in supplying the needs of the western coal markets.

DANFORTH HILLS AND GRAND HOGBACK COAL FIELD

The coal fields of the Danforth Hills and the Grand Hogback are located in the northwestern part of Colorado in Moffat, Rio Blanco, and Garfield counties. A small area is found in the western part of Pitkin County.

The Danforth Hills field lies north of White River, south of Axial Basin, west of the White River Plateau region, and east of Strawberry Creek and its extension toward the north. The Grand Hogback is a long, narrow, monoclinal ridge lying between the Grand and White rivers. It crosses the White River near Meeker and extends south and southeast crossing the Grand River at Newcastle.

A westward extension of the Danforth Hills follows along the south slopes of the Yampa Plateau and on into Utah.

The coal of the field is a good grade of bituminous. That found north of the White River is apparently similar to the coal occurring in the western part of the Yampa field. South of the White River the coal is of a somewhat higher grade than any other coal found in the northwestern part of the state, with the exception of the anthracite, occurring locally near Pilot Knob and Wolf Mountain, in Routt County.

South of the Grand River, in Pitkin County, good coking coal is found in the Gulch mine on Spring Gulch. This coal is made into coke at Cardiff. Coal from the Coalbasin mine, 12 miles west of Redstone, on a branch of Crystal River, is of a coking quality. This coal has been made into coke and shipped to the steel plants at Pueblo. Two mines were worked in Pitkin County during 1918 with a total production of 30,554 tons of coal.

The Danforth Hills area covers about 300 square miles, and is one of the most extensive coal-field units of the area. The Grand Hogback field covers an area of about 75 square miles.

Five mines were being operated in Garfield County during 1918 and the total production of the county for that year was given as 74,004 tons.[3]

During 1918 one mine was working at Axial in Moffat County. The production of coal from this mine was 548 tons.

In Rio Blanco County, three mines were operated during this same year with a production of 4,798 tons of coal.

NORTHWESTERN COLORADO

During 1907, Gale[4] made a study of the coal areas in the extreme northwestern part of Colorado, in Moffat and Rio Blanco counties. This survey showed the presence of a considerable amount of workable coal in that area.

THE UINTA COAL REGION

The great Uinta Basin stretches from the middle of Gunnison County to the southern borders of Routt and Moffat counties. In an east and west direction it stretches from the center of Gunnison County far across the state line into Utah. The Colorado part of the basin has an area of 600 square miles. The Mesaverde coal-bearing formation underlies the whole area, and its outcrops form the entire outer border of the basin. The fact that this formation is coal-bearing through this very long border is strong evidence that it is coal-bearing beneath the entire 600 square miles of the Colorado part of the basin. The studies of this basin by the geologists of the U. S. Geological Survey and by other geologists have led to this conclusion. On this basis a conservative estimate of the coal tonnage places the figure at 272,000,000,000 short tons.

The worked fields are confined to the narrow border outcrops.

The coal ranges from sub-bituminous to anthracite, and the seams, in places reach a thickness of 25 feet.

The coal tonnage of the western slope of Colorado has been estimated by the U. S. Geological Survey as follows:

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[3]Dalrymple, J., State Inspector of Coal Mines, Sixth Ann. Rept. for 1918, p. 55, 1919.

[4]Gale, H. S., Coal fields of northwestern Colorado and northeastern Utah: U. S. Geol. Survey Bull. 341, pp. 283-315, 1909.

	Short tons
Uinta region	272,000,000,000
Durango fields	21,500,000,000
Yampa fields	39,639,000,000
North Park fields	1,152,000,000
Smaller areas	500,000,000
	334,791,000,000

This is a tonnage sufficient to supply the United States, at the present rate of consumption 670 years.

COPPER

GRAND COUNTY

Some copper ore is found in the Harmon district, 12 miles southeast of Granby. The production from this district has been small. No data are available as to the production in 1919.

ROUTT COUNTY

Copper is the predominant metal in the Copper Ridge district, 9 miles northwest of Steamboat Springs; in the Slater district, 70 miles southeast of Wamsutter, Wyoming; in the Oak Creek district; the Rock Creek, or Gore Range district, 16 miles east of Yampa; in the Spring Creek district at Steamboat Springs; and in the Pearl district, 33 miles southeast of Riverside, Wyoming.

Some work has been done on a deposit of copper ore located in the extreme southeastern corner of Routt County, near the station of McCoy, on the Denver and Salt Lake Railroad.

A large deposit of copper has been reported as occurring at Douglas Mountain, in the western part of the county.

From 1873 to 1917, copper valued at $16,704 was produced in Routt County.

GOLD[5]

GRAND COUNTY

Gold occurs as the predominant metal in the ores of the Grand Lake district, 16 miles northeast of Granby, and in the La Plata district, 24 miles southeast of Granby. Only a small production has been reported from these districts.

[5]See Hill, J. M., The mining deposits of the Western United States: U. S. Geol. Survey Bull. 507, pp. 134-157, 1912. Statistics compiled by C. W. Henderson, Statistician, U. S. Geol. Survey.

MOFFAT COUNTY

Near Lay, in Moffat County, some gold has been found in placer workings. No reports are available regarding operations in this district. Placer gold is also found in the Dry Creek and Fourmile districts, in the northern part of the county.

ROUTT COUNTY

Considerable operations have been carried on from time to time in the Hahns Peak district. Placer mining, by sluicing, has been carried on in addition to lode mining. The production of gold from 1873 to 1917 totals $384,539.

SUMMIT COUNTY

During 1919, the production of gold in Summit County totaled $470,946. Gold occurs as the predominant metal in the Breckenridge, Montezuma and Swan River districts. The value of gold produced in the county from 1860 to 1917 is placed at $16,898,015.

GYPSUM

SUMMIT COUNTY

Stevenson[6] reports the occurrence of gypsiferous shales on the Snake River, (a tributary of the Blue River), in Summit County. These deposits do not appear to have any commercial value at present.

IRON

MOFFAT COUNTY

A large deposit of iron ore has been reported from the Douglas Mountain district, in the extreme western part of Moffat County. The haul of 90 miles, to the railroad at Craig, has greatly hindered the development of this deposit.

LEAD

ROUTT COUNTY

Lead predominates in the ores of the Slavonia district, 40 miles north of Steamboat Springs. No data are available concerning production in 1919.

[6]Stevenson, J. J., Geology of a portion of Colorado explored and surveyed in 1873; Wheeler Survey Rept., vol. 3, p. 374, 1875.

SUMMIT COUNTY

The ores of the Montezuma district show a predominance of lead over the other metals. This district is located 12 miles east of Dillon, and is reached from that station.

Summit County shows a lead production valued at $22,644 during 1919, and a total production valued at $6,370,510 from 1860 to 1917.

LIMESTONE

The Carboniferous formations throughout northwestern Colorado should be prospected for limestone strata. Some lime may have been burned locally, but the undertakings have never been of more than local importance.

MARBLE (Onyx)

ROUTT COUNTY

A small deposit of onyx marble is located on the south side of the Yampa, or Bear River, southwest of Steamboat Springs. The blocks of marble are somewhat limited in size, but the material is well suited for ornamental work and has been used for that purpose.

MANGANESE

MOFFAT COUNTY

It is reported that a rather extensive body of manganese and iron ore occurs on the north face of the Blue Mountains.[7] This deposit is located in the extreme northwestern part of Moffat County.

No data are available regarding the size, occurrence, or value of the deposit.

MINERAL SPRINGS

GRAND COUNTY.—Hot Sulphur Springs, pools and baths. Hotel accommodations in the town.

JACKSON COUNTY.—Mineral Springs are located 3 miles north of Cowdrey; 12 miles west of Cowdrey; 13 miles west of Walden and about 2 miles northwest of Higho. They are undeveloped.

MOFFAT COUNTY.—The Juniper Springs are improved by the building of bath houses. Hotel accommodation is available.

[7]Muilenburg, G. A., Manganese deposits of Colorado: Colo. Geol. Survey Bull. 15, p. 65, 1919.

ROUTT COUNTY.—Steamboat springs are at the town of Steamboat Springs. Bath houses, plunges, swimming pools and hotel accommodations are available.

East of Phippsburg are the Scott, Smith, and Jones Springs (undeveloped). Other springs occur in the southeastern part of the county.

SUMMIT COUNTY—Near Dillon are several mineral springs, some of which are furnished with bath houses.

MOLYBDENUM

GRAND COUNTY

It is reported that a deposit of molybdenite and molybdite (molybdenum ocher) has been found on the Grand River, one and one-half miles above the station of Radium.

ROUTT COUNTY

A property which contains some molybdenite is located on the northwest side of Little Farwell Mountain, near the head of Middle Beaver Creek. This occurrence is about five miles northeast of the town of Hahns Peak.

The molybdenite is found on both sides of a large pegmatite dike, and impregnates the country rock for several inches. The mineral occurs in grains from one-fourth of an inch up to more than one inch in diameter. Although the value of the dike as a whole is low, the presence of the molybdenite in such large grains would make the sorting of the ore extremely easy.

Several occurrences of molydenite have been reported from the Slavonia mining district. One property is located about 15 miles from Clark and is situated on the east side of a spur of the Sawtooth Range. A second property is located 10 or 12 miles from Clark on a branch of the Middle Fork of Elk River.

SUMMIT COUNTY

The largest known deposit of molybdenum ore in Colorado, and probably one of the largest in the world, is located on the Continental Divide, near Fremont Pass (Climax station), about 13 miles northeast of Leadville.

Worcester[8] describes the deposit as follows:

> "This deposit occurs in a large mineralized zone, about one mile east of the pass (Fremont) near the head of Ten-

[8]Worcester, P. G., Molybdenum deposits of Colorado: Colo. Geol. Survey Bull. 14, p. 87, 1919.

mile Creek, on the southwest slope of Bartlett Mountain and on the northwest side of Mount Ceresco. The full extent of the deposit has not yet been determined, but the surface is known to be more than one-half a square mile, and the vertical range is 500 feet and probably very much more."

The enormous amount of fracturing which the district underwent was followed by the formation of innumerable quartz veins. The country rock appears to have been chiefly a white, even-grained granite, but the alteration has been so great that even this is hard to determine.

The ore occurs as molybdenite and molybdite and is found in exceedingly small veinlets in the quartz. The whole mass of rock is more or less mineralized, and it appears that there were three periods of fracturing and vein filling; one preceded, one accompanied, and one followed the deposition of the molybdenite.

Considerable development work has been done in this area by the three companies which own, or control through leases, practically the whole mineral zone. One company had by the end of March, 1918, blocked out what is estimated as 6,000,000 tons of ore. The other companies have been developing their properties as rapidly as the market and prices paid for molybdenum would warrant.

Several deposits of molybdenite have been partially developed in the district 2 miles southeast of Kokomo. The ore in this district is very low grade, and because of the small size of the deposits they are not believed to be good.

Two molybdenum claims are located on the south slope of Quandry Mountain, about 11 miles southwest of Breckenridge.

Molybdenite has been reported as occurring on Glacier Mountain, about two miles from Montezuma; on Lenawee Mountain, near Montezuma; and near Uneva Lake.

NATURAL HYDROCARBONS

Gilsonite, or uintaite, and grahamite appear to be the only hydrocarbon minerals occurring in commercial quantities in Colorado. Other hydrocarbons, usually classed as bitumens, occur in isolated areas and in small amounts, but as they are relatively unimportant their identity has never been determined.

Although several types of hydrocarbons have been mined for years, and many others have been known to occur in Colorado, they have not been understood, as the available literature describing them has been very limited.

The natural hydrocarbons of Colorado, as well as those of eastern Utah, appear to be confined to the Tertiary formations. In these districts the various divisions of the Eocene are noted for the number, size and variety of their asphalt veins.

The shales of the Green River formation are well known for their high bitumen content, and for the numerous strata of bituminous limestone found so widely distributed throughout the formation.

Many of the asphaltic veins, near the Colorado-Utah line, occur in fissures in the Green River formation, and in the overlying formations, especially the Bridger and Uinta. According to Osbon[9] it is surmised that the bitumens of the Green River shales are the source of the asphalts, at least, of this vast area. The variation in the ultimate material as it today fills one fissure or another is perhaps due in part to a change somewhat allied to fractional distillation in petroleum technology, and in part to the degree to which oxygen absorption has taken place.

