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The
Cretaceous Formations of Northeastern
Colorado

AND

The Foothills Formations of North-
Central Colorado

BY

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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 underlying 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

¹Endlich, 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.

²Holmes, 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

³Gale, 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.

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

⁵Grout, 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.

⁶Hills, 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.

⁷Richardson, 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*, *Maetra 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

⁸Lee, 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.

⁹Washburne, 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.

¹⁰Stevenson, 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

¹¹Stevenson, 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.

¹²See 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, Veatch¹⁴ 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 supposititious 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 Beds¹⁶ and Arapahoe Beds to the formations above the unconformity, is entirely justifiable.

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

¹⁴Veatch, 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.

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

¹⁶Emmons, 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

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

¹⁸Emmons, 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

¹⁹Meek 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. Reynolds, 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.
<p style="text-align: center;">Fox Hills Beds. Formation No. 5.</p>	<p>Gray, ferruginous and yellowish sandstone and arenaceous clays, containing <i>Belemnitella bulbosa</i>, <i>Nautilus dekayi</i>, <i>Ammonites placenta</i>, <i>A. lobatus</i>, <i>Scaphites conradi</i>, <i>S. nicolletti</i>, <i>Baculites grandis</i>, <i>Busycon bairdi</i>, <i>Fusus culbertsoni</i>, <i>F. newberryi</i>, <i>Aporrhais americana</i>, <i>Pseudobuccinum nebrascensis</i>, <i>Maetra warrenana</i>, <i>Cardium subquadrata</i>, and a great many other molluscos fossils, together with bones of <i>Mosasaurus missouriensis</i>, etc.</p>	<p>Fox Hills, near Moreau River—near Long Lake above Fort Pierre. Along base Big Horn Mountains, and on North and South Platte Rivers.</p>	<p style="text-align: center;">500 feet</p>
<p style="text-align: center;">Fort Pierre Group. Formation No. 4.</p>	<p>Dark gray and bluish plastic clays, containing near the upper part, <i>Nautilus dekayi</i>, <i>Ammonites placenta</i>, <i>Baculites ovatus</i>, <i>B. Compressus</i>, <i>Scaphites nodosus</i>, <i>Dentalium gracile</i>, <i>Crassatella evansi</i>, <i>Cucullæa nebrascensis</i>, <i>Inoceramus sagensis</i>, <i>I. nebrascensis</i>, <i>I. vanuxemi</i>, bones of <i>Mosasaurus missouriensis</i>, etc., etc., etc.</p> <p>Middle zone nearly barren of fossils.</p> <p>Lower fossiliferous zone, containing <i>Ammonites complexus</i>, <i>Baculites ovatus</i>, <i>B. compressus</i>, <i>Helicoceras mortoni</i>, <i>H. tortum</i>, <i>H. umbilicatum</i>, <i>H. cochleatum</i>, <i>Ptychoceras mortoni</i>, <i>Fusus vinculum</i>, <i>Anisomyan borealis</i>, <i>Amauropsis paludiniiformis</i>, <i>Inoceramus sublaevis</i>, <i>I. tenuilineatus</i>, bones of <i>Mosasaurus missouriensis</i>, etc.</p> <p>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.</p>	<p>Sage Creek, Cheyenne River and on White River above the Mauvais Terres.</p> <p>Fort Pierre and out to Bad Lands—down the Missouri on the high country to Great Bend.</p> <p>Great Bend of the Missouri, below Fort Pierre.</p> <p>Near Bijou Hill, on the Missouri.</p>	<p style="text-align: center;">700 feet</p>

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 occurring in the lower fossiliferous zone, at the base, are *Mosasaurus missouriensis*, *Callianassa danae*, *Ammonites complexus*, *Baculites ovatus* and *B. Compressus*, *Helicoceras* [*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. nicolletii*, *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,

²⁰It 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 White²¹ and Endlich²² 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, White²³ 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

²¹White, 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.

²²Endlich, 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.

²³White, 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 Gilbert²⁴ and Eldridge²⁵ 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

²⁴Gilbert, 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.

²⁵Eldridge, 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

²⁶Hills, R. C., Geologic Atlas of the United States, Walsenburg Folio, No. 68; Elmore 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 *Mastra*, 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-

²⁷Fenneman, 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,

²⁸Henderson, Junius, "The Sandstone of Fossil Ridge in Northeastern Colorado and Its Fauna," Univ. Colo. Studies, Vol. V, pp. 179-192, 1908.

²⁹Fenneman, 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 north-east 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, south-east 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 arena-

aceous 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 publications³⁰ 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 Ridge³¹ 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.

³⁰Marvine, 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.

³¹Henderson, 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

³²See 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	Baculites ovatus Say
Inoceramus barabini Morton	Baculites compressus Say
Inoceramus sagensis Owen	Scaphites nodosus Owen
Inoceramus vanuxemi M. & H.	Heteroceras nebrascense M. & H.

THE BOULDER DISTRICT

This region has recently been discussed so fully⁸³ 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	Teredo? sp.
Nucula sp.	Anehura cf. americana (E. & S.)
Inoceramus sagensis Owen	Baculites ovatus Say
Avicula linguiformis E. & S.	Scaphites nodosus Owen
Avicula nebrascana E. & S.	Scaphites nodosus quadrangul- laris M. & H.
Ostrea sp.	Placenticeras sp.
Anomia raetiformis Meek	Fish bones
Lucina occidentalis (Morton)	Dinosaur bones
Callista deweyi (M. & H.)	
Mactra holmesii (Meek)	

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:

⁸³Emmons, Cross and Eldridge. "Geology of the Denver Basin in Colorado," U. S. Geol. Surv., Mon. XXVII. Penneman, 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.

<i>Nucula planimarginata</i> M. & H.	<i>Scaphites nodosus</i> Owen
<i>Inoceramus barabini</i> Morton	<i>Petropteron mirandum</i> Ckl.
<i>Lucina occidentalis</i> (Morton)	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 *Placenticerus* 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):

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

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 cf. vanuxemi
Inoceramus oblongus Meek	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:

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

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

THE LEFT HAND DISTRICT

Not far from the base of the foothills, north of Left Hand Creek, at the type locality of *Acanthoceras coloradoensis* Hender-

son, we found also the following species in the thin limestone layers of the upper Benton:

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

THE LONGMONT DISTRICT

In the university cabinets there are specimens of *Mactra holmesii* (Meek) labeled "Reservoir Hill, 1/4 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.	Mactra cf. warrenana M. & H.
Veniella humilis (M. & H.)	Dentalium gracile H. & M.
Lucina cf. occidentalis (Morton)	Lunatia subcrassa (M. & H.)
Sphaeriola? cf. cordata	Melania wyomingensis (Meek)
(M. & H.)	Cylichna sp.
Tancredia americana (M. & H.)	Gastropoda undetermined
Cardium speciosum M. & H.	Reptile teeth
Callista nebrascensis M. & H.	

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:

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

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

³⁴White, 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.	Avicula nebrascensis (E. & S.)
Beaumontia solitaria White	Ostrea inornata M. & H.
Chaetetes?? dimissus White	Ostrea patina M. & H.
Serpula markmani Henderson	Ostrea pellucida M. & H.
Membranipora sp.	Anomia raetiformis Meek
Panope berthoudi (White)	Modiolus meeki (E. & S.)
Pinna lakesi White	Pholadomya subventricosa M. & H.
Inoceramus barabini Morton	Anatina doddsi Henderson
Inoceramus oblongus Meek	Thracia gracilis (M. & H.)
Inoceramus sagensis Owen	Neaera sp.
Inoceramus proximus Tuomey?	Cardium speciosum M. & H.
Inoceramus vanuxemi M. & H.	Callista deweyi (M. & H.)
Tellina scitula M. & H.	Haminea sp.
Mactra warrenana M. & H.	Anisomyon borealis (Morton)
Teredo? borings in wood	Anisomyon shumardi M. & H.
Margarita nebrascensis (M. & H.)	Anisomyon patelliformis (M. & H.)
Capulus spangleri Henderson	Nautilus dekayi Morton
Gyrodes abyssina (Morton)	Ptychoceras sp.
Gyrodes crenata (Conrad)	Baculites ovatus Say
Gyrodes sp.	Baculites compressus Say
Anchura haydeni White	Scaphites nodosus Owen
Anchura americana (E. & S.)	Scaphites nicolleti (Morton)
Fasciolaria cf. Culbertsoni (M. & H.)	Placenticeras whitefieldi Hyatt
Volutoderma? elatworthyi Henderson	Placenticeras intercalare (M. & H.)
Avicula linguiformis E. & S.	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 sagensis Owen
Inoceramus barabini Morton	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:

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

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:

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

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

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

A mile northeast of Bulger, at a higher horizon, occurs a soft, irregular, grayish, calcareous sandstone, capped by a little yellowish

lowish 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.

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

<i>Nucula</i> sp.	<i>Margarita nebrascensis</i>
<i>Inoceramus barabini</i> Morton	(M. & H.)
<i>Inoceramus sagensis</i> Owen	<i>Anchura haydeni</i> White
<i>Inoceramus oblongus</i> Meek	<i>Fasciolaria</i> cf. <i>culbertsoni</i>
<i>Inoceramus vanuxemi</i> M. & H.	(M. & H.)
<i>Avicula linguiformis</i> E. & S.	<i>Anisomyon shumardi</i> M. & H.
<i>Avicula nebrascana</i> E. & S.	<i>Anisomyon patelliformis</i>
<i>Ostrea patina</i> M. & H.	(M. & H.)
<i>Tellina scitula</i> M. & H.	<i>Anisomyon subovatus</i>
<i>Modiolus meeki</i> E. & S.	(M. & H.)?
<i>Mactra gracilis</i> M. & H.	<i>Capulus spangleri</i> Henderson
<i>Callista deweyi</i> M. & H.	<i>Baculites compressus</i> Say
<i>Teredo?</i> burrows in wood	<i>Baculites ovatus</i> Say
<i>Dentalium gracile</i> H. & M.	<i>Scaphites nodosus</i> Owen
<i>Cylichna</i> sp.	<i>Turrilites</i> sp.
<i>Chemnitzia?</i> 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.	Mactra warrenana M. & H.
Bryozoa undetermined	Dentalium gracile H. & M.
Serpula markmani Henderson	Gastropods undetermined
Nucula cancellata M. & H.	Pyrifusus newberryi M. & H.?
Avicula haydeni H. & M.	Anchura americana E. & S.
Ostrea glabra White?	Actaeon concinna H. & M.
Crenella elegantula M. & H.	Cylichna scitula M. & H.
Callista owenana M. & H.	Cylichna volvaria (M. & H.)
Veniella humilis (M. & H.)	Lunatia subcrassa (M. & H.)
Spheriola? cordata (M. & H.)	Chemnitzia? sp.
Sphaeriola? cf. endotrachys Meek	Odontobasis sp.
Cardium speciosum M. & H.	Fasciolaria cf. culbertsoni (M. & H.)
Crassatella cf. cimarronensis White	Scaphites nodosus Owen
Baroda subelliptica White	Fish scales
Tellina scitula M. & H.	Shark tooth
Mactra formosa M. & H.	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.	Melania wyomingensis (Meek)
Ostrea sp.	Fasciolaria? sp.
Pholadomya subventricosa	Physa sp.
M. & H.	Gastropoda undetermined
Tancredia americana (M. & H.)	Placenticerias intercalare
Cardium speciosum M. & H.	(M. & H.)
Tellina scitula M. & H.	Corax sp.
Baroda subelliptica White	Lamna sp.
Mactra alta M. & H.	Fish vertebrae
Teredo? burrows in wood	Reptile teeth
Lunatia subcrassa M. & H.	

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

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 prosocheila*.

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 *Maetra* 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 humilis* (M. & H.), a species not found at all in the overlying sandstone. These concretions yielded the following species:

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

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

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 <i>Corbicula</i> , etc.....	3

³⁵White, 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 <i>Ostrea</i> and <i>Anomia</i>	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:

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

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

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:

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

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

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

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

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

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

³⁶Henderson, 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 north-east 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 Wildecat 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:

<i>Ostrea glabra</i> M. & H.	<i>Modiolus regularis</i> White
<i>Anomia micronema</i> Meek	<i>Corbicula cardiniaeformis</i> White

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

<i>Corbicula cardiniaeformis</i> White	<i>Melania wyomingensis</i> (Meek)
<i>Corbicula cleburni</i> White	<i>Planorbis</i> sp.
<i>Corbicula obesa</i> White	

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:

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

Four miles west of Osgood *Corbicula aughcyi* 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:

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

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 <i>Halymenites</i> concretion band, all containing ferruginous nodules, about	50
2. Sandstone filled with <i>Ostrea glabra</i>	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.	Corbula subtrigoualis M. & H.
Anomia micronema Meek	Melania wyomingensis (Meek)
Corbicula cleburni White	Reptile tooth
Corbicula fracta Meek	

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.	Cardium speciosum M. & H.
Baroda subelliptica White	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 Mor-

gan. 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.)	Lucina occidentalis (Morton)?
Pholadomya subventricosa M. & H.	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	Corbicula macropistha White
Ostrea glabra M. & H.	Corbicula planumbona Meek
Corbicula obesa White	Corbula subtrigonalis M. & H.
Corbicula subelliptica 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

³⁷White, 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 ferruginous 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:

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

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

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

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 VALLEY³⁸

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

³⁸See 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.