One vein of gilsonite or uintaite is located just east of the Colorado-Utah line in Colorado. The opening on the vein is found on the crest and eastern slope of the ridge dividing Evacuation Creek from the waters running into the White River and streams farther east.

This vein has the same trend as the Bonanza vein, located just west of the Colorado line in Utah, and appears to be either a continuation of that vein, or another vein occurring in a fissure belonging to the same system. The vein may be traced on the surface for about 2 miles, and throughout shows an average width of about 30 inches. In places it has been prospected to a depth in excess of 100 feet, and according to Eldridge[10] it should continue to a depth of at least 500 feet. This vein alone should produce a tonnage of not less than 44,000 tons of high grade gilsonite.

It has been estimated by Eldridge[11] that five of the veins of gilsonite, occurring just across the state line in Utah, will produce 31,145,571 tons of marketable ore. This estimated tonnage is based on the length of the veins exposed, their average width,

[9]Osbon, C. C., Asphalt and allied substances in 1918: U. S. Geol. Survey Mineral Resources for 1918, p. 470.

[10]Eldridge, G. H., The asphalt and bituminous rock deposits of the United States: U. S. Geol. Survey Twenty-second Ann. Rept., pt. I, p. 354.

[11]Eldridge, G. H., The asphalt and bituminous rock deposits of the United States: U. S. Geol. Survey Twenty-second Ann. Rept., pt. I, p. 354.

the probable depth to which mining can economically be carried, and the depth to which the veins will probably persist.

Cowboy	14,069,250 tons
Bonanza—	....
East Branch	10,434,387 tons
West Branch	4,084,497 tons
Black Dragon	2,086,479 tons
Duchesne	470,958 tons
Total	31,145,571 tons

A number of the smaller veins of the district have been prospected and some are now being worked. With this additional tonnage the district should produce in excess of 32,000,000 tons.

The gilsonite or uintaite, as it is often called, is an asphaltite, characterized by its black color, conchoidal fracture, bright luster, and red brown streak. It is marketed as ''selects'' or ''firsts,'' and as ''seconds.'' ''Selects'' are taken from the center of the vein while ''seconds'' come from near the walls.

The principal use of gilsonite is in the manufacture of paints, varnishes, and japans, where it is regarded as the best hydrocarbon for that purpose. During the past few years it has become an essential, and is used extensively in the rubber industry. Pure rubber is sensitive to heat and cold, but a vulcanized mixture of gilsonite and rubber has different physical and chemical properties, and will resist oxidation and changes in temperature.[12] This fact makes gilsonite a valuable constituent in rubber compounding. Gilsonite is used in the manufacture of prepared roofing and flooring materials, and in paving cements. When mixed with other hydrocarbons, gilsonite makes an ideal insulating material.

Mixed with fatty acid pitches it becomes a valuable paint for wood, iron, steel, leather, rubber, cork, concrete, and tin; when the solvent evaporates it leaves a highly luminous, black veneer coating, which is unchanged by acids, alkalies, water, or common gases. It is elastic, unaffected by moderate heat and is a good electrical insulator.

In 1918, 31,072 tons of gilsonite, valued at $663,257, were shipped by five producers in the Uinta Basin. So far as is known, no gilsonite was shipped from the Colorado vein.

[12]Ladoo, Raymond B., The natural hydrocarbons: Reports of Investigations, U. S. Bureau of Mines, May, 1920.

Henderson[13] reports the receiving of specimens of gilsonite, collected on Piceance Creek, southwest of Meeker. It is reported to occur in that area in considerable quantities.

Gilsonite, or some related hydrocarbon, probably ozokerite, occurs in the Dakota sandstones of the Rabbit Ears region. Grout[14] in describing the occurrence says:

"This is probably responsible for the mistaken idea of the settlers that several black shale banks are gilsonite. The most notable occurrence is about five miles north of Rabbit Ears, where a layer of the Dakota sandstone is sufficiently charged with hydrocarbons to give it a black or dark-brown color."

The chief use of grahamite is in the manufacture of prepared roofing, due, it is claimed, to the fact that mastic made from it is more resistant to grease and oil than that made from other ordinary hydrocarbons. It has a higher fusion point than gilsonite and so is usually softened with a heavy asphaltic flux. The resulting product becomes more rubbery and elastic, and is less susceptible to heat.

Grahamite is used as a substitute in the rubber industry, as a filler in brick and artificial stone blocks, in the manufacture of varnishes, in the manufacture of electrical wire insulation, and in molded insulation.

Many localities report the presence of bitumens, asphaltic sands, tar sands, bituminous shales, bituminous sandstones, and minor gilsonitic veins. All these deposits have been noted on the map; but owing to the lack of definite information regarding them they have been classed as natural hydrocarbons.

Deposits of native substances of variable color, hardness, and volatility composed of hydrocarbons substantially free from oxygenated bodies are called bitumens. These bitumens are sometimes associated with mineral matter, but regardless of associations, they are usually fusible and largely soluble in carbon disulphide.

A deposit of asphaltite is located on the east side of Sherman Creek in Sec. 24, T. 4N, R. 77W, near the northern edge of Middle Park. The deposit can be reached by following the road up Willow Creek from Granby station on the "Moffat" road.

The veins occur as fissure fillings in the clays, sandstones, and conglomerates of the Middle Park formation, a formation classed

[13] Henderson, Junius, Scientific expedition into Northwestern Colorado in 1909. Univ. of Colo. Studies, vol. 7, pp. 111-112.

[14] Grout, F. F., Worcester, P. G., Henderson, Junius. Reconnaissance of the geology of the Rabbit Ears region, Colorado: Colo. Geol. Survey Bull. 5, pt. I, p. 57, 1913.

as post-Laramie, but probably the equivalent of the Denver formation on the east side of the range.[15] This deposit is comparatively isolated, as the closest asphaltite is found near the Colorado-Utah line about 150 miles distant.

The fissures in this deposit were evidently filled, after opening, with material derived from adjacent strata, which are known to contain bitumens. The vein is traceable on the surface for 3,000 feet, and is very irregular, varying from a few inches to 6 feet in width. Considerable work has been done on the deposit, and the product has been hauled to Granby, from which point it was shipped to Denver and eastern markets. So far as can be ascertained, the deposit is not being worked at present.

OIL AND GAS[16]

JACKSON COUNTY

There is a large anticline east of Walden[17] in the area between the Canadian and Michigan rivers. A well is now being drilled on this structure, but accidents have delayed its earlier completion.

Another structure occurs along Pinkham Creek, near the mouth of King Canyon in the northeast corner of North Park.

MOFFAT COUNTY[18]

The principal anticlinal fold of this area appears to be a continuation of the Uinta Mountain axis. This fold is not of great magnitude, however, in the lower part of Axial Basin.

The Danforth Hills are composed of a system of folds by which the strata are bent into anticlines and synclines. The Thornburgh Mountain structure and the Sulphur Creek anticline are a part of this system.

Up to the present time no oil has been found in commercial quantity in this county.

RIO BLANCO COUNTY

The Rangely oil field is located in Raven Park, in the extreme northwestern corner of Rio Blanco County. The field occupies a basin which is a broadened portion of the lower White

[15]Willis, Bailey, Index to the stratigraphy of North America: U. S. Geol. Survey Prof. Paper, 71, p. 769, 1912.

[16]For location of anticlines, oil seeps, bitumen, oil sands, gas and oil springs, oil wells, and drill holes see accompanying map.

[17]Beekly, A. L., Geology and Coal Resources of North Park, Colorado: U. S. Geol. Survey Bull. 596, pp. 90-93, 1915.

[18]Gale, H. S., Coal fields of northwestern Colorado and Utah: U. S. Geol. Survey Bull. 415, pp. 98-102, 1910.

River valley. The valley itself has been eroded from the crest of the anticline.

Oil has been found in from 75 to 100 wells in the Mancos formation, but as these wells have not been systematically tested by pumping no conclusive data are at hand.

Practically the entire field is located within a government withdrawal which fact has retarded development work during the past few years. At present, however, substantial progress is being made and a paying field of small wells is confidently predicted.

Several structures have been located near Meeker, in the eastern part of the county, but no oil has been found up to the present time.

It is reported that oil in promising quantity has been found at a depth of less than 400 feet in a well about 15 miles north of Gunnison.

ROUTT COUNTY

According to Weston[19] a well was drilled several years prior to 1909 on a structure at Trull, on the Elk River, just above where it empties into the Yampa River.

A number of structures have been located in Routt County[20] and adjacent parts of Moffat County.

The Williams Park anticline lies southeast of Willow Creek in Moffat County, and in the Williams Park topographic basin two strong anticlines occur, the Sage Creek and the Fish Creek.

The Yampa or southern crest of the Tow Creek anticline has been tested by two wells, but the results were not favorable. The northern crest of this anticline is called the Chimney Creek dome, and the middle crest the Tow Creek.

It is reported that a heavy flow of gas was encountered in wells drilled on a structure in the Twentymile Park district, southwest of Steamboat Springs.

OIL SHALE

Immense volumes of oil shales occur in the Green River formation of western Colorado, eastern Utah, and southern Wyoming. In Colorado these areas are confined mainly to Moffat, Rio Blanco, Garfield, and Mesa counties. A small area of shale occurs in the extreme northern part of Delta County.

[19]Weston, W., The hydrocarbons of the Moffat Road, p. 24, 1909.
[20]Crawford, R. D., Some anticlines of Routt County, Colorado: Colo. Geol. Survey Bull. 23, 1920.

The total area of oil shale in Colorado is about 2,000 square miles, and may be divided into several well defined districts.

The first and largest area lies in Rio Blanco and Garfield counties, between the Grand River on the south, and the White River on the north. Government and Flag creeks mark the eastern boundary, while one branch extends along the line between Garfield and Rio Blanco counties almost to the Colorado-Utah line.

A second area lies in Moffat County, between Little Snake River and Vermilion Creek, and north of the Yampa River. This is a southern extension of the Wyoming deposits. The shales of this area are poorer than those in Rio Blanco and Garfield counties.

A small strip of oil shales extends along the Colorado-Utah line in the extreme western part of Rio Blanco County. This is the eastern edge of large deposits occurring in eastern Utah.

Small areas occur south of the Denver and Rio Grande Railroad, on Battlement Mesa, in Garfield and Mesa counties, and on Grand Mesa in Mesa and Delta counties.

The Green River formation, which contains the oil shales, is of Tertiary age. Below it lies the Wasatch, (Tertiary), and Mesaverde, (Cretaceous), formations. The Mesaverde is the principal coal-bearing formation of Northwestern Colorado.

The Green River formation is composed of a series of shales, sandstones, and calcareous oölites, with occasional beds of limestone, and conglomerate. The oil shales occur in the middle member of the formation, the top and bottom parts being barren. Where the upper member is eroded away oil shale may be exposed at the surface.

The oil shale strata vary considerably in thickness from place to place. In Colorado they are most extensively developed in Garfield and Rio Blanco counties where, in places, they attain an aggregate thickness exceeding 100 feet.

The shales range in color from black through blue and brown to gray or even yellow. They differ in character from massive to papery, limy, sandy, asphaltic, and waxy. The greater part of the Colorado shales are dark and massive.

The shale is an "oil shale" in name only, because it contains little or no free oil. The shale does, however, contain large quantities of organic remains, chiefly of vegetable origin.

Winchester[21] reports the finding of beautifully preserved beetles, flies, mosquitoes, bees, leaves of all kinds, fish skeletons,

[21]Winchester, D. E., Oil Shales: Journal of the Franklin Institute, vol. 187, pp. 689-704, 1919.

and even bird bones in the Green River series. Richer oil shales, he found, contain an abundance of vegetable material such as fragments of ferns, algae and fungi, bacteria, and pollen.

In addition to the plant and animal remains there are numerous small particles of bitumen.

By a process of destructive distillation these organic remains and the bitumen are converted into crude shale oil. This crude oil is in turn broken up by refining methods into gasoline, kerosene, lubricating oils, and paraffine.

A considerable amount of ammonium sulphate can be saved in the retorting of the shales. This is a very valuable and much desired fertilizer.