BIBLIOGRAPHY

- Cross, Whitman, Geologic Atlas of the United States, U. S. Geol. Surv., Engineer Mountain Folio, No. 171, 1910.
See also under Emmons.
- Cross, Whitman, Howe, Ernest, and Irving, J. D. Geologic Atlas of the United States, U. S. Geol. Surv., Ouray Folio, No. 153, 1907.
- Cross, Whitman, and Purington, Chester Wells. Geologic Atlas of the United States, U. S. Geol. Surv., Telluride Folio, No. 57, 1899.
- Cross, Whitman, and Ransome, F. L. Geologic Atlas of the United States, U. S. Geol. Surv., Rico Folio, No. 131, 1905.
- Cross, Whitman, Spencer, Arthur Coe, and Purington, Chester Wells. Geologic Atlas of the United States, U. S. Geol. Surv., La Plata Folio, No. 60, 1899.
- 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, 1905.
- Geology and Underground Waters of the Arkansas Valley in Eastern Colorado. U. S. Geol. Surv., Professional Paper No. 52, 1906.
- Eldridge, George H. "On Some Stratigraphical and Structural Features of the Country about Denver, Colorado," Proc. Colo. Sci. Soc., Vol. III, pp. 86-118, 1888.
- See also under Emmons, Cross and Eldridge.
- Emmons, S. F., Cross, Whitman, and Eldridge, George H. Geologic Atlas of the United States, U. S. Geol. Surv., Anthracite-Crested Butte Folio, No. 9, 1894.
- Geology of the Denver Basin in Colorado, U. S. Geol. Surv., Mon. Vol. XXVII, 1896.
- Endlich, F. M. "Report on the Geology of the White River District," 10th Ann. Rept. U. S. Geol. & Geog. Surv. Terr. (Hayden Survey), for 1876, pp. 63-131, 1878.
- Fenneman, N. M. "The Boulder, Colo., Oil Field," U. S. Geol. Surv., Bull., No. 213, pp. 322-332, 1903.
- "Structure of the Boulder Oil Field, Colorado, with Records for the Year 1903," U. S. Geol. Surv., Bull. No. 225, pp. 383-391, 1904.
- Geology of the Boulder District, Colorado, U. S. Geol. Surv., Bull. No. 265, 1905.
- Fenneman, N. M., and Gale, Hoyt S. "The Yampa Coal Field, Routt County, Colorado," U. S. Geol. Surv., Bull. No. 285, pp. 226-239, 1906, and Bull. No. 297, pp. 7-81, 1906.

- Finlay, George I. Colorado Springs Folio, Colorado, Geologic Atlas of the United States, U. S. Geol. Surv., Folio No. 203, 1916.
- 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. 264-301, 1907.
- Geology of the Rangeley Oil Field, U. S. Geol. Surv., Bull. No. 350, 1908.
- Coal Fields of Northwestern Colorado and Northeastern Utah, U. S. Geol. Surv., Bull. No. 415, 1910.
- Gilbert, G. K. "The Underground Waters of the Arkansas Valley in Eastern Colorado," 17th Ann. Rept. U. S. Geol. Surv., Part II, pp. 561-601, 1896.
- Goldman, Marcus I. "The Colorado Springs Coal Field, Colorado," U. S. Geol. Surv., Bull. No. 381, Part II, pp. 317-340, 1910.
- 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, 1913.
- Hayden, F. V. "Geology of the Missouri Valley," (4th Annual) Prelim. Rept. U. S. Geol. & Geog. Surv. Terr. (Hayden Survey), for 1870, pp. 83-188, 1871.
- "First Annual Report of the United States Geological Survey of the Territories, Embracing Nebraska," Rept. Comm. Gen. Land Office for 1867, pp. 124-177, 1867. Reprinted, with different paging, together with 2nd and 3rd reports of same survey, in 1873, under the title: "First, Second and Third Annual Reports of the United States Geological Survey of the Territories for the Years 1867, 1868, and 1869."
- See also under Meek and Hayden.
- Henderson, Junius. "The Sandstone of Fossil Ridge in Northeastern Colorado and its Fauna," Univ. Colo. Studies, Vol. V, pp. 179-192, 1908.
- "Topographic Development of Chalk Bluffs and Pawnee Buttes," Proc. Sci. Soc., Vol. VIII, pp. 247-256, 1907.
- "Paleontology of the Boulder Area," Univ. Colo. Studies, Vol. II, pp. 95-106, 1904.
- "Scientific Expedition to Northeastern Colorado, Paleontology: Account of Collections Made," Univ. Colo. Studies, Vol. III, pp. 149-152, 1907.
- "New Species of Cretaceous Invertebrates from Northern Colorado," Proc. U. S. Natl. Museum, Vol. XXXIV, pp. 259-264, 1908.
- "The Foothills Formations of North Central Colorado," First Rept. Colo. Geol. Surv., pp. 145-188, 1909.
- and Robbins, Wilfred William. "Climate and Evidence of Climatic Changes," U. S. Bur. Ethnol., Bull. No. 54, pp. 43-70, 1913.
- Hills, R. C. "Coal Fields of Colorado," U. S. Geol. Surv., Mineral resources of the United States, for 1892, pp. 319-366, 1893.
- Elmore Folio, Colorado, Geologic Atlas of the United States, U. S. Geol. Surv., Folio No. 58, 1899.

- Walsenburg Folio, Colorado, Geologic Atlas of the United States, U. S. Geol. Surv., Folio No. 68, 1900.
- Spanish Peaks Folio, Colorado, Geologic Atlas of the United States, U. S. Geol. Surv., Folio No. 71, 1901.
- Holmes, William H. "Geological Report on the San Juan District," 9th Ann. Rept. U. S. Geol. & Geog. Survey Terr. (Hayden Survey), for 1875, pp. 241-276, 1877.
- Howe, Ernest. See under Cross, Howe and Irving.
- Irving, J. D. See under Cross, Howe and Irving.
- Knowlton, F. H. "Paleobotanical Study of the Coal-bearing Rocks of the Raton Mesa Region of Colorado and New Mexico," abstract, Geol. Soc. Amer., Bull., Vol. XXIV, p. 114, 1913; Wash. Acad. Sci. Journ., Vol. III, pp. 173-174, 1913.
- "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.
- A catalogue of the Mesozoic and Cenozoic plants of North America. U. S. Geol. Surv., Bull. 696, 1919.
- See also Lee and Knowlton.
- Lakes, Arthur. Geology of the Colorado Coal Deposits, Ann. Rept. Colo. State School of Mines for 1889.
- Lee, Willis T. "Unconformity Separating the Coal-bearing Rocks in the Raton Field, New Mexico," abstract, Science, n. s., Vol. XXIX, p. 624, 1909.
- "Unconformity in the So-called Laramie of the Raton Coal Field, New Mexico," Geol. Soc. Amer., Bull., Vol. XX, pp. 357-368, 1909.
- "The Grand Mesa Coal Field, Colorado," U. S. Geol. Surv., Bull. No. 341, pp. 316-334, 1909.
- "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.
- "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.
- Coal Fields of Grand Mesa and the West Elk Mountains, Colorado, U. S. Geol. Surv., Bull. No. 510, 1912; (abstract) Wash. Acad. Sci., Journ., Vol. III, 362-363, 1913.
- and Knowlton, F. H., Geology and Paleontology of the Raton Mesa and other regions in Colorado and New Mexico, U. S. Geol. Surv., Prof. Paper 101, 1917.
- Martin, George C. "Coal of the Denver Basin, Colorado," U. S. Geol. Surv., Bull. No. 381, Part II, pp. 297-299, 1910.
- Marvine, Arch R. "Report of Arch R. Marvine, Assistant Geologist Directing the Middle Park Division," U. S. Geol. Surv. Terr. (Hayden Survey), 7th Ann. Rept., for 1873, pp. 83-192, 1874.

- Meek, F. B. A report on the Invertebrate Cretaceous and Tertiary fossils of the Upper Missouri Country. U. S. Geol. Surv. of the Territories (Hayden Survey), Monog. or Final Rept., Vol. IX, 1876.
- Meek, F. B., and Hayden, F. V. "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. Reynolds, U. S. Top. Engrs.; with some Remarks on the Rocks from which they were obtained." Proc. Acad. Nat. Sci. Phila., Vol. XIII, pp. 415-447, 1861.
- Peale, A. C. "On the Application of the Term Laramie," Amer. Journ. Sci., 4th Ser., Vol. XXVIII, pp. 45-58, 1909.
- Purington, Chester Wells. See under Cross and Purington; also under Cross, Spencer and Purington.
- Ransome, F. L. See under Cross and Ransome.
- Richardson, G. B. "The Book Cliffs Coal Field, Between Grand River, Colorado, and Sunnyside, Utah," U. S. Geol. Surv., Bull. 316, Part II, pp. 302-320, 1907.
- Reconnaissance of the Book Cliffs Coal Field, Between Grand River, Colorado, and Sunnyside, Utah, U. S. Geol. Surv., Bull. No. 371, 1909.
- "The Trinidad Coal Field, Colorado," U. S. Geol. Surv., Bull. No. 381, Part II, pp. 379-446, 1910.
- Castle Rock Folio, Colorado, Geologic Atlas of the United States, U. S. Geol. Surv., Folio No. 198, 1915.
- Robbins, W. W. See Henderson and Robbins.
- Schrader, F. C. "The Durango-Gallup Coal Field in Colorado and New Mexico, U. S. Geol. Surv., Bull. No. 285, pp. 241-258, 1906.
- 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, pp. 376-425, 1907.
- Stanton, Timothy W. The Colorado Formation and its Invertebrate Fauna, U. S. Geol. Surv., Bull. No. 106, 1893.
"Paleontological Notes," Proc. Colo. Sci. Soc., Vol. II, pp. 184-187, 1888.
- Stevenson, John J. Age of the Western Lignites, Proc. N. Y. Lyc. Nat. Hist., 2nd series, No. 4, p. 94, 1874.
- "Report on the Geology of a Portion of Colorado Examined in 1873," Geog. & Geol. Expl. & Surv. W. of the 100th Meridian (Wheeler Survey), Vol. III, Part IV, pp. 303-501, 1875.
- Spencer, Arthur Coe. See under Cross, Spencer and Purington.
- Storrs, L. S. "The Rocky Mountain Coal Fields," 22nd Ann. Rept. U. S. Geol. Surv., 1900-1901, Vol. III, pp. 415-471, 1902.
- Taff, Joseph A. "The Durango Coal District, Colorado," U. S. Geol. Surv., Bull. No. 316, Part II, pp. 321-337, 1907.

- 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 (whole number CLXXIV), pp. 18-22, 1907.
- Washburne, Chester W. "The South Park Coal Field, Colorado," U. S. Geol. Surv., Bull. No. 381, Part II, pp. 15-24, 1910.
- "The Canon City Coal Field, Colorado," U. S. Geol. Surv., Bull. No. 381, Part II, pp. 341-378, 1910.
- "The Florence Oil Field," U. S. Geol. Surv., Bull. No. 381, Part II, pp. 45-72, 1909.
- White, Charles 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. 5-60, 1878.
- "Report on the Paleontological Field-Work for the Season of 1877," 11th Ann. Rept. U. S. Geol. & Geog. Surv. Terr. (Hayden Survey), pp. 159-272, 1879.
- "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. 273-319, 1879.
- Worcester, P. G. See under Grout, Worcester and Henderson.

THE FOOTHILLS FORMATIONS OF NORTH CENTRAL
COLORADO¹

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 synchronous made caution in nomenclature desirable until correlation of our formations with those of adjacent areas could be established. Some fossils reported from the northern portion of the field seemed of sufficient importance to suggest the advisability of further work in that region and the tracing of the formations thence southward. Consequently two parties working under the Colorado Geological Survey spent ten days or more in the field in June, 1907, between the Cache la Poudre and the northern boundary of Colorado, and in October of the same year work was resumed at that stream and pushed southward to Boulder.

The results of this work, coupled with that done by others 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

¹The 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.

²For 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

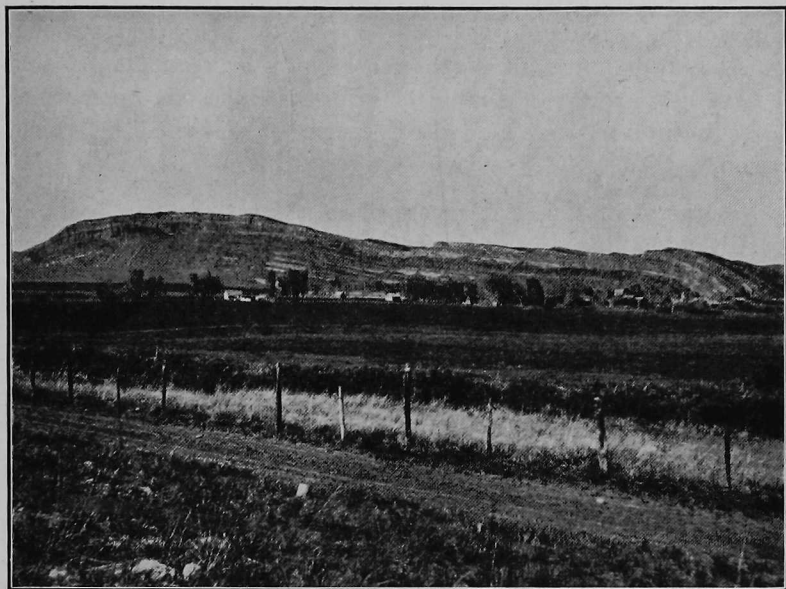


Fig. 1. Bellvue fold, looking north of east, with the village at south end of fold. Lyons formation at the top of cliff, Fountain at the base.

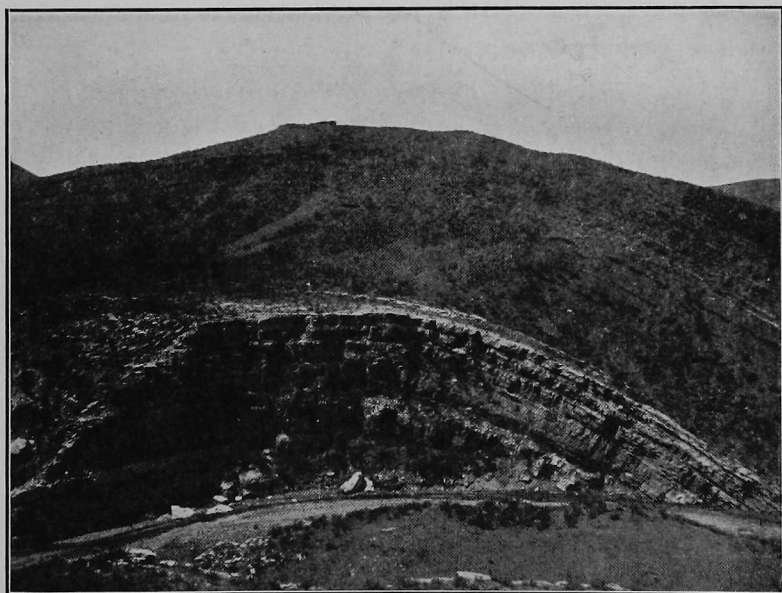


Fig. 2. Sand Creek fold, looking south. The cliff is the Lyons formation, with a little Fountain at the base, and the Lykins sloping upward from the top of the cliff to the top of the hill.

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.

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 softens 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.)

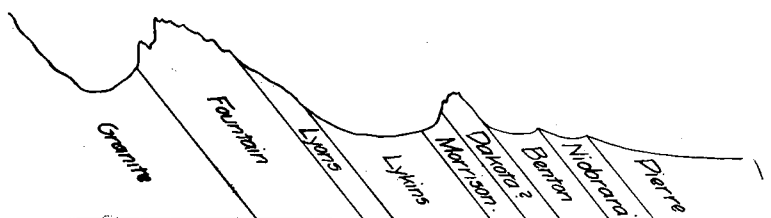


Fig. 3. Generalized section at Boulder.



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 disintegra-

tion 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 Wyoming³, 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

³This 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*, *Acrophyllum 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 them tentatively to *Orbiculoidea manhattanensis*. With them a single productoid shell, resembling *Marginifera ingrata*, has been collected, but the specimen is not sufficiently good for identification. *Orbiculoidea manhattanensis* has a wider range than Carboniferous, but its occurrence at this horizon points strongly to the Pennsylvanian age of the Fountain beds near Manitou."

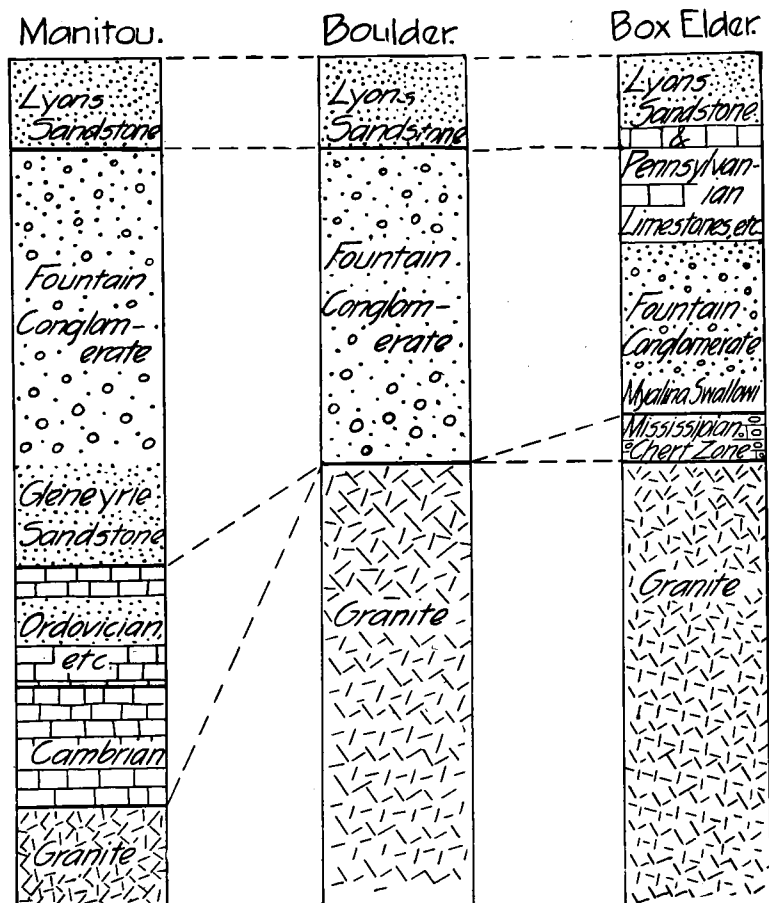


Fig. 6. Generalized geologic columns from granite to Lyons sandstone at Box Elder, Boulder and Manitou.

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 Fennerman'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 Emons (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-

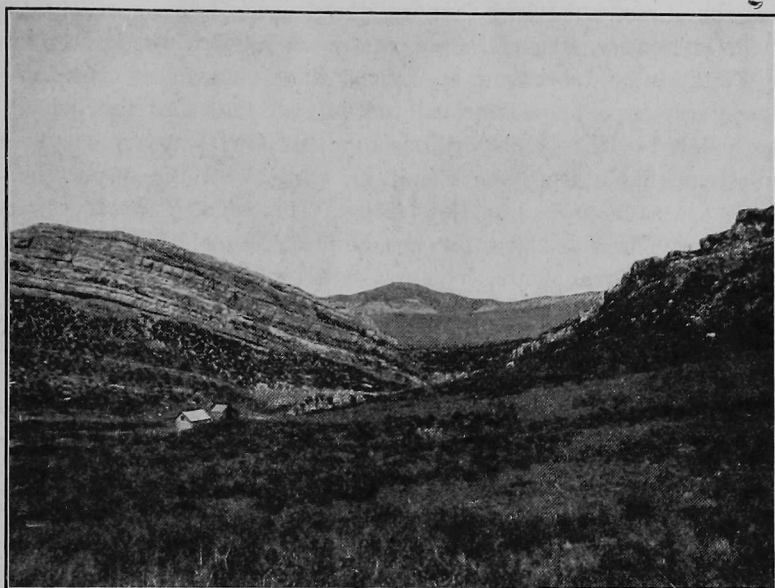


Fig. 7. Looking east through Owl Canyon. The ridge in the foreground is crowned by Pennsylvania limestones, with Fountain conglomerates at the base.

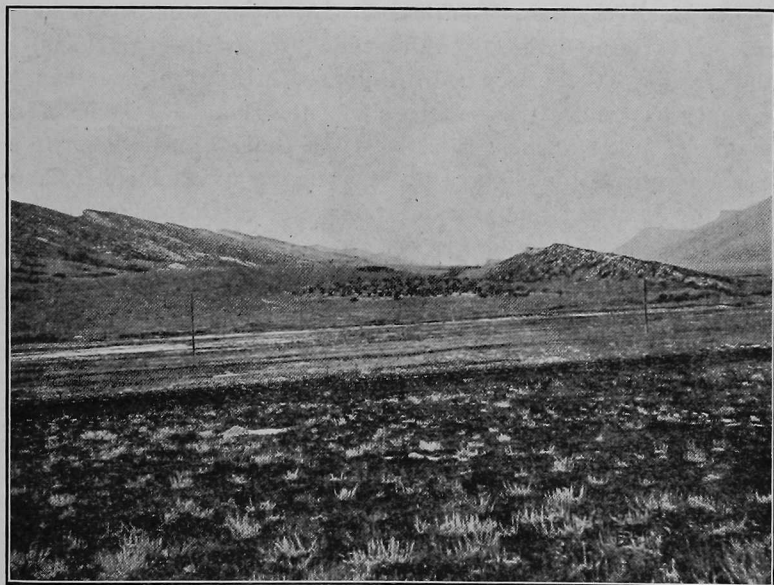


Fig. 8. Ridge making, cross-bedded sandstone in the lower part of the Lykins formation, south of Owl Canyon, looking north, with Carboniferous limestone ridge on the left, and Dakota-Morrison escarpment showing dimly on the extreme right.

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,

⁴This 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-

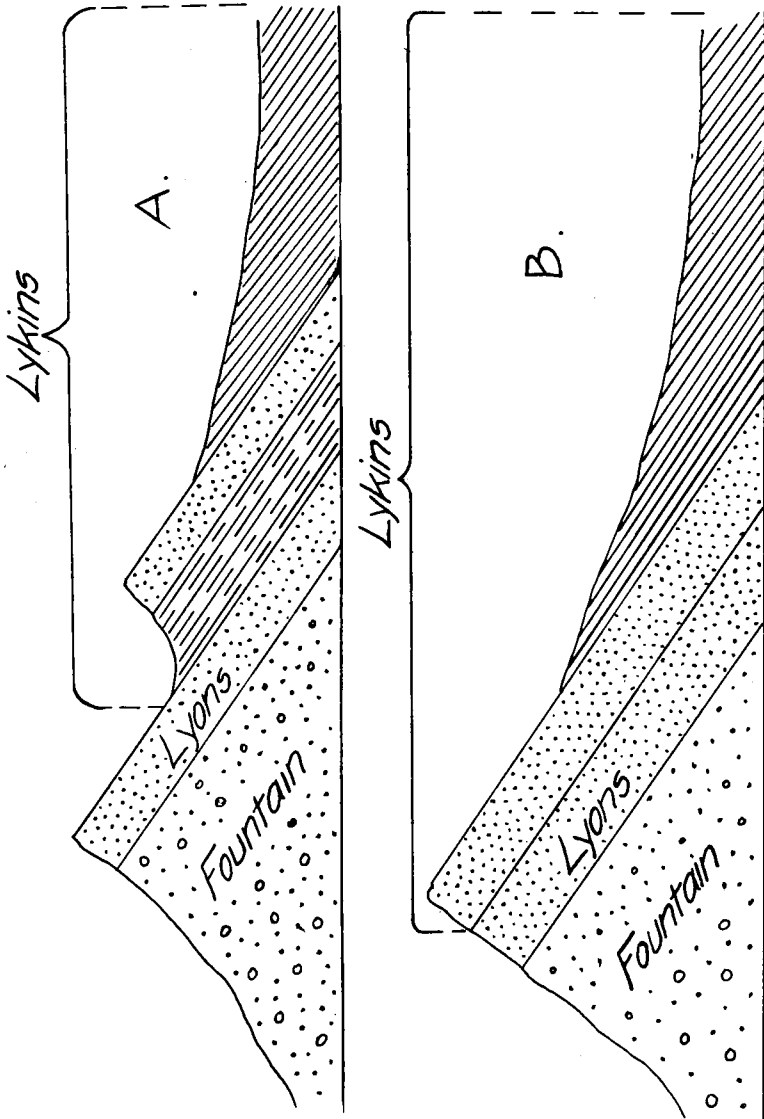


Fig. 9. A. East-West section, showing ridge of cross-bedded sandstone in the Lykins formation west of Fort Collins. B, showing apparently the same sandstone crowning the Lyons escarpment north of the Little Thompson.

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.*

⁵Since 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 underlain 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 *Belcmites 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 man-

ner 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.