In discussing the by-products of oil shales, R. D. George[22] makes the following statement:

> "Analysis of several samples of spent shale showed an average potash content of eighteen pounds per ton of spent shale. This is water soluble and could be leached out at little cost."
>
> "The tars, still carbon, or coke and the heavy residual oils will be utilized about the plants or converted into marketable products."

Dean B. Winchester of the United States Geological Survey, has estimated that in Colorado alone there is sufficient shale, in beds that are three feet or more thick, to yield 20,000,000,000 barrels of crude oil, and that in addition, with but little more cost, there might be produced about 300,000,000 tons of ammonium sulphate.[23]

Although much of the oil shale region in western Colorado is remote from railroad transportation and not easily accessible, a large part is adjacent to transcontinental railroads. Branches can easily be built into many areas which are now without rail transportation.

PRECIOUS STONES

A large amount of chalcedony of gem variety is found throughout the northwestern part of the state. Agate is also found in some localities.

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[22]George, R. D., Oil Shale Problems: Railroad Red Book, vol. 37, No. 7, pp. 651, July, 1920. (Published by the Denver and Rio Grande Railway, Denver.)

[23]Winchester, D. B., Oil shale in northwestern Colorado and adjacent areas: U. S. Geol. Survey Bull. 641, p. 140, 1917.

SCORIA

Near Volcano, in Routt County, large quantities of scoria occur. This material has been used quite extensively in the ballasting of the tracks of the Moffat road through Routt and Moffat counties.

SILVER[24]

SUMMIT COUNTY

From the standpoint of value silver is the most important metal in the ores of the Tenmile mining district (Kokomo and Robinson) and in the Peru district, 8 miles east of Dillon.

URANIUM

MOFFAT COUNTY

Gale[25] reports the presence of a deposit of carnotite at the southern foot of Blue Mountain (called Yampa Plateau on the early maps of the region), about 18 miles east from the Colorado-Utah boundary. The deposit lies along the summit and flanks of the highest hogback, about 2 miles west of Skull Creek, which is the main east fork of the Red Wash.

The carnotite in this locality occurs in thick beds of white sandstone which show a large amount of cross bedding. The strata are undoubtedly Jurassic in age, as are those in which the carnotite occurs in southwestern Colorado.

RIO BLANCO COUNTY

Carnotite has been found about 14 miles by wagon road northeast of Meeker, on Coal Creek, which is one and one-half miles southeast of the locality known as "The Transfer," on Coal Creek.

In this region the carnotite is found at the summit of the hogback formed by the lowest of the most massive sandstones. The sedimentary rocks of the area are much more steeply tilted than those in southwestern Colorado.

VOLCANIC ASH

GRAND COUNTY

A small deposit of volcanic ash occurs, on the south side of the Grand River, about one and one-half miles southeast of Krem-

[24]See Hill, J. M., The mining districts of the western United States: U. S. Geol. Survey Bull. 507, pp. 134-157, 1912. Statistics compiled by C. W. Henderson, Statistician. U. S. Geol. Survey.

[25]Gale, Hoyt S., Carnotite and associated minerals in Western Routt County, Colorado: U. S. Geol. Survey Bull. 340, pp. 257-262, 1908.

mling. The ash is very uniform in size and is composed of thin white flakes with very angular edges.

The material of the deposit is generally white, although in places it has been stained a light brown by percolating solutions containing iron.

A gray appearing volcanic ash is now being shipped from a deposit near Troublesome. This material is shipped to Denver where it is used in the manufacture of hand soaps and scouring powders.

MOFFAT COUNTY

Volcanic ash has been reported as occurring in the extreme northwestern part of Moffat County,[26] near the Colorado-Utah line.

[26]Montgomery, Henry, Volcanic dust in Utah and Colorado: Science, new series, vol. I, pp. 656-657, 1895.

CHAPTER II

MINERAL DEPOSITS

OF

WESTERN COLORADO

BARITE

GUNNISON COUNTY

Barite occurs as a gangue mineral in the ores of several mines in Gunnison County. Particularly fine specimens have been found at various times, but deposits of commercial importance are not yet known.

MESA COUNTY

It is reported that low-grade barite has been found in the vicinity of Grand Junction, but no further information has been obtained concerning the deposit.

OURAY COUNTY

In the Ouray district, deposits of baritic siliceous ores are found as flat masses associated with vertical fissures, and as a gangue mineral in lateral enrichments of silver veins in the Newsboy, the Pony Express, and the Mineral Farm mines.[27]

In the Mineral Farm mine the ores consist of fine-grained silica heavily charged with crystalline barite, and containing argentiferous gray copper, galena, and chalcopyrite. The barite could easily be saved in the milling of the ore.

PITKIN COUNTY

Barite is a common gangue mineral in the ores of the Smuggler and Mollie Gibson mines at Aspen. In the Smuggler mine[28] rich silver ore is enclosed in flesh-colored or gray barite. In the Mollie Gibson mine most of the ores carry barite as a gangue min-

[27]Cross, Whitman, Howe, Ernest, Irving, J. D., Geology of the Ouray quadrangle, Colorado: U. S. Geol. Survey Geol. Atlas, Ouray folio (No. 153), p. 18, 1907.

[28]Spurr, J. E., Geology of the Aspen Mining district: U. S. Geol. Survey Mon., 31, pp. 184-189, 1898.

eral. Other mines of the district contain barite as a common gangue mineral.

No attempt has been made to separate or save the barite of the district. The high freight rates to outside points of consumption naturally prevent the mining and shipment of the mineral.

SAN MIGUEL COUNTY

In San Miguel County, barite occurs 2 miles north of Placerville in veins from 2 to 7 feet wide.[29]

Barite is a common gangue mineral in the ores of many of the metal mining camps of the western and southwestern parts of the state. In prospecting for the metals, barite is often encountered, but as it has a low value compared to the metals very little attention is paid to saving it. Up to the present time there has been no commercial production in western or southwestern Colorado.

BUILDING STONE

GUNNISON COUNTY

Granite.—The Aberdeen granite quarry is located in Gunnison County, on South Beaver Creek, about 4 miles from the point where that stream empties into the Gunnison. It is 11 miles from the town of Gunnison. The quarry site includes about 120 acres of land.

The quarry was opened in 1889 and has produced a total of 290,000 cubic feet of very high grade building stone, most of which was used in the State Capitol. The area affords an inexhaustible supply of the highest grade of building granite.

GUNNISON COUNTY

Lava.—A good grade of lava rock has been quarried near Gunnison. The deposits are large, the rock is easily worked and is suitable for sills, belt courses, and quoins.

GUNNISON COUNTY

Marble.—Large deposits of extremely good marble, of medium fine texture, and of several colors are found on Yule Creek and in the adjacent areas. This marble has been used extensively for building purposes in Denver and eastern localities.

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[29] Schrader, F. C., Stone, R. W., Sanford, Samuel, Useful minerals of the United States: U. S. Geol. Survey Bull. 624, p. 82, 1916.

PITKIN COUNTY

Granite.—Some granite has been produced from a quarry 10 miles southeast of Aspen. There is much excellent stone available.

PITKIN COUNTY

Marble.—Some marble has been found in Pitkin County, near Aspen. It is of a beautiful gray color, varies in texture from coarse to fine and even. It is easily worked and could be used freely as a substitute for the Bedford (Indiana) stone which finds a ready market in Colorado.

GUNNISON COUNTY

Slate.—Slate is reported as being quarried in the same area of metamorphism as that in which large deposits of marble are found on Yule Creek.

Sandstone.—The standstones of the McElmo, Dakota, and White Cliff formations are especially well suited for building purposes. These formations occupy large areas in western Colorado, and furnish good, easily quarried building material. In certain localities a light red sandstone from the Hermosa formation is utilized for building. Dark red sandstone from the Cutler, and gray sandstone from the La Plata formation are used in other localities. The quantity of these is very large.

DELTA COUNTY

Sandstone.—Quarries are located near Austin and at Delta. The product has been used locally in building operations.

EAGLE COUNTY

Considerable red sandstone has been shipped from quarries at Peachblow, east of Basalt, on the Colorado Midland Railroad. The sandstone is rather soft, and very little has been used during the past few years.

MESA COUNTY

Pink sandstone has been quarried from the La Plata formation southwest of Fruita. The rock has been used locally for building purposes.

MONTROSE COUNTY

Sandstone has been quarried at Montrose and Olathe. It is reported that the entire output was used locally.

OURAY COUNTY

Light red sandstone from the Hermosa formation, dark red sandstone from the Cutler formation, and gray sandstone from the La Plata formation are used locally in Ouray County.

CLAYS

WESTERN COLORADO

The shales of the Mancos formation are abundant in the western part of the state. These shales are well suited for the manufacture of ordinary brick, and are being utilized at a number of places. The shales of certain other strata in the Mancos formation are suitable for the manufacture of pressed brick, soft mud bricks, and earthenware. Clay from a bed near the top of the Mancos formation appears suitable for the manufacture of semi-refractory brick.

The Dakota and Mesaverde formations contain numerous lenticular beds of fire clay. The fire clays of the Dakota formation are generally found within the sandstone, and are indicated by a black clay line which is readily recognizable. The fire clays of the Mesaverde formation are found underneath the coal seams, or are mined with the coal. These clays are impure, and not as good as those found in the Dakota formation.

The Lewis formation should furnish shales suitable for the manufacture of ordinary brick.

River terrace clays are worked at Glenwood Springs, Aspen, Grand Junction, and numerous other localities in western Colorado. Wherever these are being worked, the less sandy clays are more likely to be found the greatest distance back from the river.

In Garfield County, plastic clay from the Dakota sandstone near Glenwood Springs, has been mixed with crushed quartz, and made into bricks for coke ovens at Cardiff.[30]

COAL

BOOK CLIFFS COAL FIELD

The Book Cliffs form the southern margin of the Book or Tavaputs Plateau, and extend from Grand River, Colorado, to Helper, Utah.

The Book Cliffs field, in Colorado, covers approximately 360 square miles, most of which is easily accessible.

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[30]Schrader, Frank C., Stone, Ralph W., and Sanford, S., Useful minerals of the United States: U. S. Geol. Survey Bull. 624, p. 84, 1917.

Coal of commercial importance occurs in the lower part of the sandstone and shale formation which is known as the Mesaverde. The coal is found at various intervals from 35 to 700 feet above the shale that underlies the lowland.

It occurs at different horizons, and no bed has been traced continuously for more than a few miles. In some places only one bed of coal is present while at others there are several.

The coals of the Book Cliffs may be classed as medium-grade bituminous, and they compare favorably with the product of the Rocky Mountain region and the Mississippi Valley.

The total production from 15 mines operated in Mesa County during 1918 was 220,369 tons.

GRAND MESA COAL FIELD

The Grand Mesa coal field extends from Cameo, on the Grand River, south and then east as far as the Somerset and Bardine districts in Gunnison County. The district includes approximately 550 square miles of coal lands.

The coals of the field vary from the low-grade bituminous coals, found in the western part of the field, to the semi-anthracite of the east end of the field.

No close estimate can be made of the amount of coal in this field, until a more extensive study has been made of the area. The average thickness of the coal varies from 11 feet in the Palisades district to 65 feet in the Somerset district.

According to Lee,[31] after deducting 25 per cent for waste in mining, there would remain 14,881,703,160 short tons of available coal in this district, mainly on Government land.

During 1918, 13 mines in Delta County produced a total output of 94,870 tons of coal. During the same period two mines in Montrose County produced 1,020 tons of coal.

COPPER[32]

MESA COUNTY

The Unaweep Copper district is located 25 miles southwest of Grand Junction, and about 12 to 13 miles west of Whitewater, on the Montrose branch of the Denver & Rio Grande Railroad. This district has possibilities which have not been developed up to the present time.

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[31]Lee, W. T., The Grand Mesa Coal field, Colorado: U. S. Geol. Survey Bull. 341, pp. 316-334, 1909.

[32]Also see Hill, J. M. The mining districts of the western United States: U. S. Geol. Survey Bull. 507, pp. 134-157, 1912. Statistics compiled by C. W. Henderson, Statistician U. S. Geol. Survey.

MONTROSE COUNTY

Copper is found in the ores of the La Sal and Paradox mining districts, located 76 miles west of Placerville, in the extreme western part of Montrose County.

OURAY COUNTY

In the Red Mountain district, between Silverton and Ouray, copper predominates over silver, gold, and lead. The production of Ouray County in 1919 was $7,696. The total production from 1878 to 1917 was $3,207,240.

FLUORSPAR

GUNNISON COUNTY

Fluorspar is found as a gangue mineral in the lead ores of the Lead King mine at Crystal. Some colorless material suitable for optical purposes has been found, but its occurrence is not common.

HINSDALE COUNTY

The ores of the Hidden Treasure mine contain occasional crystals of fluorspar among the gangue minerals. Although a small amount of flourspar is common in the ores of the district, the quantity is not sufficient to be of commercial importance.[33]

MONTROSE COUNTY

A small vein of flourspar has been prospected about 14 miles northeast of Montrose. This deposit is located on the south side of the Gunnison Canyon, on Vernal Mesa. The samples show a calcium fluoride content of 33 per cent, whereas, 80 per cent or greater is the desired content.

OURAY COUNTY

Fluorspar occurs as a gangue mineral in many of the veins of the district. In the Camp Bird, Micky Breen, and Grizzly Bear mines green fluorspar in pieces up to 4 inches in diameter is found associated with quartz, rhodochrosite, galena, pyrite, and sphalerite.

A vein of fluorspar from 3 to 5 feet in width was found in the Barstow mine during the summer of 1917. About 1700 tons (averaging above 90 per cent calcium fluoride) was shipped from

[33] Irving, John D., and Bancroft, Howland, Geology and ore deposits near Lake City, Colorado: U. S. Geol. Survey Bull. 478, p. 46, 1911.

the property during 1917-1918. Some of the fluorspar appears to be suitable for optical purposes, as it is nearly colorless or light green, and seems to be only slightly fractured.

The vein was first cut at a depth of 1050 feet. It was then opened in a level 140 feet above that point and 600 feet distant horizontally. Additional work has proven that the vein continues in the opposite direction, and that the ore bodies are of far greater size than was at first supposed.

The fluorspar is of very high grade and can be sorted and washed to meet any demands. Under normal conditions, the high freight rates and cost of haulage to the railroad will not permit its competition with eastern fluorspar.

It may pay, however, to mine and ship fluorspar from this deposit when there is a demand for high grade fluorspar for use in the chemical industry.

The Torpedo Eclipse and Ruby Trust mines, at Sneffels, contain large bodies of good grade fluorspar, and discoveries have also been reported in other metal mines in the county.[34]

SAN MIGUEL COUNTY

Flourspar is found as a gangue mineral in the ores of the Telluride district. In the Tomboy mine, many small crystals of colorless to greenish flourspar are found.[35]

GOLD[36]

EAGLE COUNTY

Gold is the predominant metal in the ores of the Fulford district, 18 miles southeast of Eagle, and in the Holy Cross district, 18 miles southwest of Red Cliff. During 1919, the value of the gold produced in Eagle County was $19,059. The total production of the county from 1879 to 1915 was $2,145,464.

GUNNISON COUNTY

Although more silver than gold has been produced in Gunnison County, gold is the predominant metal in the ores of several districts. Gold predominates in the ores of the Box Canyon district, 11 miles south of Pitkin; in the ores of the Cebolla district, 18 miles south of Iola; in the Cochetopa district, 5 miles south

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[34] Carroll, Fred., Colorado State Bur. Mines Fifteenth Bienn. Rept. for 1917-1918, p. 131, 1919.

[35] Cross, Whitman, and Purington, C. W., U. S. Geol. Survey Geol. Atlas, Telluride folio (No. 57), p. 16, 1899.

[36] See Hill, J. M., The mining deposits of the western United States: U. S. Geol. Survey Bull. 507, pp. 134-157, 1912. Statistics compiled by C. W. Henderson, Statistician U. S. Geol. Survey.

of Parlin; in the Gold Brick district, 3 miles north of Ohio City; and in the Tincup district, 37 miles southwest of Buena Vista.

From 1873 to 1917 Gunnison County produced $2,112,520 in gold.

OURAY COUNTY

In Ouray County the following districts show a predominance of gold over other metals:

Imogene Basin (Camp Bird), 8 miles southwest of Ouray; the Sneffels district, 8 miles west of Ouray; and the Uncompahgre district around Ouray.

Between 1878 and 1917, $34,675,607 in gold was produced from Ouray County.

SAN MIGUEL COUNTY

Gold predominates in the ores of the Telluride district, the Iron Spring district at Ophir, and the Lower San Miguel district around Placerville, Sawpit, and Vanadium (Newmire).

The production of gold in San Miguel County in 1919 was valued at $2,124,837. The total production from 1875 to 1917 amounted to $49,956,607.

GRAPHITE

GUNNISON COUNTY[37]

There are three parallel nearly vertical "veins" about 50 feet apart and conforming to the bedding of the enclosing sedimentary rocks. The largest vein has a width of 4 to 6 feet. The graphite is the result of the extreme metamorphism of coal seams of Cretaceous age.

The deposits are near the head of Cement Creek, about 10 miles from the railroad. The development consists of a number of open cuts near the summit of Italian Mountains.

The quality of the graphite varies with the intensity of the metamorphism, but there appears to be an immense tonnage of good material.

A large vein of amorphous graphite is traceable for more than 10 miles between White Pine and the Tin Cup district. The vein varies from a few inches to several feet in width, but shows a considerable amount of marketable graphite.

Some development work has been done on the vein, and in the Quartz Creek district several mines have shipped ore. Prior

[37]U. S. Geol. Survey Mineral Resources, pt. II, p. 1067, 1912.

to May 3, 1918, the property operated by Woodruff and Woodruff shipped over 1,000 tons of graphite,[38] while several other properties shipped smaller amounts.

After the signing of the armistice there was a sharp decline in the price of graphite. This resulted in a suspension of operations in the mines on Quartz Creek, as the cost of mining and hauling the ore 5 miles to Quartz station and the freights beyond this point were excessive.

During 1919 only 2 cars of graphite were shipped from the Quartz Creek district.

GRINDSTONES

GUNNISON COUNTY

A sandstone stratum, suitable for the making of grindstone, occurs near Gunnison. The deposit lies just outside the city limits, on the bank of the Gunnison River, and in close proximity to the railroad. Water for power purposes and for quarry use is readily available.

The Dakota formation outcrops at this point and is exposed for about one-half mile. It consists of about 21 feet of workable material.[39] The top 8 feet of sandstone is suitable for grindstone purposes, the next 8 feet for fine grindstones and oil stones, and the next 5 feet for very fine oil stones and razor hones. It is claimed that when pulverized the finer-grained sandstone makes a fine polish for gold and silver ware.

The sandstone appears to be well adapted for abrasive purposes, as it is fine grained, even textured, and has good adhesive properties.

GYPSUM[40]

Gypsum is widely distributed throughout the western slope of Colorado, though commercial deposits appear to be confined to but few geological formations. In quantity, the supply is almost unlimited and unless very important new uses are found either for the raw mineral or the manufactured products there is enough to meet the demands for centuries. By far the larger part of the gypsum is of the granular rock variety, occurring interstratified with other sedimentary rocks. Here and there through the weath-

[38] Carrol, Fred., Colorado State Bur. Mines Fifteenth Bienn. Rept. for 1917-1918, p. 134, 1919.

[39] Mining Science, Gunnison, Colorado, Grindstone Quarries: vol. 62, p. 625, 1910.

[40] Excerpts from paper by R. D. George on "Gypsum deposits of Colorado."

ering of the rock gypsum considerable accumulations of gypsite have been formed.

Of the vast volume of gypsum in the state a very large proportion is of excellent quality, and analyses show as high as 99 per cent of hydrous calcium sulphate. In places the deposits must be classed as gypsiferous shales and are commercially useless.

On the western slope the Carboniferous was by far the most important period of gypsum deposition, and probably 90 per cent of the gypsum occurs in strata of Pennsylvanian and Permo-Pennsylvanian age.

RIO BLANCO, GARFIELD, EAGLE AND PITKIN COUNTIES

Along the valleys of the White, Grand, and Eagle rivers, and such tributaries as the Roaring Fork, Frying Pan, Brush, Gypsum, Cottonwood, and others, large areas of the Upper Carboniferous formations of the Hayden geologists are exposed. In many places along these streams the outcropping edges of the strata show large deposits of gypsum and gypsiferous shale varying in color from pure white to pink, gray, and almost black. The predominant color of the gypsiferous shale is gray, and that of the gypsum beds is an ashy gray which is very easily recognized.

In some places the weathering of the gypsum has covered wide slopes with a soft flour-like gypsite more or less mingled with alluvial materials from the higher strata. The general geological relationships are such as to suggest an equivalence of age with the deposits along the eastern foothills of the range, though in places gypsum is possibly in strata corresponding to the Hermosa of the San Juan country, and is thus of Pennsylvanian age.

At Ruedi on Frying Pan Creek in Pitkin County a plaster mill was in operation for a few years, but it is now closed down. A few carloads of gypsum have been shipped from Gypsum station to Portland, Colorado, for use in the manufacture of cement.

The supply is almost unlimited.

Northward from Gypsum station, gypsum[41] occurs in large masses, outcropping in hillsides, in the gullies and on mountain tops for about 4 miles back from the Eagle River. The strip of land 3 or 4 miles wide, including the divide between the Eagle River and Grand River basins, appears to be composed of a limy shale and thin limestone carrying little or no gypsum. On the

[41] Burchard, E. F., Gypsum deposits in Eagle County, Colorado: U. S. Geol. Survey Bull. 470, pp. 360-361, 1911.

slope towards Grand River gypsum is again present in abundance, occurring in enormous masses in the gulches and on the hillsides.

None of the deposits on the slope toward the Grand River can become commercially important until a railroad is built down the Grand River connecting the Denver and Salt Lake Railroad at Orestod, with the Denver and Rio Grande Railway at Dotsero.

The gypsum also appears on both sides of Spruce Creek and on both sides of the Roaring Fork. In all these areas the strata and gypsum deposits are very similar to those along the Eagle River.

Gypsum[42] occurs in strata and lenses of various dimensions interbedded with shale, but is not confined to definite horizons. The lenses range from a few yards to miles in length, and in thickness from a few feet up to 200 feet or more. The lenses generally contain shale bands or beds mixed with gypsum and consequently contain more or less impurities. Two and one-half miles east of Gypsum, in a stratigraphic section 140 feet thick, the gypsum measures 90 feet. Here selenite and anhydrite are plentiful.

Along the open valley of the Eagle River, between the Canyon and a point five or six miles above the Grand, the bordering hills are formed of gypsiferous shale and gypsum, which break down into a soft powdery gray to white mass of impure gypsite and alluvium. In the lower canyon of Eagle River gypsum beds dip from the river in both directions, and the peculiar erosion of these hills has developed a topography resembling that of the bad lands.

A section measured on the Eagle River consists of about 1,500 feet of shales, sandstones and limestones, often showing transitions from one type to another.[43]

Of the total thickness probably one half is gypsum bearing. From fossil evidence Lesquereux[44] determined the age to be Permian. Recent work supports this finding.

UNCOMPAHGRE REGION

Siebenthal[45] describes the occurrence of gypsum along the Grand Canyon of Gunnison River in Delta and Montrose counties. The gypsum measures outcrop uninterruptedly for 20 miles, from

[42]Burchard, E. F., Gypsum deposits in Eagle County, Colorado. U. S. Geol. Survey Bull. 470, p. 357, 1911.
[43]Burchard, E. F., Gypsum deposits in Eagle County, Colorado. U. S. Geol. Survey Bull. 470, pp. 354-364, 1911.
[44]Lesquereux, Leo., Permo-Carboniferous strata of Eagle River: U. S. Geol. Survey of the Territories by F. V. Hayden, vol. 8, pp. 118-119, 1874.
[45]Siebenthal, C. E., Gypsum of the Uncompahgre region, Colorado: U. S. Geol. Survey Bull. 285, pp. 401-403, 1905.

a point below the mouth of Smiths Fork southward to Red Rock Canyon. These measures average 110 feet in thickness and reach a maximum of 150 feet.