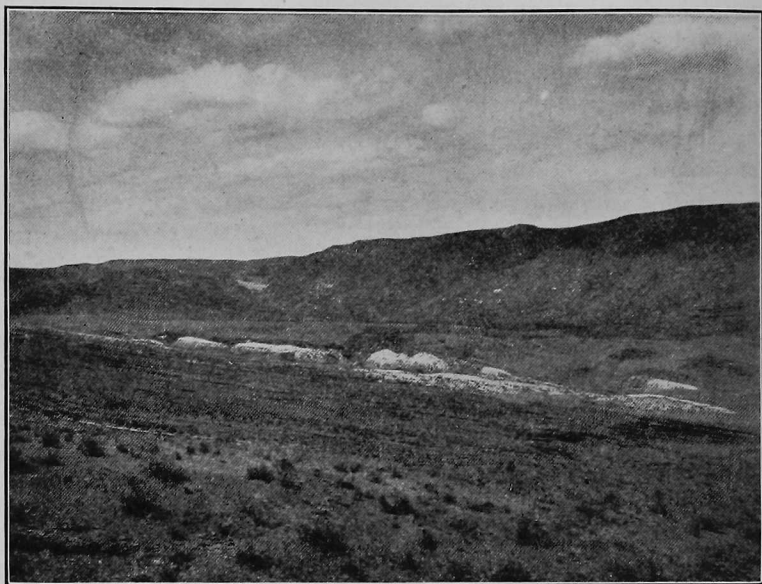


Fig. 10. Gypsum beds in the Lykins formation, southeast of Box Elder post-office, looking northeast.

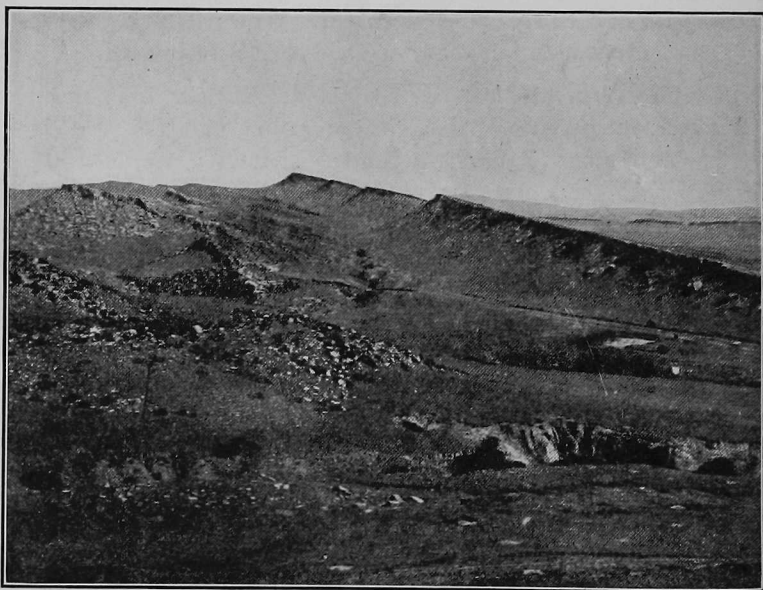


Fig. 11. Valley in shales, between the upper and lower "Dakota" sandstone, at Owl Canyon, looking northeast. Fossils on the inner slope of the right hand ridge.

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 forma-

tions 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 valve 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., *Placentoceras 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*, *Mastra 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*, *Mastra*, *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

⁶As 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

⁷F. 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 sub-aerial 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.

BIBLIOGRAPHY

-
0. Butters, R. M. "Permian or Permo-Carboniferous of the Eastern Foothills of the Rocky Mountains in Colorado." *Colo. Geol. Surv., Bull. No. 5*, 1913, pp. 62-94.
 1. Cannon, George L. "Notes on the Geology of Palmer Lake, Colo., and the Paleozoic Exposures Along the Front Range." *Proc. Colo. Sci. Soc., Vol. IV*, 1892, pp. 224-234.
 2. Crosby, W. O. "Archæan-Cambrian Contact near Manitou, Colo." *Bull. Geol. Soc. Amer., Vol. X*, March 23, 1899, pp. 141-164.
 3. Cross, Whitman. See, also, under Emmons.
 4. —————. "Pike's Peak Folio." *U. S. Geol. Surv., Geol. Atlas of U. S., Folio No. 7*.
 5. ————— and Ernest Howe. "Red Beds of Southwestern Colorado and Their Correlation." (Includes bibliography.) *Bull. Geol. Soc. Amer., Vol. XVI*, Dec. 15, 1905, pp. 447-498. Abstract: *Science*, Vol. XXI, March 2, 1905, p. 349.
 6. —————. "Laramie Formation." *Science*, Vol. XXVIII, July 24, 1908, p. 128. (Abstract by Ralph Arnold.)
 7. Darton, N. H. "Comparison of the Stratigraphy of the Black Hills with that of the Front Range of the Rocky Mountains." Abstract: *Bull. Geol. Soc. Amer., Vol. XII*, 1901, p. 478.
 8. —————. "Preliminary Report on the Geology and Underground Waters of the Central Great Plains." *U. S. Geol. Surv., Prof. Paper No. 32*, 1905.
 9. —————. "Discovery of the Comanche Formation in Southeastern Colorado." *Science*, Vol. XXII, July 28, 1905, p. 120.
 10. —————. "Geology and Underground Waters of the Arkansas Valley in Eastern Colorado." *U. S. Geol. Surv., Prof. Paper No. 52*, 1906.
 11. Eldridge, George H. See under Emmons.
 12. Emmons, S. F., and G. H. Eldridge and Whitman Cross. "Geology of the Denver Basin." *U. S. Geol. Surv., Mon. Vol. XXVII*, 1896. General Geology by Emmons. Mesozoic Geology by Eldridge.
 13. Fenneman, N. M. "Geology of the Boulder District, Colorado." *U. S. Geol. Surv., Bull. No. 265*. 1905.

14. ————. "Effect of Cliff Erosion on Form of Contact Surfaces." *Bull. Geol. Soc. Amer.*, Vol. XVI, April, 1905, pp. 205-214.
15. Finlay, George I. "The Gleneyrie Formation and its Bearing on the Age of the Fountain Formation in the Manitou Region, Colorado." *Journal Geol.*, Vol. XV, Sept.-Oct., 1907, pp. 586-589.
16. Fisher, Cassius A. "Nepesta Folio." *U. S. Geol. Surv., Geol. Atlas of U. S., Folio No. 135.*
17. Girty, George H. "The Carboniferous Formations and Faunas of Colorado." *U. S. Geol. Surv., Prof. Paper, No. 16. 1903.*
- 17A. ————. "On some Invertebrate Fossils from the Lykins Formation of Eastern Colorado." *Annals of N. Y. Acad. of Sci.*, Vol. XXII, 1912, pp. 1-8.
18. Gilbert, G. K. "Pueblo Folio." *U. S. Geol. Surv., Geol. Atlas U. S., Folio No. 36.*
19. ————. "Underground Water of the Arkansas Valley in Eastern Colorado." *17th Ann. Rep. U. S. Geol. Surv., Part II, 1895-6, pp. 551-601.*
20. Hay, O. P. "The American Paleontological Society. Section A—Vertebrata." *Science*, Vol. XXI, Feb. 24, 1905, pp. 294-300. Report of 3d Ann. Meeting, quoting Williston as to age of Hallopus Beds at Canyon City.
21. Hayden, F. V. "Geological Report." Preliminary Field Report of the U. S. Geol. Surv. of Colo. and N. Mex., 1869. Reprinted in First, Second and Third Ann. Repts. U. S. Geol. Surv. Terr. (Hayden Survey), for 1867, 1868, 1869, pp. 109-199. 1873.
22. ————. "Report on Geology of Central Portion of Colorado." *Seventh Ann. Rep. U. S. Geol. & Geog. Surv. Terr. (Hayden Survey) for 1873, pp. 15-361. 1874.*
23. Henderson, Junius. "Paleontology of the Boulder Area." *Univ. Colo. Studies, Vol. II, 1904, pp. 95-106.*
- 23A. ————. "The Overturns of the Denver Basin." *Journal Geol.*, Vol. XI, 1903, pp. 584-586; reprinted in *Univ. Colo. Studies, Vol. I, 1904, pp. 345-347.*
24. ————. "Scientific Expedition to Northeastern Colorado. Paleontology: Account of Collections Made." *Univ. Colo. Studies, Vol. III, 1907, pp. 149-152.*
25. ————. "Topographic Development of Chalk Bluffs and Pawnee Buttes." *Proc. Colo. Sci. Soc.*, Vol. VIII, 1907, pp. 247-256.
26. ————. "The Sandstone of Fossil Ridge in Northern Colorado and its Fauna." *Univ. Colo. Studies, Vol. V, 1908, pp. 179-192.*

27. ————. "New Species of Cretaceous Invertebrates from Northern Colorado." Proc. U. S. Nat. Mus., Vol. XXXIV, 1908, pp. 259-264.
28. ————. "The Red Beds of Northern Colorado." Journal Geol., Vol. XVI, 1908, pp. 491-492.
29. Hills, R. C. "Elmoro Folio." U. S. Geol. Surv., Geol. Atlas U. S., Folio No. 58.
30. ————. "Walsenburg Folio." U. S. Geol. Surv., Geol. Atlas U. S., Folio, No. 68.
31. Hovey, Edmund Otis. "The Geological Society of America." Science, Vol. XXI, Feb. 10, 1905, pp. 216-223. Rept. 17th Ann. Meeting, quoting Darton as to Morrison formation.
32. Howe, Ernest. See under Cross.
33. Lee, Willis T. "The Morrison Formation in Southeastern Colorado." Journal Geol., Vol. IX, May-June, 1901, pp. 343-352.
34. ————. "The Areal Geology of the Castle Rock Region, Colorado." Amer. Geol., Vol. XXIX, Feb., 1902, pp. 96-109.
- 34A. ————. The Geologic Story of the Rocky Mountain National Park, Colorado. U. S. Dept. of Interior, National Park Service, 1917.
35. Marvine, Arch. B. "Report of Arch. B. Marvine, Assistant Geologist Directing the Middle Park Division." Seventh Ann. Rep. U. S. Geol. & Geog. Sur. Terr. (Hayden Survey) for 1873, pp. 83-192. 1874.
36. Stanton, T. W. "The Morrison Formation and Its Relation with the Comanche Series and the Dakota Formation." Journal Geol., Vol. XIII, Nov.-Dec., 1905, pp. 657-669. Abstract: Science, Vol. XXII, Dec. 8, 1905, pp. 755-756.
- 36A. Vail, C. E. "Lithologic Evidence of Climatic Pulsations." Science, XLVI, 1917, pp. 90-93.
37. Van Hise, C. R. "Correlation Papers: Archæan and Algonkian." U. S. Geol. Surv., Bull. No. 86.
38. Veatch, A. C. "On the Origin and Definition of the Geologic Term 'Laramie.'" Journal Geol., Vol. XV, Sept.-Oct., 1907, pp. 526-549.
39. White, Charles A. "Report of the Paleontological Field Work for the Season of 1877." Eleventh Ann. Rep. U. S. Geol. & Geog. Sur. Terr. (Hayden Survey) for 1877, pp. 161-319. 1879.
40. ————. "Carboniferous Fossils from the Western States and Territories." Twelfth Ann. Rept. U. S. Geol. & Geog. Sur. Terr. (Hayden Survey) for 1878, Part I, pp. 119-141. 1883.
41. Williston, S. W. "The Hallopus, Baptonodon and Atlantosaurus Beds of Marsh." Journal Geol., Vol. XIII, May-June, 1905, pp. 338-350.

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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

His Excellency, William E. Sweet, Governor of Colorado.

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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.

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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. Tiejé, 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 cemented 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 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 deformatis* 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 determinè 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 Bi'ou 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 conglom-

erates, 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 quadrangles 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 Tertiary 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., R. 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

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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



~~COLORADO GEOLOGICAL SURVEY~~

~~Boulder, - - - Colo.~~

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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.

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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 $105^{\circ} 30'$, 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 Chatham, 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 geology 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 un-metamorphosed 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 moraines 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

¹Cross, 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 Bastin² 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 Bastin³ 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 Hise⁴ 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

¹Ball, S. H., General geology [of the Georgetown quadrangle, Colo.]: U. S. Geol. Survey Prof. Paper 63, p. 37, 1908.

²Bastin, 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.

³Bastin, E. S., and Hill, J. M., op. cit., p. 30.

⁴Van 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.

HORNBLLENDE 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 granite¹ 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.

¹Spurr, 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 south¹ 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.

Cross³ 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.

¹Bastin, 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.

²Fenneman, N. M. Geology of the Boulder District, Colorado: U. S. Geol. Survey Bull. 265, pp. 35-40, 1905.

³Cross, 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 Tele-

graph 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 anhedral, 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 anhedral and euhedral. 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 Four-mile 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 com-

position 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 $3\frac{1}{2}$ 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 accessories, 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.

¹Breed 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

¹Breed, 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 badly 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

¹Crawford, 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 report¹ 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 coarse-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.

¹Op. 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.

4. 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, there-

fore 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 mine¹ 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

¹George, 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	Forest Queen	Orphan Boy
*Baxter	Giles	Pennsylvania
*B. & M.	Gold Queen	Philadelphia
*Big Five	Gov. Routt	Puzzler
Boston	Homestake	*Ruby
Cardiff	Humboldt	Skandia
*Celestial	Idaho	Stoughton
*Celestial Extension	Innsbruck	*Sullivan No. 5
Centennial	*Madaline	Texas
Chatham	Maid of Erin	*U. P. Group
Colorado	Milwaukee	*Utica
*Columbia	*Morning and	*Ward Rose
Copper Glance	Evening Star	*White Raven
Dew Drop	Nelson	Wirth
Dolly Varden	Newmarket	

DESCRIPTIONS OF MINES

RUBY MINE

Location.—The Ruby mine is situated at Sunnyside on Four-mile 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 exten-

sively 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. t

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.

BIBLIOGRAPHY

- Blake, John C., A mica andesite of West Sugarloaf Mountain, Boulder County, Colorado: Colorado Sci. Soc. Proc., vol. 7, p. 1, 1901.
- Breed, Robert, The Sunset trachyte, from near Sunset, Boulder County, Colo.: Colorado Sci. Soc. Proc., vol. 6, pp. 216-229, 1899.
- Ekeley, J. B., Some Colorado Tungsten Ores: Mining World, vol. 30, p. 280, 1909.
- Emmons, S. F., Geological sketch of the Rocky Mountain Division: Tenth Census of the United States, vol. 13, pp. 64-67 et seq., 1880.
- George, R. D., Mineral Industry: Vol. 17, pp. 827-828, 1908.
- Hogarty, Barry, The andesite of Mount Sugarloaf, Boulder County, Colo.: Colorado Sci. Soc. Proc., vol. 6, p. 173, 1899.
- Hollister, O. J., Mines of Colorado: 1867.
- Henry, Carl D., The white country granite of West Sugarloaf or Bald Mountain, Boulder County, Colo.: Colorado Sci. Soc. Proc., vol. 7, pp. 112-116, 1902.
- Mining Reporter, vol. 40, pp. 18-20, 49-50, 65-66, 78-79, 94-95, 1899.
- Mint Reports for the years 1887 to 1891, inclusive.
- Palmer, S., A preliminary paper on the eruptive rocks of Boulder County and adjoining counties, Colorado: Colorado Sci. Soc. Proc., vol. 3, pt. 2, pp. 230-236, 1889.
- Rickard, T. A., Geological distribution of the precious metals in Colorado: Min. and Sci. Press, vol. 100, p. 91, 1910.
- Van Diest, P. H., The mineral resources of Boulder County, Colo.: Colorado School of Mines Bienn. Rept., p. 28, 1886.

REPORTS ON AREAS ADJACENT TO THE WARD REGION

- Bastin, E. S., and Hill, J. M., Economic Geology of Gilpin County and adjacent parts of Clear Creek and Boulder counties, Colo.: U. S. Geol. Survey Prof. Paper 94, 1917.
- Crawford, R. D., Geology and petrography of the Sugarloaf district, Boulder County, Colo.: Univ. Colo. Studies, vol. 6, No. 2, pp. 97-131, 1909.
- George, R. D., The main tungsten area of Boulder County, Colorado, with notes on the intrusive rocks by R. D. Crawford: Colo. Geol. Survey First Report, 1908.

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COLORADO GEOLOGICAL SURVEY

Denver, - - Colo.

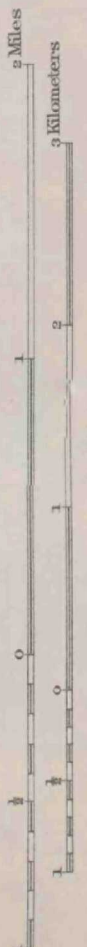
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SECRET



TOPOGRAPHIC MAP OF WARD, SUGARLOAF, AND NEAR-BY REGIONS, BOULDER COUNTY, COLORADO

Scale 2000 or approximately 1/2 inches to 1 mile



Topography east of 105°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 White Pine
- 3 Diagonal
- 4 Mountain View
- 5 Barro
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COLORADO GEOLOGICAL SURVEY
BOULDER

R. D. GEORGE, State Geologist

BULLETIN 22

MINERAL DEPOSITS
OF THE WESTERN SLOPE



COLORADO STATE
TEACHERS COLLEGE
Greeley, Colo.

BY
H. A. AURAND

EAMES BROS.
STATE PRINTERS FOR COLORADO
DENVER, COLORADO

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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.

**COLORADO STATE
TEACHERS COLLEGE
Greeley, Colo.**

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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.

¹Smith, J. Alden, Report of Colorado State Geologist for 1881-1882; p. 131, 1888.

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 Beekly² 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.

²Beekly, 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, monoclinical 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, Gale⁴ 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:

³Dairymple, J., State Inspector of Coal Mines, Sixth Ann. Rept. for 1918. p. 55, 1919.

⁴Gale, 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
	<hr/>
	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. Harmon

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.

GOLD⁵

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.

⁵See 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

Stevenson⁶ 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.

⁶Stevenson, 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 Higo. They are undeveloped.

MOFFAT COUNTY.—The Juniper Springs are improved by the building of bath houses. Hotel accommodation is available.

⁷Muilenburg, G. A., Manganese deposits of Colorado: Colo. Geol. Survey Bull. 15, p. 33, 1913.

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 molybdenite 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.

Worcester⁸ 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-

⁸Worcester, 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 Osbon⁹ 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 Eldridge¹⁰ 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 Eldridge¹¹ 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,

⁹Osbon, C. C., Asphalt and allied substances in 1918: U. S. Geol. Survey Mineral Resources for 1918, p. 470.

¹⁰Eldridge, G. H., The asphalt and bituminous rock deposits of the United States: U. S. Geol. Survey Twenty-second Ann. Rept., pt. I, p. 354.

¹¹Eldridge, 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
	<hr/>
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.

¹²Ladoo, Raymond E. The natural hydrocarbons: Reports of Investigations, U. S. Bureau of Mines, May, 1920.

Henderson¹³ 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. Grout¹⁴ 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

¹³Henderson, Junius. Scientific expedition into Northwestern Colorado in 1909. Univ. of Colo. Studies, vol. 7, pp. 111-112.

¹⁴Grout, 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 GAS¹⁶

JACKSON COUNTY

There is a large anticline east of Walden¹⁷ 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 COUNTY¹⁸

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

¹⁵Willis, Bailey, Index to the stratigraphy of North America: U. S. Geol. Survey Prof. Paper, 71, p. 769, 1912.

¹⁶For location of anticlines, oil seeps, bitumen, oil sands, gas and oil springs, oil wells, and drill holes see accompanying map.

¹⁷Beekly, A. L., Geology and Coal Resources of North Park, Colorado: U. S. Geol. Survey Bull. 596, pp. 90-93, 1915.

¹⁸Gale, 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 Weston¹⁹ 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 County²⁰ 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.

¹⁹Weston, W., The hydrocarbons of the Moffat Road, p. 24, 1909.

²⁰Crawford, 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 oolites, 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.

Winchester²¹ reports the finding of beautifully preserved beetles, flies, mosquitoes, bees, leaves of all kinds, fish skeletons,

²¹Winchester, 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. George²² 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.

²²George, 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.)

²³Winchester, 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.

SILVER²⁴**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**

Gale²⁵ 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-

²⁴See 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.

²⁵Gale, 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.

²⁶Montgomery, 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 News-boy, 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 argenterous 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 mine²⁸ 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-

²⁷Cross, 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.

²⁸Spurr, 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.

²⁹Schrader, 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 sandstones 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.

³⁰Schrader, Frank C., Stone, Ralph W., and Sanford, S. Useful minerals of the United States: U. S. Geol. Survey Bull. 624, pp. 24, 1917.

Coal of commercial importance occurs in the lower part of the sandstone and shale formation which is known as the Mesa-verde. 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.

COPPER³²

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.

³¹Lee, W. T., The Grand Mesa Coal field, Colorado: U. S. Geol. Survey Bull. 341, pp. 316-334, 1909.

³²Also 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 fluorspar 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 fluorspar 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

³³Irving, 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

Fluorspar is found as a gangue mineral in the ores of the Telluride district. In the Tomboy mine, many small crystals of colorless to greenish fluorspar are found.³⁵

GOLD³⁶

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

³⁴Carroll, Fred., Colorado State Bur. Mines Fifteenth Bienn. Rept. for 1917-1918, p. 131, 1919.

³⁵Cross, Whitman, and Purington, C. W., U. S. Geol. Survey Geol. Atlas, Telluride folio (No. 57), p. 16, 1899.

³⁶See 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 (Newwire).

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 COUNTY³⁷

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

³⁷U. 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.

GYPSUM⁴⁰

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-

³⁸Carrol, Fred., Colorado State Bur. Mines Fifteenth Bienn. Rept. for 1917-1918, p. 134, 1919.

³⁹Mining Science, Gunnison, Colorado, Grindstone Quarries: vol. 62, p. 625, 1910.

⁴⁰Excerpts 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, gypsum⁴¹ 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

⁴¹Burchard, 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.

Gypsum⁴² 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 Lesquereux⁴⁴ determined the age to be Permian. Recent work supports this finding.

UNCOMPAHGRE REGION

Siebenthal⁴⁵ 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

⁴²Burchard, E. F., Gypsum deposits in Eagle County, Colorado. U. S. Geol. Survey Bull. 470, p. 357, 1911.

⁴³Burchard, E. F., Gypsum deposits in Eagle County, Colorado. U. S. Geol. Survey Bull. 470, pp. 354-364, 1911.

⁴⁴Lesquereux, Leo., Permo-Carboniferous strata of Eagle River: U. S. Geol. Survey of the Territories by F. V. Hayden, vol. 8, pp. 118-119, 1874.

⁴⁵Siebenthal, 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

Howell⁴⁶ 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.

⁴⁶Howell, 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.

LEAD⁴

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

⁴See 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 manufacture, 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.

MANGANESE⁴⁸

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.

⁴⁸For 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

⁴⁹Umpleby, 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 separating 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

Burchard⁵⁰ 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.”

Loughlin⁵¹ 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-

⁵⁰Burchard, E. F., U. S. Geol. Survey, Mineral Resources of the United States for 1912, pt. II, p. 810.

⁵¹Loughlin, 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.

MOLYBDENUM⁵²

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.

⁵²For a full discussion see Worcester, P. G., Molybdenum deposits of Colorado: Colo. Geol. Survey Bull. 14, 1919.

Worcester⁵³ 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 north-westerly 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 north-west 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.

⁵³Worcester, 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

Worcester⁵⁴ 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.

⁵⁴Worcester, 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.

SILVER⁵⁵

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.

⁵⁵See 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. Bailar⁵⁶ 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

⁵⁶Bailar, J. C., The non-metallic minerals of Colorado: Colorado School of Mines Bienn. Rept., p. 37, 1910.

⁵⁷Lakes, 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

Smith⁵⁹ 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 hübnerite 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.

⁵⁸Lakes, Arthur, Gunnison region (Rocks and their relation to ore deposits in Mammoth and Vulcan mines): Coll. Eng., vol. 16, p. 280, 1895-6.

⁵⁹Smith, P. S., U. S. Geol. Survey, Mineral Resources for 1916, pt. II, p. 407.

⁶⁰Worcester, 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

⁶¹Burchard, E. F. U. S. Geol. Survey Mineral Resources for 1912, p. 813.

⁶²Shaler, 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.

⁶³Shaler, 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

⁶⁴Cross, Whitman, and Ransome, F. L., U. S. Geol. Survey Geol. Atlas, Rico folio (No. 130), p. 15, 1905.

⁶⁵Cross, Whitman, Spencer, A. C., and Purington, C. W., U. S. Geol. Survey Geol. Atlas, La Plata folio (No. 69), p. 10, 1900.

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.

GOLD⁶⁷

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. Prosser⁶⁸ 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.

⁶⁶Cross, Whitman, Howe, Ernest, and Ransome, F. L., U. S. Geol. Survey Geol. Atlas, Silverton folio (No. 120), p. 29, 1905.

⁶⁷See 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.

⁶⁸Personal 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 gypsum⁷¹ 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.

⁶⁹Cross, Whitman, and Ransome, F. L., U. S. Geol. Survey Geol. Atlas, Rico folio (No. 130), p. 3, 1905.

⁷⁰Cross, Whitman, and Ransome, F. L., U. S. Geol. Survey Geol. Atlas, Rico folio (No. 130), p. 3, 1905.

⁷¹Henderson, 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 that⁷² which Peale⁷³ regarded as Permian. They think the beds may be Cutler.

Coffin⁷⁴ 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.

⁷²Cross, W. and Howe, E., The Red Beds of southwestern Colorado: Geol. Soc. Am. Bull., vol. 16, pp. 447-498, 1905.

⁷³Peale, A. C., Geological report on the Grand River district: Hayden Survey, Tenth Ann. Rept., pp. 167-168, 1878.

⁷⁴Coffin, 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

Lakes⁷⁶ 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-

⁷⁶Lakes, Arthur, Mg. Rept., vol. 54, pp. 389-390, 1906.