The gypsum occurs in a series of shales and sandstones of undetermined age, but separated from the so-called Dakota by 400 feet of variegated but predominantly reddish shales, with interbedded red and buff sandstones. The description of the sandstone, resting on the pre-Cambrian schists suggests the ''Crinkled Sandstone'' of the Lykins east of the range.

Efforts have been made to develop the gypsum deposits northeast of Montrose, but so far all the enterprises have failed, due to the lack of capital, and to the cost of transporting the product to market. In this vicinity there appear to be four distinct strata, two are six feet, one ten feet, and one sixteen feet in thickness.

GUNNISON COUNTY

Howell[46] mentions the occurrence of gypsum on the east side of the river near Gunnison.

IRON

GUNNISON COUNTY

Numerous deposits of iron ore have been found in Gunnison County. The greatest of these deposits, and perhaps the largest in the state, is located about two and one-half miles southeast of Powderhorn, on the north side of Cebolla Creek. This deposit contains a large tonnage of magnetite and limonite. Very little development work has been done because of the lack of transportation facilities.

Several thousand tons of iron ore were shipped from the Iron King mine at White Pine, and used as a flux in the old lead smelter at Gunnison.

Large deposits of iron ore are found on Taylor River, but have never been developed, because of the lack of transportation facilities in that district.

Bog iron is found in various localities in the Crested Butte district. The largest deposit occurs in Redwell basin, on the north side of Scarp ridge. Another deposit of almost equal size is found in the valley of Coal Creek, nearly opposite the deposit in Redwell basin.

[46]Howell, E. E., Geology of a portion of Colorado explored and surveyed in 1873; Wheeler Survey Rept., vol. 3, p. 264, 1875.

OURAY COUNTY

Magnetite-pyrite ore occurs in the Bright Diamond and Iron Clad mines, high up on the sides of the Uncompahgre Canyon, below Ouray.

PITKIN COUNTY

A deposit of iron ore is found high up the side of one of the mountains forming the base of Hayden Peak. This deposit is practically inaccessible at present.

LEAD[47]

GUNNISON COUNTY

Considerable lead is mined in the Tomichi (Whitepine) and Elk Mountain mining districts in Gunnison County. The Tomichi district is located 12 miles northeast of Sargents, on the Denver & Rio Grande Railroad. The Elk Mountain district is located near Crested Butte.

Gunnison County produced lead to the value of $154,620 during 1919, and between 1873 and 1917 the value of the lead produced was $1,723,272.

HINSDALE COUNTY

Lead is the principal metal produced in the Galena mining district, 5 miles west of Lake City.

PITKIN COUNTY

Lead is the principal metal in the ores of the Ashcroft district, 12 miles south of Aspen, and in the Aspen district itself.

During the past few years the value of the lead produced has been greater than that of the silver. During 1919 the high prices paid for silver reversed this condition.

The production of lead in 1919 was valued at $301,141. The total production from 1880 to 1917 was valued at $23,802,993.

A fine grained blue gray limestone is found in the vicinity of Aspen. This rock is particularly well suited for building purposes, as it has a good color, cuts well, and is quite resistant to weathering. It is only slightly harder than the well known Bedford limestone, but should cut and market equally well.

LIMESTONE

Nearly all the Carboniferous formations of western Colorado contain strata of commercial limestone which could be used for

[47]See Hill, J. M., The mining districts of the western United States: U. S. Geol. Survey Bull. 507, pp. 134-157, 1912. Statistics compiled by C. W. Henderson, Statistician, U. S. Geol. Survey.

fertilizers, or in the manufacture of lime and Portland cement. Shale necessary for cement manufacture is readily available throughout many areas in western Colorado, and in most cases is adjacent to the limestone deposits.

The limestones show a low magnesium content, and would make an excellent lime.

DELTA COUNTY

Limestone has been quarried near Dominguez, in Delta County. The entire product has been used locally for building purposes.

GUNNISON COUNTY

Considerable quantities of limestone are found in the vicinity of Gunnison. Lime has been burned in kilns on Cement Creek. Limestone was used as a flux during the earlier smelting activity in Gunnison County.

OURAY COUNTY

Almost inexhaustible quantities of limestone may be had from the Ouray and Hermosa formations in the Ouray district. The limestone is suitable for nearly all purposes, such as lime and cement manuacture, flux for smelting, and stone for building purposes.

PITKIN COUNTY

Lime kilns were operated at Thomasville and Meridith for some years. The quarries at Thomasville were at one time operated on a fairly large scale, and a good grade of lime was produced.

MANGANESE[48]

EAGLE COUNTY

Two immense lenses of low-grade manganiferous iron ore have been developed at Red Cliff, by the Empire Zinc Company.

These great lenses occur parallel to the bedding of the Carboniferous limestone of the district. They crop out on the sides of the canyon wall 400 or 500 feet above the river, two or three miles below the town of Red Cliff. The two lenses appear to occupy the same stratigraphic position, but are found nearly one-half mile apart.

[48]For a full discussion see Muilenburg, G. A., Colo. Geol. Survey Bull. 15, 1919.

In the western one of these great lenses, manganese oxides form the greater part of an ore body 3,000 feet long by 1,000 feet wide. The thickness is variable, but will probably average 50 feet.

It has been estimated that this deposit alone is capable of producing 500,000 tons of marketable manganiferous iron ore.[49]

The eastern deposit is somewhat smaller than the west, but it has been estimated that this deposit is capable of producing between 250,000 and 500,000 tons of manganiferous iron ore. It is said that 200,000 tons have already been produced from this deposit. This would make a total of from 750,000 to 1,000,000 tons of marketable ore in the two great lenses.

Four miles south of Sapinero, manganese occurs in pockets having the shape of large kidneys or botryoidal masses. This occurrence is in many ways similar to that in Steuben Valley.

Small deposits of manganese have been found on the ridge between Little Cimarron and Big Blue creeks, about 12 miles from Cimarron, and in the extreme southwestern part of Gunnison County and adjoining parts of Hinsdale County.

HINSDALE COUNTY

A small amount of development work has been done on a deposit of manganese, located near Burrows Park, from 12 to 14 miles above Lake City on the Lake Fork of the Gunnison River. The vein material is practically all rhodochrosite which has altered to pyrolusite in the oxidized zone.

Small deposits of manganese have been reported as occurring on Henson Creek, 10 miles from Lake City, and on Alpine Plateau, near the foot of Uncompahgre Peak.

OURAY COUNTY

A small amount of manganese ore was shipped to the smelter at Ouray from the Ackerson property, on the lower part of Hayden Mountain. This ore body was opened to obtain a flux for the smelter, but only a small tonnage was shipped before the smelter was closed.

The deposit occurs in the Carboniferous limestones just back of the Mineral Farm mine, and the ore is said to be very well suited for fluxing purposes as it contains a small amount of lime.

GUNNISON COUNTY

Large bodies of manganiferous iron ore have been found along Taylor River, northeast of Gunnison, in the vicinity of White Pine

[49] Umpleby, J. B., Manganiferous iron ore occurrences at Red Cliff, Colorado: Eng. and Min. Jour., vol. 104, pp. 1140-1141, Dec. 29, 1917.

and Tincup, and 2 miles southeast of Powderhorn postoffice, in the southwestern part of Gunnison County.

The ores in the Taylor River, White Pine and Tincup areas are mainly hematite and magnetite, with unaltered sulphides and silicate minerals. Analyses show the main ore body is mostly iron, in which the silica and phosphorous contents are low and the sulphur content is high.

In the Cebolla Valley district the manganese is associated with the deposits of siderite, hematite, and limonite ores. The manganese occurs in the form of pockets or lenticular beds. These lenses are from 1 to 4 feet thick and occur as replacements along the bedding and joint planes of the limestone.

The ore occurs in a series of hills north of Cebolla Creek, and the rocks appear to have a strike north and south, parallel to the creek.

Manganese, associated with limonite, is found irregularly distributed through metamorphic rocks and intrusive granites of the area 4 miles southeast of Powderhorn.

A small quantity of manganese ore has been found in Steuben Valley, a tributary of the Gunnison River. The ore is widely scattered and occurs in cavities in a breccia composed of angular and partly rounded fragments imbedded in a sandy matrix.

SAN MIGUEL COUNTY

A deposit of high grade manganese ore occurs near the top of the divide separting Gypsum Valley from Dry Creek Basin. This location is 45 miles southwest of Placerville, a station on the Denver and Rio Grande Railroad.

Development work on one of four claims has proven the existence of an ore body at least 1,200 feet long and 235 feet wide, with an average thickness of about 20 inches. It is said that 50,000 tons of marketable manganese can be mined from this claim alone, whereas, three other adjacent claims should furnish a considerable tonnage of good ore.

A small deposit of manganese has been located about five miles southeast of Naturita, near the top of the divide between the San Miguel River and Dry Creek Basin.

MARBLE

GUNNISON COUNTY

Burchard[50] describes the occurrence of marble on Yule Creek in Gunnison County as follows:

"The most extensively developed deposits of marble in Colorado are on Yule Creek, in northern Gunnison County. The deposits that are quarried here are high on the left bank of the creek and dip westward at an angle of about 52°. The marble bed is reported to be about 240 feet thick, and to contain four bands of chert, each 2 to 4 feet thick. The underlying rock is cherty blue dolomite, and overlying the marble is a sill of igneous rock which is, in turn, overlain by 500 to 800 feet of blue cherty limestone. The marble itself is for the most part white and of medium, fine grain, but there are bands of handsome green-stained material within the mass."

Loughlin[51] reports the presence of three varieties of marble in the district, the white, the "Colorado Cloud" with black veining, and the "golden vein" with yellow veining. Many other types of marble have been found in the Yule Creek district and adjacent areas.

A large amount of marble was shipped from the Yule district prior to the time operations were stopped. One of the finest buildings constructed of Colorado-Yule marble is the United States postoffice in Denver.

A black, white vein brecciated marble has been found in the Pitkin district. Several localities in the region of Gunnison report the occurrence of marble. A particularly fine piece of coarsely crystallized, banded marble was seen in Gunnison, and was reported to have been found southeast of the town.

MICA

MESA COUNTY

A deposit of mica is located in Ladder Canyon, Mesa County, about 8 miles south of Grand Junction. The mica streak ranges from 1 to 3 feet in thickness and is composed of nearly solid masses of muscovite crystals. The crystals are much ruled and broken, and nearly all have the "herring bone" structure. It is probable that the entire yield of mica from this deposit is suitable for grind-

[50]Burchard, E. F., U. S. Geol. Survey, Mineral Resources of the United States for 1912, pt. II, p. 810.

[51]Loughlin, G. F., U. S. Geol. Survey, Mineral resources of the United States for 1914, pt. II, p. 866.

ing purposes. As yet there has been found only a little mica that can be cut into sheets, but further development may open up more.

MONTROSE COUNTY

A considerable amount of mica occurs in the pegmatite vein on Vernal Mesa, north of Montrose. Nearly all the mica of the deposit has the "herring bone" structure and would, in all probability, have to be ground.

MINERAL COKE

GUNNISON COUNTY

Natural coke has been reported as occurring in the Anthracite-Crested Butte district.

MINERAL WATERS

Western Colorado is remarkable for the abundance and variety of her mineral waters. Many of the springs are in the midst of scenery of the greatest beauty and grandeur. In many places the climatic conditions are ideal for health and summer resorts. Many of the waters are of such composition and curative properties as to justify the expectation of a large sale if they were better known.

A report on the Mineral Springs of the State, by the Colorado Geological Survey, is now in press, and will be available in a short time. Only the briefest references to the mineral waters will be made in this bulletin.

DELTA COUNTY—Sulphur Springs occur near Austin. An artesian well near the mouth of Black Canyon yields a very strong mineral water.

The Doughty springs near Hotchkiss are well known.

EAGLE COUNTY—The Dotsero springs are among the largest in the State.

GARFIELD COUNTY—The Glenwood Springs are a large group of highly mineralized springs well provided with baths, plunges, pools and hotel accommodations.

At South Canon a short distance below Glenwood are several developed springs.

Near Cardiff is a sulphur spring.

GUNNISON COUNTY—In the general vicinity of Crested Butte there are several springs. Two are about 8 miles northeast of the town, two others are on Cement Creek about 8 miles from Crested Butte, and another occurs between Irwin and the town.

Waunita Springs are well developed as a health and pleasure resort.