⁷⁶Schrader, F. C., Stone, R. W., and Sanford, S., Useful Minerals of the United States: U. S. Geol. Survey Bull. 624, pp. 61, 64, 33, 134-135.

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.

Ransome⁷⁷ reports the occurrence of molybdenite in the Sunny-side 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. Lee⁷⁸ 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.

⁷⁷Cross, Whitman, Howe, Ernest, and Ransome, F. L., U. S. Geol. Survey Geol. Atlas, Silverton folio (No. 120), p. 30, 1905.

⁷⁸Lee, 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.

SILVER⁷⁹

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

⁷⁹See 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 COUNTY⁸⁰

R. D. George⁸¹ 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.

URANIUM⁸²

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

⁸⁰Cross, Whitman, Howe, Ernest, Ransome, F. L., U. S. Geol. Survey Geol. Atlas, Silverton folio (No. 120), p. 30, 1905.

⁸¹George, R. D., The main tungsten area of Boulder county, Colorado: Colo. Geol. Survey First Ann. Rept., pp. 55-56, 1908.

⁸²For 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.

Coffin⁸⁶ 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.

⁸³Coffin, R. C., Preliminary statement from Bulletin 16 on the carnotite area of southwestern Colorado: Colo. Geol. Survey 1920.

⁸⁴Coffin, R. C., Preliminary Statement from Bull. 16 on the carnotite area of southwestern Colorado: Colo. Geol. Survey 1920.

⁸⁵Coffin, 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 Value	SILVER		LEAD Pounds	LEAD Value	COPPER		ZINC Pounds	ZINC Value	TOTAL
		Fine Ounces	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	-----	-----	4,537,184
Mesa, 1885-1915	5,040	4,934	2,970	20	1	35,280	5,222	-----	-----	43,233
Montrose, 1886-1917	46,259	184,448	110,734	64	3	453,616	83,023	-----	-----	540,019
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	-----	-----	421,277
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	82,607,032
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	\$414,000,000

*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.

VANADIUM⁸⁴

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 rooseelite, 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 Durango⁸⁷ 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.

⁸⁴Hess, Frank L., U. S. Geol. Survey, Mineral Resources for 1911, pp. 949-950.

⁸⁷Woolsey, L. H., Volcanic Ash near Durango, Colorado: U. S. Geol. Survey Bull. 285, pp. 476-478, 1905.

BIBLIOGRAPHY

COAL, OIL, OIL SHALE AND NATURAL HYDROCARBONS

- ADKINSON, H. M., Colorado and Utah oil shale: Railroad Red Book, vol. 35, pp. 5, 7, 9, 11, 13, Sept. 1918.
- ALDERSON, V. C., The oil shale industry: Colo. Sch. of Mines Quarterly, vol. 13, No. 2, 1918.
- BEEKLY, A. L., Geology and coal resources of North Park, Colorado: U. S. Geol. Survey Bull. 596, 1915.
- CAMPBELL, M. R., Analysis of coal samples from various fields of the United States: U. S. Geol. Survey Bull. 541, pp. 491-526, 1912.
- CHASE, R. L., The oil shale industry in Colorado: Min. and Sci. Press, vol. 118, pp. 82-83, 1919.
- CLARKE, F. W., A report of work done in the division of chemistry and physics mainly during the fiscal year 1888-1889: U. S. Geol. Survey Bull. 64, p. 55, 1890. (Coal.)
- COLLIER, A. J., Coal south of Mancos, Montezuma county, Colorado: U. S. Geol. Survey Bull. 691, pp. 293-310, 1919.
- CRAWFORD, R. D., Some anticlines of Routt county, Colorado: Colo. Geol. Survey Bull. 23, 1920.
- CROSS, W., HOWE, E., IRVING, J. D., U. S. Geol. Survey Geol. Atlas, Ouray folio (No. 153), p. 19, 1907. (Coal.)
- CROSS, W., and PURINGTON, C. W., U. S. Geol. Survey Geol. Atlas, Telluride folio (No. 57), p. 18, 1899. (Coal.)
- CROSS, W., SPENCER, A. C., PURINGTON, C. W., U. S. Geol. Survey Geol. Atlas, La Plata folio (No. 60), p. 14, 1899. (Coal.)
- DE BEQUE, G. R., Bituminous shales of Colorado: Eng. and Min. Jour., vol. 99, pp. 773-774, 1915.
- The bituminous-shale industry in northwestern Colorado: Eng. and Min. Jour., vol. 102, pp. 1011-1012, 1916.
- ELDRIDGE, G. H., The asphalt and bituminous rock deposits of the United States: U. S. Geol. Survey Twenty-second Ann. Rept., pt. 1, pp. 327-330, and p. 346, 1901.
- The uintaite (gilsonite) deposits of Utah: U. S. Geol. Survey Seventeenth Ann. Rept., pt. 1, pp. 915-949, 1896.
- Origin and distribution of asphalt and bituminous rock deposits in the United States: U. S. Geol. Survey Bull. 213, pp. 301-302, 1913.
- EMMONS, S. F., CROSS, W., ELDRIDGE, G. H., U. S. Geol. Survey Geol. Atlas, Anthracite-Crested Butte folio (No. 9), p. 9, 1894. (Coal.)

- FENNEMAN, N. M., and GALE, H. S., The Yampa coal field, Routt county, Colorado: U. S. Geol. Survey Bull. 285, pp. 226-239, 1906.
- The Yampa coal field, Routt county, Colorado: U. S. Geol. Survey Bull. 297, 1906.
- GALE, H. S., Coal fields of the Danforth Hills and Grand Hogback in northwestern Colorado: U. S. Geol. Survey Bull. 316, pp. 264-301, 1907.
- Coal fields of northwestern Colorado and northeastern Utah: U. S. Geol. Survey Bull. 341, pp. 283-315, 1909.
- Coal fields of northwestern Colorado and northeastern Utah: U. S. Geol. Survey Bull. 415, 1910.
- Geology of the Rangely oil district, Rio Blanco county, Colorado, with a section on the water supply: U. S. Geol. Survey Bull. 350, 1908.
- GARDNER, J. H., The coal field between Durango, Colo., and Monero, New Mexico: U. S. Geol. Survey Bull. 341, pp. 352-363, 1909.
- GAVIN, M. J., HILL, H. H., and PERDEW, W. E., Notes on the oil shale industry with particular reference to the Rocky Mountain district: U. S. Bureau of Mines, 1919.
- GEORGE, R. D., Development of future petroleum industry depends upon shale: Petroleum, vol. 5, pp. 40, 43, 72, 74, 76, 1918.
- Oil shale problems: Railroad Red Book, vol. 37, pp. 643-653, July, 1920.
- GEORGE, R. D., and PEARSE, A. L., Statement before the Committee on Public Land of the House of Representatives, Feb. 26, 1918. Reprinted from hearings before the Committee on the Public Land, House of Representatives, 65th Congress on H. R. 3232. (Oil shale.)
- 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. Survey Bull. 5, pt. I, p. 57, 1913. (Building stone, coal, hydrocarbons.)
- HENDERSON, JUNIUS, Scientific expedition into northwestern Colorado in 1909: Univ. Colo. Studies, vol. 7, pp. 111-112, 1910. (Clay, coal, gypsum, natural hydrocarbons.)
- HILL, R. C., Coal fields of Colorado: U. S. Geol. Survey Mineral Resources for 1892, pp. 319-365, 1893.
- HOSKINS, A. J., The winning of oil from rocks: Min. and Sci. Press, vol. 118, pp. 701-707, 1919.
- Oil shale: Colorado Bureau of Mines Fifteenth Bienn. Rept. for 1917-1918.
- JONES, J. B., The oil shale industry: The Oil and Gas News, Oct. 3, 10, 17, 24 and 31 and Nov 7, 1918.
- LADOO, RAYMOND B., The natural hydrocarbons; gilsonite, elaterite, wurtzilite, grahamite, ozokerite and others: Reports of Investigations, U. S. Bureau of Mines, May, 1920.
- LAKES, ARTHUR, The geology of the oil fields of Colorado: Colo. Sch. Mines Bull. 3, vol. 1, pp. 221-226, 1901.
- A trip to San Juan: Mines and Minerals, vol. 27, pp. 351-352, 1907. (Natural hydrocarbons, oil.)

- Coal and asphalt deposits along the Moffat railway: Mines and Minerals, vol. 24, pp. 134-136, 1903.
- Hydrocarbons in the United States: Mg. Sci., vol. 60, pp. 340-342, 1909.
- Oil springs of Rio Blanco county: Mines and Minerals, vol. 22, pp. 150-152, 1901.
- LEE, H. A., Report of Commissioner of Mines for 1901-1902, Colo. Bureau of Mines, pp. 17, 121, 163, 1903. (Coal, natural hydrocarbons, oil.)
- The asphalt deposits of Middle Park: Eng. and Min. Jour., vol. 67, p. 468, 1899.
- LEE, W. T., Coal fields of Grand Mesa and the West Elk Mountains, Colorado: U. S. Geol. Survey Bull. 510, 1912.
- The Grand Mesa coal field, Colorado: U. S. Geol. Survey Bull. 341, pp. 316-334, 1909.
- LETTER of R. D. GEORGE, State Geologist of Colorado, transmitting economic maps and a statement of the mineral resources, prepared under his direction, of the region served and to be served by the Denver and Salt Lake Railroad, 1918. (Coal, natural hydrocarbons, oil shale.)
- LUNT, H. F., The oil shales of northwestern Colorado: Colo. Bureau of Mines Bull. 8, Aug. 1, 1919.
- MINING WORLD, Rangely oil field, Colorado: Mining World, vol. 29, p. 314, 1908.
- PARSONS, H. F., and LIDDELL, CHAS. A., The coal and mineral resources of Routt county, Colorado: Colo. Sch. of Mines Bull. 4, vol. 1, pp. 47-59, 1903.
- PETROLEUM REVIEW, Oil shales in Colorado and Utah: New Series, vol. 36, p. 85, 1918.
- OIL AND GAS JOURNAL, Colorado, Utah, and Nevada oil shales: vol. 16, pp. 38-40-42, Mar. 28, 1918; pp. 48-49-54, Apr. 11, 1918.
- OSBON, C. C., Asphalt and allied substances in 1918: U. S. Geol. Survey Mineral Resources for 1918, p. 470.
- RAILROAD RED BOOK, Articles on oil shales: Sept., Oct., Dec., 1917, all issues of 1918, 1919, and 1920.
- RICHARDSON, G. B., The Book Cliffs coal field, between Grand River, Colo., and Sunnyside, Utah. U. S. Geol. Survey Bull. 316, pp. 302-320, 1907.
- + Reconnaissance of the Book Cliffs coal field between Grand River, Colo., and Sunnyside, Utah: U. S. Geol. Survey Bull. 371, 1909.
- RUSSELL, W. C., Commercial possibilities of the oil shale industry in Colorado: Railroad Red Book, vol. 35, pp. 15-18, Dec. 1918.
- SCHRADER, F. C., The Durango-Gallup coal field of Colorado and New Mexico: U. S. Geol. Survey Bull. 285, pp. 241-258, 1906.
- SHALER, M. K., A reconnaissance survey of the western part of the Durango-Gallup coal field of Colorado and New Mexico: U. S. Geol. Survey Bull. 316, pp. 375-426, 1907.

- STONE, G. H., Note on the asphaltum of Utah and Colorado: *Am. Jour. Sci.*, 3rd Ser., vol. 42, pp. 148-159, 1891.
- Oil shales: *Jour. of the Franklin Institute*, vol. 187, pp. 689-704, 1919.
- TAFF, J. A., Asphalt, related bitumens, and bituminous rock. *U. S. Geol. Survey Mineral Resources for 1908*, pt. 2, pp. 710-711, 1909.
- The Durango coal district. *U. S. Geol. Survey Bull.* 316, pp. 321-337, 1907.
- WESTON, W., The hydrocarbon field of western Colorado and eastern Utah, 1903.
- WINCHESTER, D. E., Oil shale in northwestern Colorado and adjacent areas. *U. S. Geol. Survey Bull.* 641, pp. 139-198, 1917.
- Oil shale of the Uinta Basin, northeastern Utah; and results of dry distillation of miscellaneous shale samples: *U. S. Geol. Survey Bull.* 691, pp. 27-55, 1918.
- WOODRUFF, E. G., Geology and petroleum resources of the DeBeque oil field, Colorado: *U. S. Geol. Survey Bull.* 531, pp. 54-68, 1913.
- The coal resources of Gunnison Valley, Mesa and Delta counties, Colorado: *U. S. Geol. Survey Bull.* 471, pp. 565,573, 1912.

METALLIC MINERALS

- BROWN, H. L., and HAYWARD, M. W., Molybdenum mining at Climax, Colorado: *Eng. and Min. Jour.*, vol. 105, pp. 905-907, 1918.
- CARROLL, FRED, Colorado State Bur. Mines Fifteenth Bienn. Rept. for 1917-1918: (Copper, gold, lead, molybdenum, silver, uranium, vanadium, zinc.)
- CHAUVENET, REGIS, Preliminary notes on the iron resources of Colorado: *Colorado School of Mines Rept. of field work and analysis*, 1886, pp. 5-16, 1888.
- Iron resources of Gunnison county: *Colorado School of Mines Rept.*, pp. 9-26, 1887.
- COFFIN, R. C., Preliminary statement from Bulletin 16 on the carnotite area of southwestern Colorado: *Colo. Geol. Survey*, 1920.
- COOPER, C. A., The tungsten ores of San Juan county, Colorado: *Eng. and Min. Jour.* vol. 67, p. 499, 1899.
- CRAWFORD, R. D., Geology and ore deposits of the Monarch and Tomichi districts, Colorado: *Colo. Geol. Survey Bull.* 4, 1913, (Copper, gold, iron, lead, manganese, molybdenum, silver, zinc.)
- CRAWFORD, R. D. and WORCESTER, P. G., Geology and ore deposits of the Gold Brick district, Colorado: *Colo. Geol. Survey Bull.* 10, 1916. (Copper, gold, iron, lead, molybdenum, silver, zinc.)
- CROSS, W., and PURINGTON, C. W., *U. S. Geol. Survey Geol. Atlas*, Telluride folio (No. 57), 1899. (Copper, gold, iron, lead, silver, zinc.)
- CROSS, W., and RANSOME, F. L., *U. S. Geol. Survey Geol. Atlas*, Rico folio (No. 130), 1905. (Copper, gold, iron, lead, silver, zinc.)

- CROSS, W., and SPENCER, A. C., Geology of the Rico Mountains, Colorado: U. S. Geol. Survey Twenty-first Ann. Rept., pt. 2, 1900. (Copper, iron, lead, silver, zinc.)
- CROSS, W., HOWE, E., IRVING, J. D., U. S. Geol. Survey Geol. Atlas, Ouray folio (No. 153), 1907. (Copper, gold, iron, silver.)
- CROSS, WHITMAN, HOWE, ERNEST, and RANSOME, F. L., U. S. Geol. Survey Geol. Atlas, Silverton folio (No. 120,) 1905. (Copper, gold, iron, lead, molybdenum, silver, tungsten, zinc.)
- CROSS, WHITMAN, SPENCER, A. C., and PURINGTON, C. W., U. S. Geol. Survey Geol. Atlas, La Plata folio (No. 60), 1899. (Copper, gold, iron, lead, silver, zinc.)
- CROSS, W., HOWE, E., IRVING, J. D., EMMONS, W. H., U. S. Geol. Survey Geol. Atlas, Needle Mountains folio (No. 131), 1905. (Copper, gold, iron, lead, silver, zinc.)
- CURRAN, THOMAS, F. V., Carnotite in the Paradox valley, Colorado: Eng. and Min. Jour., vol. 92, pp. 1287-1288, 1911.
- DEVEREUX, W. B., Notes on iron-ore deposits in Pitkin county: Am. Inst. Min. Eng. Trans., vol. 12, pp. 638-641, 1884.
- DRAPER, MARSHALL, Hahns Peak: Coll. Eng., vol 17, pp. 437-438, 1897; Mg. Ind. & Rept., vol. 14, nos. 1 and 2, pp. 16-18, 1897. (Gold, iron, silver.)
- EMMONS, S. F., Copper in the Red Beds of the Colorado Plateau region: U. S. Geol. Survey Bull. 260, pp. 221-232, 1905.
- U. S. Geol. Survey Geol. Atlas, Tenmile folio, (No. 48), 1898. (Iron, lead, manganese, silver, zinc.)
- EMMONS, S. F., CROSS, W., and ELDRIDGE, G. H., U. S. Geol. Survey Geol. Atlas, Anthracite-Crested Butte folio (No. 9), 1894. (Copper, iron, lead, silver, zinc.)
- EMMONS, W. H., Ore deposits of Bear Creek, near Silverton, Colorado: U. S. Geol. Survey Bull. 285, pp. 25-27, 1906. (Copper, gold, silver.)
- The Cashin Mine, Montrose county, Colorado: U. S. Geol. Survey Bull. 285, pp. 125-128, 1906; Abstract: Mg. Rept., vol. 54, pp. 263-264, 1906. (Copper.)
- The Neglected mine and nearby properties, Durango quadrangle, Colorado: U. S. Geol. Survey Bull. 260, pp. 121-127, 1905. (Gold.)
- FLECK, HERMAN, Uranium and vanadium deposits of Colorado: Mg. World, vol. 30, pp. 596-598, 1900.
- Welfare of Colorado's rare metal industry: Colorado School of Mines Bull. 4, vol. 4, pp. 234-242, 1909. Abstract: Mines and Minerals, vol. 30, pp. 63-64, 1909. (Uranium, vanadium.)
- FLECK, HERMAN, and HALDANE, Wm. G., A study of the uranium and vanadium belts of southern Colorado: Colorado State Bur. Mines Rept. for 1905-1906, pp. 47-115.
- Radioactivity of the carnotite of southwestern Colorado: Mg. Science, vol. 60, pp. 512-514, 1909; Mg. World, vol. 31, pp. 1121-1124, 1909.

- FRENZEL, A. B., The growth of the rare metal industry: Mg. Sci., vol. 65, pp. 73-74, 1912. (Molybdenum, uranium, vanadium, zinc.)
- GALE, HOYT, S., Carnotite and associated minerals in western Routt county, Colorado: U. S. Geol. Survey Bull. 340, pp. 257-262, 1908.
- Carnotite in Rio Blanco county, Colorado: U. S. Geol. Survey Bull. 315, pp. 110-117, 1907.
- Gold placers near Lay, Routt county, Colorado: U. S. Geol. Survey Bull. 340, pp. 84-85, 1906.
- The Hahns Peak gold field, Colorado: U. S. Geol. Survey Bull. 285, pp. 28-34, 1906.
- GEORGE, R. D., A bibliography of uranium and vanadium: Mg. Science, vol. 63, p. 241, 1911.
- Common minerals and rocks: Colo. Geol. Survey Bull. 12, 1917. (Copper, gold, iron, lead, manganese, silver, tungsten, uranium, vanadium, zinc.)
- GEORGE, R. D., and CRAWFORD, R. D., The Hahns Peak region, Routt county, Colorado: Colo. Geol. Survey First Ann. Rept., pp. 221-228, 1909. (Gold, lead, silver.)
- The main tungsten area of Boulder county, Colorado: Colo. Geol. Survey First Ann. Rept., pp. 55-56, 1909. Describes occurrence of tungsten in the San Juan area.
- HARDER, E. C., Manganese deposits of the United States: U. S. Geol. Survey Bull. 380, p. 273, 1909.
- Manganese deposits of the United States: U. S. Geol. Survey Bull. 427, pp. 149-151, 1910.
- The Taylor Peak and Whitepine iron ore deposits, Colorado: U. S. Geol. Survey Bull. 380, pp. 188-198, 1909.
- HENAHEN, T. R., Colorado State Bur. Mines Twelfth Bienn. Rept. for 1911-1912. (Copper, gold, lead, silver, zinc.)
- HESS, FRANK L., Notes on the vanadium deposits near Placerville, Colorado: U. S. Geol. Survey Bull. 530, pp. 142-156, 1913.
- Tungsten, vanadium, uranium, molybdenum: U. S. Geol. Survey Mineral Resources for 1911, pt. 1, pp. 941-955, 1912.
- Vanadium: U. S. Geol. Survey Mineral Resources for 1909, pt. 1, pp. 584-587, 1911.
- Vanadium: U. S. Geol. Survey Mineral Resources for 1910, pt. 1, pp. 759-760, 1911.
- HILL, J. M., Notes on the economic geology of southeastern Gunnison county, Colorado: U. S. Geol. Survey Bull. 380, pp. 21-40, 1909. (Copper, gold, iron, lead, silver, zinc.)
- The mining districts of the western United States: U. S. Geol. Survey Bull. 507, pp. 134-157, 1912. (Copper, gold, lead, silver, uranium, vanadium, zinc.)
- HILLEBRAND, W. F., and RANSOME, W. F., On carnotite and associated vanadiferous minerals in western Colorado: U. S. Geol. Survey Bull. 262, pp. 9-31, 1905.
- IRVING, J. D., Ore deposits in the vicinity of Lake City, Colorado: U. S. Geol. Survey Bull. 260, pp. 78-84, 1905. (Copper, iron, lead, silver, zinc.)

- Ore deposits of the Ouray district, Colorado: U. S. Geol. Survey Bull. 260, pp. 50-77, 1905. (Copper, iron, silver.)
- IRVING, J. D., and BANCROFT, H., Geology and ore deposits near Lake City, Colorado: U. S. Geol. Survey Bull. 478, 1911. (Bismuth, copper, iron, lead, manganese, silver, zinc.)
- KEDZIE, G. E., The bedded ore-deposits of Red Mountains mining district, Ouray county: Am. Inst. Min. Eng. Trans., vol. 16, pp. 570-581, 1888; Eng. and Min. Jour., vol. 46, pp. 104-106, 1888. (Copper, gold, iron, lead, manganese, silver, zinc.)
- LAKES, ARTHUR, A peculiar occurrence of native mercury, free gold and telluride minerals near Trimble Springs, Durango: Mg. Reporter, vol. 54, pp. 389-390, 1906. (Mercury.)
- Geology of Western Ore Deposits, 1905. (Gold, manganese, molybdenum, tungsten, uranium, vanadium, zinc.)
- Iron and Manganese. The great Cebolla River deposits: Coll. Eng. and Met. Min., vol. 16, pp. 267-268, 1896.
- LEE, HARRY A., Mineral production of Colorado, 1901: Eng. and Min. Jour., vol. 73, p. 548, 1902. (Bismuth, copper, iron, lead, manganese, silver, zinc.)
- Colorado State Bur. Mines Rept. for 1901-1902, p. 133, 1902. (Copper, gold, iron, lead, silver, uranium, vanadium, zinc.)
- LEITH, C. K., Iron ores of the western United States and British Columbia: U. S. Geol. Survey Bull. 285, pp. 196-198, 1906. (Iron, manganese.)
- LINDGREN, WALDEMAR, Copper, silver, lead, vanadium, and uranium ores in sandstone and shale: Econ. Geol., vol. 6, pp. 568-581, 1911.
- MEANS, A. H., Geology and ore deposits of Red Cliff, Colorado: Econ. Geol., vol. 10, pp. 1-27, Jan. 1915. (Copper, gold, iron, lead, silver, zinc.)
- MINERAL RESOURCES of the United States: U. S. Geol. Survey Mineral Resources for the years 1882-1919. Where references to deposits are missing see Hill, J. M., U. S. Geol. Survey Bull. 507, 1912. (Copper, gold, iron, lead, manganese, molybdenum, silver, tungsten, uranium, vanadium, zinc.)
- MINING WORLD, Occurrence, preparation, and uses of vanadium: Mg. and Eng. World, vol. 35, pp. 191-192, 1911.
- MOORE, RICHARD B., and KITHIL, KARL L., Uranium, radium and vanadium: U. S. Bur. Mines Bull. 70, 1916.
- MUILENBURG, G. A., Manganese deposits of Colorado: Colo. Geol. Survey Bull. 15, 1919.
- OHLY, J., Rare metals and minerals: Ores and Metals, vol. 9, No. 10, pp. 8-10, 1900. (Molybdenum, tungsten, uranium, vanadium.)
- OUR mineral supplies. The rarer metals U. S. Geol. Survey Bull. 666, 1917. (Bismuth, iron, manganese, molybdenum, vanadium.)
- PATTON, H. B., The Montezuma mining district of Summit county, Colorado: Colo. Geol. Survey First Ann. Rept., pp. 136-144, 1909. (Copper, gold, lead, silver, zinc.)