The Cebolla or Powderhorn Springs are also a notable group of developed springs.

HINSDALE COUNTY—A short distance east of Lake City in Sparlin Gulch; and in Slumgullion Gulch west of Lake San Cristobal are mineral springs.

MESA COUNTY—Several springs are found in the valley of Plateau Creek south of DeBeque.

MONTROSE COUNTY—There are mineral springs near the junction of Cimarron Creek and the Gunnison; at Long Park and elsewhere. They are undeveloped.

OURAY COUNTY—Mineral springs occur near Ridgway; in Ironton Park, and at the town of Ouray. Only the last are developed.

PITKIN COUNTY—Near Thomasville there are two large sulphur springs beside the Midland railway.

At Avalanche in the valley of Crystal River there are several mineral springs, some of which are slightly improved.

There is also a mineral spring near Castle Peak at the head of Conundrum Creek.

SAN MIGUEL COUNTY—A developed spring at Placerville is known as "Warm Geyser Spring." There are others in the county.

MOLYBDENUM[52]

Commercial deposits of molybdenum, in Colorado, are confined to the igneous and metamorphic rock ages, or to contact deposits on the borders of igneous rock areas. Large areas in Colorado show conditions which are apparently favorable for the occurrence of molybdenum.

Molybdenum is very likely to be found near the borders of granite intrusions and in pegmatite dikes. Intrusions of acidic igneous rocks may contain some molybdenum, while basalts and other basic rocks are not likely to contain molybdenum, except where they come in contact with the more acidic intrusions.

GUNNISON COUNTY

Quartz and Tincup Mining Districts

Several veins which contain molybdenite have been located in the vicinity of Gold Hill, 9 or 10 miles north of Pitkin.

[52]For a full discussion see Worcester, P. G., Molybdenum deposits of Colorado: Colo. Geol. Survey Bull. 14, 1919.

Worcester[53] describes the occurrences in this district as follows:

"One large fissure vein, which has been traced more or less continuously for more than two miles, crosses Gold Hill in a northwesterly direction. Another vein is indicated by float in the timber south of Gold Hill and the creek. On top of Gold Hill there are still several outcrops which indicate that there are several veins only imperfectly exposed."

The molybdenite occurs as grains, flakes, crystals, or facings in quartz veins which cut through the quartz monzonite of the district. The molybdenite is usually associated with some pyrite and chalcopyrite. Copper is present in one of the veins to such an extent as to make the ore valueless for ordinary purposes. Tungsten (Hübnerite) is also present in one of the veins on the Ida May claim.

A deposit of molybdenite occurs near the outlet of Lamphere Lake, seven miles due north of Ohio City. The molybdenite is found in both large and small quartz veins cutting the granite of the district. Most of the molybdenite occurs as crystals, but some fine grained facings have been found.

Molybdenite has also been found on Cross Mountain, in Taylor Park, between Gunnison and Tincup, near the old town of Spencer, 15 miles south and west of Iola; on Paradise Pass, 12 miles northwest of Crested Butte, and on the southwest slope of Treasury Mountain.

HINSDALE COUNTY

An occurrence of molybdenite has been located 3 or 4 miles north of Lake City and about one mile west of the railroad.

The molybdenite occurs as small flakes in quartz veins. The quartz veins cut the fine grained rhyolite, which is the principal country rock of the area.

MESA COUNTY

What appears to be a very low grade molybdenum ore has been found in the Gavette claim, on the north side of Unaweep Canyon, about 29 miles from Whitewater.

A second occurrence is located about 2 miles northeast of the Gavette property. This occurrence is also on the north side of Unaweep Canyon.

[53]Worcester, P. G., Molybdenum deposits of Colorado: Colo. Geol. Survey Bull. 14, p. 59, 1919.

OURAY COUNTY

Molybdenite occurs in the Irene claim, about one-half mile north of Ironton, 400 feet above and parallel to the creek.

The molybdenite occurs in a quartz vein associated with pyrite, traces of gold and silver, and 7 per cent of lead. The molybdenite is fine grained and intimately mixed with the quartz of the vein.

A second occurrence, in the Ironton district, is located on the creek about one-fourth of a mile west of Ironton.

Molybdenite has been reported from Poughkeepsie Gulch and from the Sneffels region.

PITKIN COUNTY

A deposit of molybdenite, associated with pyrite and small amounts of molybdite, is located near the head of Lincoln Gulch, 20 miles southeast of Aspen.

The molybdenite is found in quartz veins which cut the granite country rock of the district.

SAN MIGUEL COUNTY

Worcester[54] has described two molybdenum claims located on the west side of Nevada Gulch, about one mile southeast of Ophir.

OIL AND GAS

DELTA COUNTY

An anticlinal structure has been reported near Hotchkiss. Several oil seeps and gas springs are also known to exist in the district. Oil and gas have not been found in commercial quantities in Delta County.

MONTROSE AND SAN MIGUEL COUNTIES

An open anticline occurs near the border of Montrose and San Miguel counties, southwest of Naturita. A trace of oil and gas was found in a well in San Miguel County, south of Naturita.

MESA COUNTY

The De Beque oil field covers an area only a few square miles in extent. Wells have been drilled along the Grand River near De Beque; up Roan Creek for a distance of 2 miles, and on the terrace to the north and northwest of the town.

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[54]Worcester, P. G., Molybdenum deposits of Colorado: Colo. Geol. Survey Bull. 14, p. 86, 1919.

Only a small amount of oil and gas has been produced by the various wells in the field, and this has not been put to commercial use.

The drilling in the district has not been done along the axis of the structure, but off to one side. This field should not be condemned without properly drilling it out, as it still shows possibilities.

ONYX

MESA COUNTY

Onyx occurs in several areas west of Fruita, near the Colorado-Utah line. Some of this material takes a high polish and is suitable for ornamental purposes.

PRECIOUS STONES

Amethyst quartz is found in the Elk Mountains, in Gunnison County, and on Henson Creek, in Hinsdale County. Chalcedony of gem variety is found in Ouray and Gunnison counties. A gem variety of epidote has been found near Italian Mountain, in Gunnison County. Garnet (grossularite) is found on Italian Mountain, in Gunnison County.

PYRITE

EAGLE COUNTY

Pyrite deposits of considerable size have been developed in the Red Cliff district. Pyrite from this district has been shipped to the sulphuric acid plant of the Western Chemical Company, at Denver.

SILVER[55]

GUNNISON COUNTY

Silver is the principal metal produced in the Quartz Creek district, 3 miles north of Pitkin; in the Rock Creek and Crystal districts near Marble; and in the Ruby district near Floresta. The production of silver in Gunnison County in 1919 was valued at $18,100. From 1873 to 1917 the silver production was valued at $4,816,026.

HINSDALE COUNTY

In the district around Lake San Cristobal, the metallic ores are found in veins which occur in the Tertiary volcanic rocks. The predominant metal of the district is silver.

[55]See Hill, J. M., The mining districts of the western United States: U. S. Geol. Survey Bull. 507, pp. 134-157, 1912. Statistics compiled by C. W. Henderson, Statistician. U. S. Geol. Survey.

During 1919, silver to the value of $17,726 was produced in Hinsdale County. The total value of the silver produced in the county from 1875 to 1917 was $4,428,964.

PITKIN COUNTY

Silver is predominant among the metals produced in the Lincoln mining district, 15 miles southeast of Aspen, and in Aspen.

During 1919, $718,333 worth of silver was produced in Pitkin County. The production of silver from 1880 to 1917 was valued at $70,012,602.

SAN MIGUEL COUNTY

The silver ores of the Mount Wilson district occur in veins in the Cretaceous sediments and Tertiary volcanics. The Mount Wilson mining district is located 12 miles south of Newmire.

SLATE

GUNNISON COUNTY

J. C. Bailar[56] reports the presence of slate near Gunnison, as follows:

"A large deposit of slate has been opened near Gunnison. The plates are large, smooth and of good texture, superior to most of the slate found on the market."

OURAY COUNTY

A large section of slates is exposed in the Uncompahgre Canyon, near the mouth of Bear Creek. So far as yet opened the slates of this area are very badly shattered, and consequently are of little commercial value. But further development may prove the existence of better material.

SULPHUR

GUNNISON COUNTY

A small amount of sulphur was mined and refined at the Vulcan mine, 12 miles southeast of Iola. No data are available, however, regarding the amount of sulphur mined, or the time of shipment.

The main ore bodies occur in a chimney between walls of sericite schists.[57] "In the Vulcan mine at 100 feet the walls on either

[56] Bailar, J. C., The non-metallic minerals of Colorado: Colorado School of Mines Bienn. Rept., p. 37, 1910.

[57] Lakes, Arthur, Gunnison region (Rocks and their relation to ore deposits in Mammoth and Vulcan mines): Coll. Eng., vol. 16, p. 280, 1895-6.

side of the main brecciated, dark, opaline zone, were of yellow granulated sulphur, said to be 15 feet thick.'' The sulphur then grades into loose pyrites, below which is found solid massive pyrite.

Hot ascending solutions have undoubtedly dissolved out the silica of the surrounding rocks, and after transporting the material in solution, it has been deposited in the form of opaline silica. The sulphur may have been due to the desulphurizing of the pyrite lower down, in which action the sulphur was set free, or it may be the result of the precipitation of sulphur from the ascending sulphurated hydrogen gases.[58].

DELTA COUNTY

Sulphur has been reported as occurring near the mouth of the Black Canyon of the Gunnison above Delta. No information concerning this deposit (Smith, P. S. Mineral Resources of the United States: U. S. Geol. Survey, 1917, pt. II, p. 20) is available.

MESA COUNTY

Smith[59] reports the occurrence of a deposit of sulphur in Mesa County, near Grand Junction. No data are available concerning this deposit.

TUNGSTEN

GUNNISON COUNTY

Considerable quantities of tungsten (hübnerite) are found in a large quartz vein in the Ida May claim, on Gold Hill, north of Pitkin.[60] Some tungsten ore was shipped from this property during 1916-1917.

Rich streaks of hübernite have also been found in the Monitor vein. This is undoubtedly a continuation of the Ida May vein.

ZINC

SUMMIT COUNTY

Large amounts of zinc are found in the ores of the Breckenridge and Kokomo mining districts. The production of zinc during 1919 amounted to $342,326. The value of the production from 1860 to 1917 was $8,270,063.

[58]Lakes, Arthur, Gunnison region (Rocks and their relation to ore deposits in Mammoth and Vulcan mines): Coll. Eng., vol. 16, p. 280, 1895-6.

[59]Smith, P. S., U. S. Geol. Survey, Mineral Resources for 1916, pt. II, p. 407.

[60]Worcester, P. G., Molybdenum deposits of Colorado: Colo. Geol. Survey Bull. 14, pp. 63-64, 1919.

EAGLE COUNTY

During 1919, Eagle County produced 2,929,798 pounds of zinc, valued at $205,086. The total production of the county from 1879 to 1915 was valued at $9,463,104.

GUNNISON COUNTY

The value of the zinc produced in Gunnison County during 1919 amounted to $154,620. The total production from 1873 to 1917 sold for $960,087.

SAN JUAN COUNTY

The value of the zinc produced in San Juan County during 1919 was $121,944. The total production from 1873 to 1917 sold for $2,013,632.

SAN MIGUEL COUNTY

The zinc produced in San Miguel County during 1919 was valued at $40,022. The total production from 1875 to 1917 was valued at $1,199,375.

CHAPTER III

MINERAL DEPOSITS

OF

SOUTHWESTERN COLORADO

BISMUTH

Bismuth occurs in commercial quantity in at least two mines in the La Plata Mountains.

BUILDING STONE

LA PLATA COUNTY

Granite.—According to Burchard,[61] some granite is quarried near Durango. No information is available, however, concerning the production or output of this quarry.

SAN JUAN COUNTY

Quartz monzonite from Anvil and Kendall Mountains has been used for building purposes in the town of Silverton.

LA PLATA COUNTY

Sandstone is being quarried near Durango. The entire product is used in building operations in the immediate vicinity.

CLAYS

Very little is known of the clay resources of western Colorado; for the reason that no systematic investigation has been made and but little has been published on them. Up to the present time the demand for clay products has been so small that no effort has been made to create an interest in the clay industry.

SOUTHWESTERN COLORADO

The clays of the area may be classed as clay shales, plastic clays, and fire clays.[62]

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[61]Burchard, E. F., U. S. Geol. Survey Mineral Resources for 1912, p. 813.

[62]Shaler, M. K., and Gardner, J. H., Clay deposits of the western part of the Durango-Gallup coal field of Colorado and New Mexico: U. S. Geol. Survey Bull. 315, p. 296, 1906.

The clay shales include the thick shales of the Mancos and Lewis formations, and many thinner beds found associated with the coal beds of the Mesaverde and Laramie formations.

The plastic clays include alluvial beds, river terrace clays, adobe clays, and in fact all shales or clays derived from the weathering and decomposition of clay shales. Deposits of this kind are being worked at Glenwood Springs, Aspen, and Grand Junction. In all these cases the less sandy clays are likely to be found back from the river.

Fire clays of different grades are found interstratified with the sandstones, shales, and coals of the Mesaverde formation.

In the southwestern part of the state shales of various parts of the Mancos formation are well suited for the manufacture of brick. The shales, as a whole, make ordinary brick of good quality. Certain strata, however, will furnish materials for the manufacture of semi-refractory brick.

The Lewis shales, which in western Colorado lie between the Mesaverde and Laramie formations, appear suitable for the manufacture of ordinary brick. They are very similar to the shales of the Mancos formation, but so far no tests have been made to show their suitability for the manufacture of clay products as other shales and clays of known value are readily available.

Careful prospecting will undoubtedly show the presence of a considerable amount of fire clay in both the Dakota and Mesaverde formations.

At Durango, ordinary red brick have been manufactured from strata about 100 feet below the lowest coal seams in the Mesaverde formation, and semirefractory bricks, suitable for boiler linings, have been made from a clay bed just below the lowest coal bed of the Mesaverde formation.

Many of the shales could be mixed with the limestones of the district in the manufacture of Portland cement.[63]

At present the market for clay and shale products in this district is local, as the freight rates will not permit their shipment to outside points. This condition has hindered the development of the industry, regardless of the fact that enormous bodies of suitable material are available in the district.

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[63]Shaler, M. K., and Gardner, J. H., Clay deposits of the western part of the Durango-Gallup coal field of Colorado and New Mexico: U. S. Geol. Survey Bull. 315, p. 298, 1906.

COAL

SOUTHWESTERN COLORADO

The Mesaverde is the principal coal-bearing formation in southwestern Colorado. Some coal, however, is found in the Laramie formation, and some in the Dakota.

Outcrops of the coal-bearing strata of the Mesaverde formation have been traced from Durango, La Plata County, to a point near Mancos, in Montezuma County. Between Durango and Monero, New Mexico, the Mesaverde formation outcrops almost continuously, but not a single workable bed on the northeast side of the basin has been found for a distance of 60 miles along the outcrop.

The Mesaverde formation is productive in various parts of western Montezuma County, and small amounts are being mined for local purposes. Some coal is being mined near Cortez in the central part of the county.

West of Durango, the coals of the Laramie formation are sub-bituminous in character. Those of the Mesaverde formation are very good bituminous. The coal mined at Porter is a very good coking coal, and has been made into coke at Porter and Durango. The coke produced is used locally in the smelting industry.

East of Durango the Mesaverde measures are barren, but some coal is mined from the Laramie formation. This coal is of a low grade and might be classed as sub-bituminous.

Eight mines in La Plata County produced 141,040 tons of coal during 1918. Five mines in Montezuma County produced 1,927 tons of coal during the same period.

The Dakota coal is commonly of low grade, and the seams are usually thin. A few mines or pits are opened for purely local use.

FLUORSPAR

DOLORES COUNTY

Fluorspar is found sparingly as a gangue mineral in the ores of the Rico mining district. It is abundant in the displacement ore bodies of the Blackhawk mine and Fortune and Duncan prospects.[64]

LA PLATA COUNTY

In the La Plata mining district, fluorite occurs as a gangue mineral, associated with quartz, calcite, and rhodochrosite.[65]

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[64] Cross, Whitman, and Ransome, F. L., U. S. Geol. Survey Geol. Atlas, Rico folio (No. 130), p. 15, 1905.

[65] Cross, Whitman, Spencer, A. C., and Purington, C. W., U. S. Geol. Survey Geol. Atlas, La Plata folio (No. 60), p. 10, 1899.

SAN JUAN COUNTY

Small amounts of flourspar occur as a gangue mineral in the ores of the district. Colorless, to lilac, and deep green flourspar is found in the Aspen, Anglo Saxon, and Dakota mines, while smaller amounts are found in the ores of many other mines.[66]

The mineral does not occur in sufficient quantity to be commercially important, and it is too badly fractured to be used for optical purposes.

GOLD[67]

LA PLATA COUNTY

Gold is the most important metal in the ores of the district near California, 14 miles northwest of Durango, and in the West Needle Mountains district, 25 miles northeast of Tacoma. La Plata County produced only $6,202 worth of gold in 1919, but the production of La Plata and Montezuma counties from 1878 to 1917 was $3,470,943. La Plata County produced by far the greater part of this amount.

MONTEZUMA COUNTY

A small amount of gold is produced in the district 12 miles northeast of Mancos. This placer district is known as the East Mancos mining district.

SAN JUAN COUNTY

During 1919, San Juan County produced $153,674 in gold. From 1873 to 1917 the production amounted to $21,778,759.

GRAPHITE

SAN JUAN COUNTY

Warren C. Prosser[68] reports the finding of a large deposit of low grade graphite near the divide between Cascade Creek and the south fork of Mineral Creek. This deposit lies in the extreme western part of San Juan County, near the junction of Dolores, San Miguel, and San Juan counties.

[66]Cross, Whitman, Howe, Ernest, and Ransome, F. L., U. S. Geol. Survey Geol. Atlas, Silverton folio (No. 120), p. 29, 1905.

[67]See Hill, J. M., The mining districts of the western United States: U. S. Geol. Survey Bull. 507, pp. 134-157, 1912. Statistics compiled by C. W. Henderson, Statistician, U. S. Geol. Survey.

[68]Personal communication January 11, 1912. Warren C. Prosser, Silverton, Colorado.

GYPSUM

RICO DISTRICT

In the Rico quadrangle gypsum occurs well down in the Hermosa formation.[69] At Newman Hill a bed of rock gypsum 30 feet thick occurs locally above one of the black shales in the lower part of the Hermosa formation.

DURANGO DISTRICT

Near Hermosa Creek north of Durango, the lower part of the Hermosa formation above the limestone is made up of green sandstones and shales with bands of gypsiferous shales.[70]

Gypsum also occurs in numerous localities throughout the western and southwestern parts of the state. These occurrences have not been taken up in detail, because of the lack of definite information concerning them or because of the unimportance of the occurrence.

No gypsum has been mined on the "Western Slope" during the past few years. The demand for the finished product is not large, and the high freight rate to "Eastern Slope" markets does not permit its competition with gypsum mined east of the range.

RIO BLANCO COUNTY

According to Henderson, large deposits of gypsum[71] occur in the earlier formations of upper White River Valley.

SOUTHWESTERN COLORADO

A thick bed of gypsum occupies the whole head of Big Gypsum Valley and extends along the north side of the valley to the Dolores River. It reappears down the river at the mouth of Little Gypsum Valley and extends some distance up that valley, especially on the north side. The deposit is overlain by a crumpled limestone, and this is overlain unconformably by the Dolores sandstone and conglomerates. The unconformity may represent Cutler time. In places a rich Pennsylvanian fauna occurs a distance above the gypsum. The area covered by gypsum in the two valleys is probably between 20 and 30 square miles. The mineral occurs as massive white gypsum in beds from 5 to 10 feet thick throughout a series of strata between 200 and 300 feet thick. Weathering has formed impure gypsite.

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[69]Cross, Whitman, and Ransome, F. L., U. S. Geol. Survey Geol. Atlas, Rico folio (No. 130), p. 3, 1905.

[70]Cross, Whitman and Ransome, F. L., U. S. Geol. Survey Geol. Atlas Rico folio (No. 130), p. 3, 1905.

[71]Henderson, Junius, Scientific expedition into northwestern Colorado in 1909. Univ. Colo. Studies, vol. 7, pp. 111-112, 1910.

In East Paradox Valley gypsum covers about 8 square miles, and in West Paradox about one-half square mile. In these valleys the gypsum is associated with limestones and shales and is overlain by red shales and shaly sandstone.

In Sinbad Valley gypsum covers about 7 square miles and is associated with limestone and shale. Cross and Howe believe the gypsiferous series to be the same as that[72] which Peale[73] regarded as Permian. They think the beds may be Cutler.

Coffin[74] reports the presence of an intricately folded and faulted series of limestone, gypsum and shale appearing in the bottoms of Sinbad, Paradox, and Gypsum valleys. Fossils from this district prove that at least a part of this complex belongs to the Pennsylvanian division of the Carboniferous, and is equivalent to the Hermosa of the San Juan Mountains.

From the various views expressed, and from the field relations which exist, it would seem probable that the beds in all this region are Permian or late Pennsylvanian.

IRON

SAN JUAN COUNTY

Deposits of bog iron occur in the swampy ground along Mineral Creek and in Ironton Park. Some of this ore was mined and used as a flux in the smelter formerly operated at Silverton.

LIMESTONE

LA PLATA COUNTY

A very high grade limestone is quarried at Rockwood, north of Durango. Although the limestone is burned, or shipped as a flux, it might easily be used with the shales of the Mancos formation in the manufacture of cement.

SAN JUAN COUNTY

A small amount of limestone was taken from a quarry about one and one-half miles south of Silverton on the east bank of the Animas River. This limestone was used as a flux in the early day smelters of the Silverton district.

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[72]Cross, W. and Howe, E., The Red Beds of southwestern Colorado: Geol. Soc. Am. Bull., vol. 16, pp. 447-498, 1905.

[73]Peale, A. C., Geological report on the Grand River district: Hayden Survey, Tenth Ann. Rept., pp. 167-168, 1878.

[74]Coffin, R. C., Preliminary statement from Bull. 16 on the carnotite area of southwestern Colorado: Colo. Geological Survey, p. 8, 1920.

MANGANESE

SAN JUAN COUNTY

Rhodonite and rhodochrosite frequently occur as gangue minerals in the metalliferous veins of the district. No deposits of commercial value are known to occur in the county.

A small deposit of manganese has been located about eight and one-half miles east of Needleton, on the east slope of Hope Mountain.

DOLORES COUNTY

Manganese occurs in the form of rhodochrosite (manganese carbonate) in many of the ores of the Rico district. The mineral is frequently mixed with quartz and fluorite.

MERCURY

LA PLATA COUNTY

Lakes[75] reports the finding of a peculiar occurrence of native mercury, free gold, and telluride minerals near Trimble Springs.

Cinnabar is also reported as occurring in the sandstones of La Plata County, and in ores of the Ruby claim south of Cumberland Peak.[76]

MINERAL SPRINGS

ARCHULETA COUNTY—The Pagosa Springs are a noted group about which a resort town is built.

DOLORES COUNTY—There are excellent mineral springs within and about Rico.

LA PLATA COUNTY—The Trimble Springs on the Animas are well developed as a resort. The Pinkerton Springs are also on the Animas but are not well developed for use.

SAN JUAN COUNTY—A mineral spring is located about 4 miles up South Mineral Creek. Other springs occur in the county.

MOLYBDENUM

LA PLATA COUNTY

About a dozen shallow shafts have been sunk on molybdenum-bearing quartz veins in the gray granite country rock of the dis-

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[75]Lakes, Arthur, Mg. Rept., vol. 54, pp. 389-390, 1906.

[76]Schrader, F. C., Stone, R. W., and Sanford, S., Useful Minerals of the United States: U. S. Geol. Survey ~~Bull. 624, pp. 61, 64, 33, 1917.~~

trict on East Silver Mesa. The district lies about nine miles from Needleton and within 2,000 feet of Lake Lillie.

Molybdenite has also been reported from the Vallecito Basin, about 7 miles from Needleton. This occurrence is at an elevation of about 12,600 feet.

MONTEZUMA COUNTY

It is reported that molybdenite has been found at Giles Mountain, near Mancos.

SAN JUAN COUNTY

Molybdenite has been found in the Hidden Treasure and Gold Finch groups of claims, about half a mile south of Chattanooga.

The Gold Finch group lies just west of Mineral Creek. Surface cuts show the occurrence of the vein for 750 feet west of the creek. The Hidden Treasure group lies east of Mineral Creek and shows outcrops of ore for 800 feet along the vein.

Molybdenite has been reported as occurring two and one-half miles south of Chattanooga, on the east side of Mineral Creek; on the north side of South Mineral Creek about a mile from the mouth of the gulch; on the southwest slope of Bear Mountain about four miles west of Silverton, and near Molas Lake in Cascade Basin.

Ransome[77] reports the occurrence of molybdenite in the Sunnyside Extension mine, where it has been mistaken for graphite. Here some of it contains free gold.

NATURAL COKE

LA PLATA COUNTY

Natural coke has been found at several localities in the Durango district.

OIL AND GAS

ARCHULETA COUNTY

Several structures and oil seeps have been located in the eastern part of the county. Lee[78] says the Navajo oil spring is the best known in the county. This spring issues from a crevice in the base of the Fox Hills sandstones on the south side of Navajo Creek, a short distance from the foot of the Conejos range.

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[77]Cross, Whitman, Howe, Ernest, and Ransome, F. L., U. S. Geol. Survey Geol. Atlas, Silverton folio (No. 120), p. 30, 1905.

[78]Lee, H. A., Colorado State Bur. Mines Rept. for 1901-1902: p. 17, 1903.

MONTEZUMA COUNTY

Several anticlines have been found in Montezuma County. Some gas was encountered in a well drilled near Toltec.

POTASH

DOLORES COUNTY

A deposit of alunite has been found near Rico. Considerable attention has been given to this deposit, but no great amount of development work has been done.

PRECIOUS STONES

SAN JUAN COUNTY

Several varieties of garnet, as well as calcite and wollastonite are found in an old limestone quarry about one mile southeast of Silverton.

Rhodonite occurs in large sized pieces of excellent color in the Sunnyside mine at Eureka. A considerable amount of this material has already been cut for the manufacture of jewelry

It is reported that a few crystals of topaz have been found in San Juan County.

PYRITE

LA PLATA COUNTY

It is reported that large bodies of pyrite have been developed in the La Plata district. No data are available concerning the exact location or size of these deposits.

SILVER[79]

DOLORES COUNTY

Silver is the predominant metal produced in the Dutton mining district, sixteen and one-half miles northwest of Rico.

In the Rico district the main ore bodies occur as veins, replacements, and stockworks in the pre-Cambrian and Palezoic sediments. The production of silver in Dolores County during 1919 amounted to $36,631.

The total value of the silver produced in Dolores County from 1879 to 1917 amounted to $11,468,112.

SULPHUR

MONTEZUMA COUNTY

A large deposit of low-grade sulphur ore has been reported as occurring about 20 miles east of Dolores. Very little work has

[79]See Hill, J. M., The mining districts of the western United States: U. S. Geol. Survey Bull. 507, pp. 134-157, 1912. Statistics compiled by C. W. Henderson, Statistician, U. S. Geol. Survey.

been done on the deposit, and no sulphur has been shipped up to the present time. Data are lacking as to nature of the occurrence and the size of the deposit.

TUNGSTEN

SAN JUAN COUNTY[80]

R. D. George[81] reports the presence of tungsten in San Juan County as follows:

"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 occurrences of tungsten in Dry Gulch, a tributary of Cement Creek, below Gladstone, have proven of considerable extent. Several shipments of high grade concentrates were made from this locality in 1915-1916.

During the tungsten excitement of 1915-1916 a number of new deposits were developed in the Silverton district. Production was stopped, however, with the return to normal prices.

URANIUM[82]

SOUTHWESTERN COLORADO

By far the greater part of the world's supply of uranium and radium is produced from the deposits of carnotite in southwestern Colorado and southeastern Utah.

In Colorado, the carnotite production is limited, almost entirely, to the McElmo formation and rather definitely to certain beds or zones within the lower half of the formation. The most important carnotite zone is located from 275 to 325 feet above the base of the formation, in a massive white cross-bedded sandstone. A second zone extends from 60 to 125 feet above the base of the formation. The carnotite in this zone is found in a sandstone very similar to the sandstone of the upper zone.

In the faulted areas of Gypsum Valley some carnotite stains have been found in the Carboniferous and Dolores beds which occur at a considerable depth below the McElmo formation. In

[80]Cross, Whitman, Howe, Ernest, Ransome, F. L., U. S. Geol. Survey Geol. Atlas, Silverton folio (No. 120), p. 30, 1905.

[81]George, R. D., The main tungsten area of Boulder county, Colorado: Colo. Geol. Survey First Ann. Rept., pp. 55-56, 1908.

[82]For a full discussion of the Carnotite deposits of southwestern Colorado see: Coffin, R. C., Preliminary statement from Bulletin 16 on the carnotite area of southwestern Colorado: Colo. Geol. Survey, 1920.

McElmo Canyon a vanadium-bearing sandstone containing small amounts of uranium was found near the top of the Dolores formation.

According to Coffin,[83] the term "carnotite ore" has been applied to ores of different sorts, often including any uranium-bearing material in the district. Although carnotite is a common mineral in the ore, its value may depend upon one or more of several uranium and vanadium minerals. The types of ore include the following:

"1. Impregnated sandstones—the uranium-vanadium minerals cementing the sand grains.

"2. 'Spotted ore'—the ore occurs in sandstones or shaly sandstone as dark blotches wherein vanadium-bearing minerals predominate; as almond-shaped pieces and small fragments of shale and carbonaceous material speckled with carnotite.

"3. Nearly pure carnotite—in seams, crusts, irregular vugs, and elongated masses called 'bug holes.'

"4. Replacements of wood—ore often of extremely high grade."

The workable deposits of ore may be classed as follows:[85]

"1. Rather continuous bodies, in plate-like masses and lenses, but of irregular outline.

"2. Discontinuous bodies, consisting of seams, crusts, bunches, and irregular pockets of many sizes and shapes.

"3. Cylindrical masses, commonly called 'trees' or 'logs'; ores frequently of very high grade."

During 1919 the demand for vanadium gave an added stimulus to carnotite mining. Prices were advanced somewhat and there was also a lowering of the mining uranium and vanadium content requirements.

It is exceedingly difficult to obtain information as to the amount of carnotite mined, since much of the ore that is mined does not reach the point of treatment for many months.

Coffin[86] estimates that the carnotite mined in southwestern Colorado during 1919 was equivalent to 9,550 tons of ore having a 2 per cent uranium oxide (U_3O_8) content. The vanadium oxide (V_2O_5) content of this ore averaged between 3.5 and 4.3 per cent.

[83]Coffin, R. C., Preliminary statement from Bulletin 16 on the carnotite area of southwestern Colorado: Colo. Geol. Survey 1920.

[85]Coffin, R. C., Preliminary Statement from Bull. 16 on the carnotite area of southwestern Colorado: Colo. Geol. Survey 1920.

[86]Coffin, R. C. Preliminary statement from Bull. 16 on the carnotite area of southwestern Colorado: Colo. Geol. Survey 1920.

SHOWING BY COUNTIES THE MINERAL PRODUCTION OF THE "WESTERN SLOPE," COLORADO, TO 1917.

NAME OF COUNTY	GOLD	SILVER		LEAD		COPPER		ZINC		TOTAL
	Value	Fine Ounces	Value	Pounds	Value	Pounds	Value	Pounds	Value	
Archuleta, 1897-1904	$ 1,489	505	302	....	....	....	....	....	....	$ 1,791
Delta, 1894-1915	4,273	305	176	....	....	....	....	....	....	4,449
Dolores, 1879-1917	1 962,948	11,468.112	8,996,793	36,465,224	1,548,495	5,272,441	934 828	9,690,171	635,040	14,078,104
Eagle, 1879-1915	2,745,464	5,461,203	4,399,638	82,266,163	3,602,817	2,059,043	323,928	95,627,005	9,463,104	20,534,951
Garfield, 1878-1917	15,996	513	312	....	....	1,044	153	....	....	16,461
Grand, 1859; 1896-1917	13,182	2,195	1,234	2,253	90	5,171	805	....	....	15,311
Gunnison, 1861; 1873-1917	2,112,520	5,346,744	4,816,026	39,631,677	1,723,272	936,636	168.917	9,787,842	960,087	9,780,822
Hinsdale, 1871; 1875-1917	1,425,834	5,499,825	4,428,964	96,173,156	3,920,004	2,801,734	392,338	1,104,034	57,928	10,225,068
La Plata and Montezuma, 1878-1917	3,470,943	1,683,564	1,060,083	247,952	11,451	276,855	44 707	....	....	4,587,184
Mesa, 1885-1915	5,040	4,934	2,970	20	1	35,280	5,222	....	....	13 233
Montrose, 1886-1917	46,259	184,448	110,734	64	3	453,616	83,023	....	....	240,019
Ouray, 1878-1917	34,675,607	37,043,150	27,588,110	151,757,744	6,482,595	22,387,879	3,207,240	1,128,010	95,146	72,048,698
Pitkin, 1880-1917	577,928	94,338,923	70,012,602	535,184,709	23,802,993	1,118,546	195,021	15,250,926	945,037	95,533,581
Routt & Moffat, 1866; 1873-1917	384,539	24.805	15,397	132 954	4,737	78,570	16,704	....	....	421,377
San Juan, 1873-1917	21,778,759	26,534,675	18,299,546	271,947,107	12,215,249	45,736,915	6,909,418	24 433,213	2,013,632	61,216,604
San Miguel, 1875-1917	49,956,607	34,651.778	23 609,818	129,367,490	6,105,649	10,821,858	1,735,633	16,652,835	1,199,375	82,607,082
Summit, 1860-1917	16,898,015	12,895,696	11,037,402	147,047,816	6,370,510	905,689	128,529	100,754,237	8,270,063	42,704,519
	$135,482,015	235,140,692	174,379,869	1,490,226,320	65,787,866	92,891.277	11,146,466	274,428,273	23,639,372	$414,[illegible]

*From statistics compiled by C. W. Henderson, Statistician, United States Geological Survey. Published in the Fifteenth Biennial Report for 1917-1918: Colorado Bureau of Mines, 1919.

The estimate does not represent the tons of ore actually handled, as a large part of this amount was "mill ore" whose uranium oxide (U_3O_8) content was 1 per cent or less.

VANADIUM[84]

SOUTHWESTERN COLORADO

The vanadium deposits at Vanadium (formerly Newmire) have been the source of much of the vanadium produced in the district.

The ore is made up of a green, fine grained sandstone impregnated with roscoelite, and is easily mined. The rock must carry about 3 per cent vanadium in order to be of shipping grade. It is necessary to select the material carefully as the percentage of vanadium in most of the vanadiferous sandstones is less than 1 per cent.

VOLCANIC ASH

LA PLATA COUNTY

Deposits of volcanic ash suitable for abrasive purposes have been reported from near Durango[87] in La Plata County. These deposits consist of three isolated beds of ash, all lying within a radius of 4 miles of Durango.

One bed of ash is located at the east end of the dry valley north of Animas City Mountain, on the shoulder of the southward-facing spur. A second bed is located opposite the west end of the same valley, while a third lies nearly east of Durango on the east slope of Florida Mesa.

All three of the beds are at approximately the same elevation and appear to have been deposited under similar conditions. The beds appear to be lens shaped, occupying irregularities in the former bed-rock surface. One lens is over 150 feet long and 15 feet wide, while a second is 100 feet long and from 25 to 50 feet thick.

In age the deposits are probably Pleistocene. However, no fossils have been found, and the age has been judged mainly from the relations of occurrence.

A small amount of the ash has been used locally, but no great effort has been made to create an outside market for the product.

[84]Hess, Frank L., U. S. Geol. Survey, Mineral Resources for 1911, pp. 949-950.

[87]Woolsey, L. H., Volcanic Ash near Durango, Colorado: U. S. Geol. Survey Bull. 285, pp. 476-478, 1905.

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INDEX

M

N

W

Page

Y

Z

COAL DEPOSITS OF THE WESTERN SLOPE

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