- PENROSE, R. A. F. Jr., Manganese, its uses, ores, and deposits: Arkansas Geol. Survey Rept., vol. 1, pp. 448-451, 1891.
- PROSSER, WARREN C., Tungsten in San Juan county, Colorado: Eng. and Min. Jour., vol. 90, p. 320, 1910.
- PURINGTON, C. W., Preliminary report on the mining industries of the Telluride quadrangle, Colorado: U. S. Geol. Survey Eighteenth Ann. Rept., pt. 3, pp. 751-850, 1898. (Copper, gold, iron, lead, manganese, silver, zinc.)
- RANSOME, F. L., A report on the economic geology of the Silverton quadrangle, Colorado: U. S. Geol. Survey Bull. 182, pp. 1-265, 1901. (Bismuth, copper, gold, iron, lead, molybdenite, silver, tungsten, zinc.)
-
- Geology and ore deposits of the Breckenridge district, Colorado: U. S. Geol. Survey Prof. Paper 75, 1911. (Copper, gold, iron, lead, silver, zinc.)
-
- The ore deposits of the Rico Mountains, Colorado: U. S. Geol. Survey Twenty-second Ann. Rept., pt. 2, pp. 229-397, 1901. (Copper, gold, iron, lead, manganese, silver, zinc.)
- SALT LAKE MINING REVIEW, Paradox valley carnotite deposits: Salt Lake Mg. Rev., p. 14, Jan. 15, 1912.
- SCHRADER, F. C., STONE, R. W., and SANFORD, SAMUEL, Useful minerals of the United States: U. S. Geol. Survey Bull. 642, 1917. (Bismuth, copper, gold, iron, lead, manganese, mercury, molybdenum, silver, tungsten, uranium, vanadium, zinc.)
- SEBBEN, E. W., Molybdenum; its uses, composition, and occurrence: Ores and metals, vol. 14, No. 10, p. 25.
- SPURR, J. E., Geology of the Aspen mining district, Colorado: U. S. Geol. Survey Mon. 31, 1898. (Copper, iron, lead, silver, zinc.)
- THOMAS, KIRBY, Vanadium in southwestern Colorado: Min. and Sci. Press, vol. 104, p. 168, 1912.
- UMPLEBY, J. B., Manganiferous iron ore occurrences at Red Cliff, Colorado: Eng. and Min. Jour., vol. 104, pp. 1140-1141, Dec. 29, 1917.
- WORCESTER, P. G., Molybdenum deposits of Colorado: Colo. Geol. Survey Bull. 14, 1919.
- ZALINSKI, EDWARD R., Occurrence of vanadium near Telluride: Eng. and Min. Jour., vol. 85, pp. 1152-1153, 1908.

MISCELLANEOUS NON-METALLIC MATERIALS

- AURAND, HARRY A., Fluorspar deposits of Colorado: Colo. Geol. Survey Bull. 18, 1920.
- BAILAR, J. C., The non-metallic minerals of Colorado: Colorado School of Mines Bienn. Rept. for 1908. (Building stone, clay, marble.)
-
- The non-metallic minerals of Colorado: W. Chem. and Met., vol. 4, pp. 330-336, 1908. (Clay.)
- BURCHARD, ERNEST F., Gypsum deposits in Eagle county, Colorado: U. S. Geol. Survey Bull. 470, pp. 354-365, 1911.

- U. S. Geol. Survey Mineral Resources for 1912, pt. II, pp. 809-813. (Building stone.)
- BUTLER, G. M., The clays of eastern Colorado: Colo. Geol. Survey Bull. 8, 1914.
- CARROLL, FRED, Colorado State Bur Mines Rept., 1919. (Building stone, clay, fluorspar, graphite, gypsum, sulphur.)
- COONS, A. T., U. S. Geol. Survey Mineral Resources for 1908, pt. II, pp. 521-579. (Building stone, slate.)
- CRAWFORD, R. D. Geology and ore deposits of Monarch and Tomichi districts: Colo. Geol. Survey Bull. 4, 1913. (Fluorspar.)
- CROSS, WHITMAN, and HOWE, E., The Red Beds of southwestern Colorado: Geol. Soc. Am. Bull., vol. 16, pp. 447-498, 1905. (Gypsum.)
- CROSS, WHITMAN, and PURINGTON, C. W., U. S. Geol. Survey Geol. Atlas, Telluride folio (No. 57), 1899. (Barite, fluorspar.)
- CROSS, WHITMAN, and RANSOME, F. L., U. S. Geol. Survey Geol. Atlas, Rico folio (No. 130), 1905. (Building stone, fluorspar, gypsum.)
- CROSS, WHITMAN, HOWE, ERNEST, IRVING, J. D., U. S. Geol. Survey Geol. Atlas, Ouray folio (No. 153), p. 16, 1907. (Barite, building stone.)
- CROSS, WHITMAN, HOWE, ERNEST, RANSOME, F. L., U. S. Geol. Survey Geol. Atlas, Silverton folio (No. 120), 1905. (Barite, building stone, fluorspar.)
- CROSS, WHITMAN, SPENCER, A. C., and PURINGTON, C. W., U. S. Geol. Survey Geol. Atlas, La Plata folio (No. 60), p. 13, 1899. (Barite, fluorspar.)
- EMMONS, S. F., CROSS, W., ELDRIDGE, G. H., U. S. Geol. Survey Geol. Atlas, Anthracite-Crested Butte folio (No. 9), p. 2, 1894. (Building stone, clay.)
- FERGUSON, HENRY G., U. S. Geol. Survey Mineral Resources for 1916, pt. II, p. 57. (Graphite.)
- GEORGE, R. D., Common minerals and rocks: Colo. Geol. Survey Bull. 12, 1917. (Barite, building stone, clay, graphite, gypsum, sulphur.)
- HALL, C. L., The marble works of Gunnison county: Mg. Science, vol. 64, pp. 178-179, 1911.
- HENAHEN, T. R., Colorado State Bur. Mines Thirteenth Bienn. Rept., p. 145, 1914. (Building stone, clay, grindstone, marble.)
- Colorado State Bur. Mines Twelfth Bienn. Rept., 1913. (Graphite, gypsum.)
- HENDERSON, JUNIUS, Scientific expedition to northwestern Colorado in 1909: Univ. Colo. Studies, vol. 7, p. 111, 1910. (Building stone, clay, gypsum.)
- HILL, JAMES M., U. S. Geol. Survey Mineral Resources for 1915, pt. II, p. 170. (Barite.)
- HOWELL, E. E., Geology of a portion of Colorado explored and surveyed in 1873: Wheeler Survey Rept., vol. 3, p. 264, 1875. (Gypsum.)

- HUNTER, J. F., The Aberdeen granite quarry, near Gunnison, Colorado: U. S. Geol. Survey Bull. 540, pp. 359-363, 1912.
- INGALLS, W. R., The mineral industry during 1906: *Min. Ind.*, vol. 15, p. 697, 1906. (Sulphur.)
- IRVING, JOHN D., and BANCROFT, HOWLAND, Geology and ore deposits near Lake City, Colorado: U. S. Geol. Survey Bull. 478, p. 46, 1911. (Barite, fluorspar.)
- LAKES, ARTHUR, Geology of the mineral resources of Colorado: *Mg. World*, vol. 30, pp. 977, 978, 1909. (Building stone, clay, marble.)
- Gypsum deposits of Colorado: U. S. Geol. Survey Bull. 223, pp. 86-88, 1904.
- Occurrence of marble: *Mg. Science*, vol. 61, pp. 268-269, 1910.
- Ores in volcanic craters and fumarole orifices: *Mg. World*, vol. 30, pp. 425-427, 1909. (Sulphur.)
- Ores of the Vulcan Mine, Gunnison county, Colorado: *Mines and Minerals*, vol. 18, pp. 562-563, 1898. (Sulphur.)
- Sketch of a portion of the Gunnison gold belt: *Am. Inst. Min. Eng. Trans.*, vol. 26, pp. 440-448, 1896. (Sulphur.)
- Some remarkably fine marble quarries in Colorado: *Mg. World*, vol. 32, pp. 609-611, 1910.
- MINERAL RESOURCES of the United States: U. S. Geol. Survey Mineral Resources for the years 1885-1919. (Building stone, graphite, gypsum, marble, sulphur.)
- MINING SCIENCE, Gunnison, Colorado, Grindstone quarries: vol. 62, p. 625, 1910.
- MONTGOMERY, HENRY, Volcanic dust in Utah and Colorado: *Science*, new series, vol. I, pp. 656-657, 1895.
- NEWBERRY, J. S., Marble deposits of the western United States: *Columbia School Mines, Quart.*, vol. 10, pp. 69-72, 1889.
- PEALE, A. C., Report of Geologist of Middle Division: Hayden Survey Eighth Ann. Rept., p. 178, 1876. (Gypsum.)
- RIES, HEINRICH, The clays and clay-working industry of Colorado: *Am. Inst. Min. Eng. Trans.*, vol. 27, pp. 336-340, 1898.
- ROTHWELL, R. P., The mineral industry, its statistics, technology, and trade in the United States and other countries for 1897: *Min. Ind.*, vol. 6, p. 24, 1897. (Volcanic ash.)
- SCHRADER, F. C., STONE, RALPH W., SANFORD, SAMUEL, Useful minerals of the United States: U. S. Geol. Survey Bull. 624, 1916. (Barite, building stone, clay, graphite, grindstone, gypsum, marble, precious stones, sulphur.)
- SHALER, M. J., 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, pp. 296-302, 1907.
- SIEBENTHAL, C. E., Gypsum of the Uncompahgre region, Colorado: U. S. Geol. Survey Bull. 285, pp. 401-403, 1906.

- SMITH, J. ALDEN, Report of Colorado State Geologist for 1881-1882, p. 131, 1883. (Barite, graphite, gypsum.)
- SPURR, J. E., Geology of the Aspen mining district: U. S. Geol. Survey Mon. 31, pp. 187-188, 1898.
- STERRETT, DOUGLAS B., Mica in Idaho, New Mexico, and Colorado: U. S. Geol. Survey Bull. 530, pp. 389-390, 1913.
- WESTON, W., The white marble quarries of Colorado, (Colorado Yule Marble Company): Min. and Eng. World, vol. 36, p. 761, 1912.
- WOOLSEY, L. H., Volcanic ash near Durango, Colorado: U. S. Geol. Survey Bull. 285, pp. 476-478, 1906.

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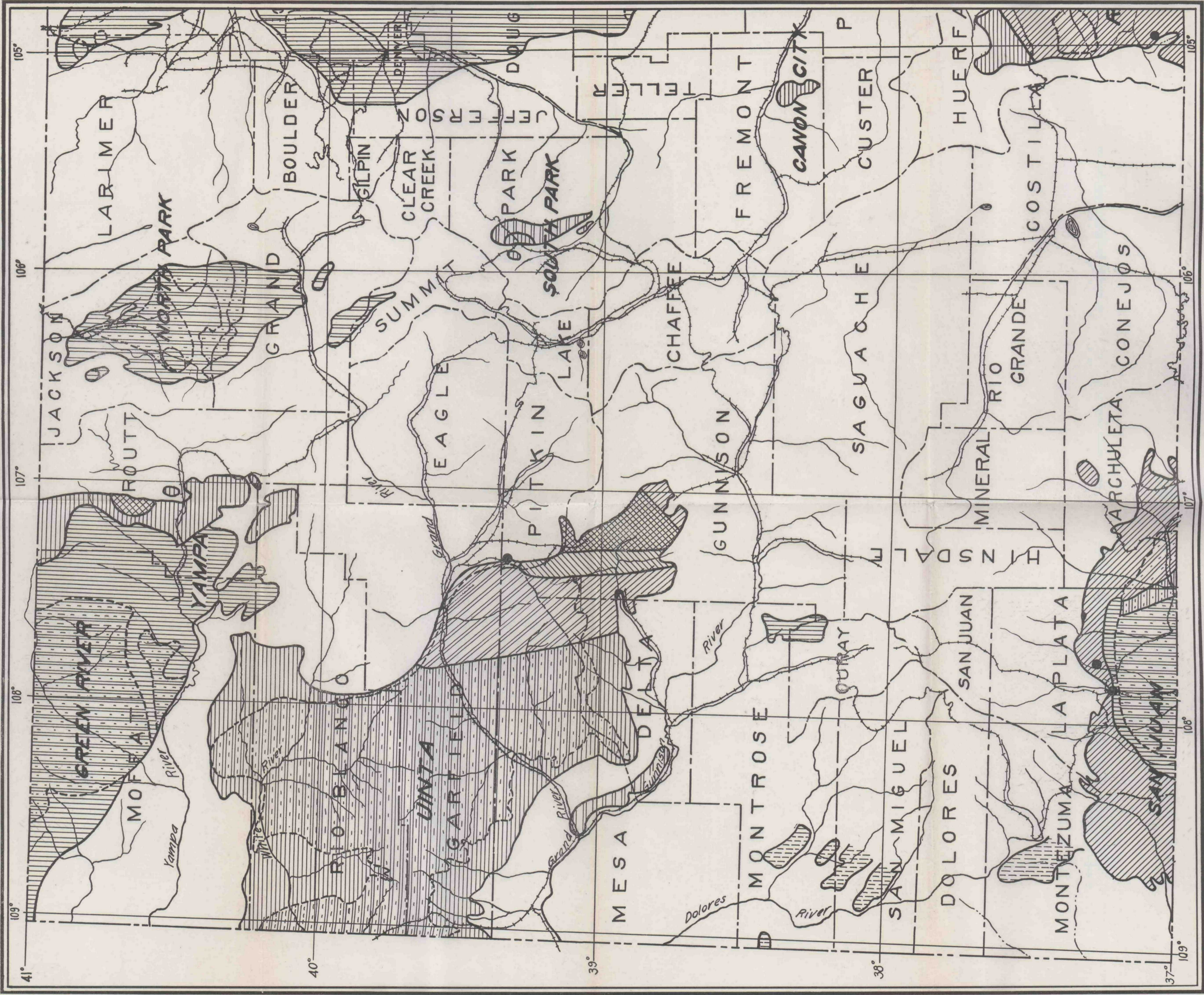
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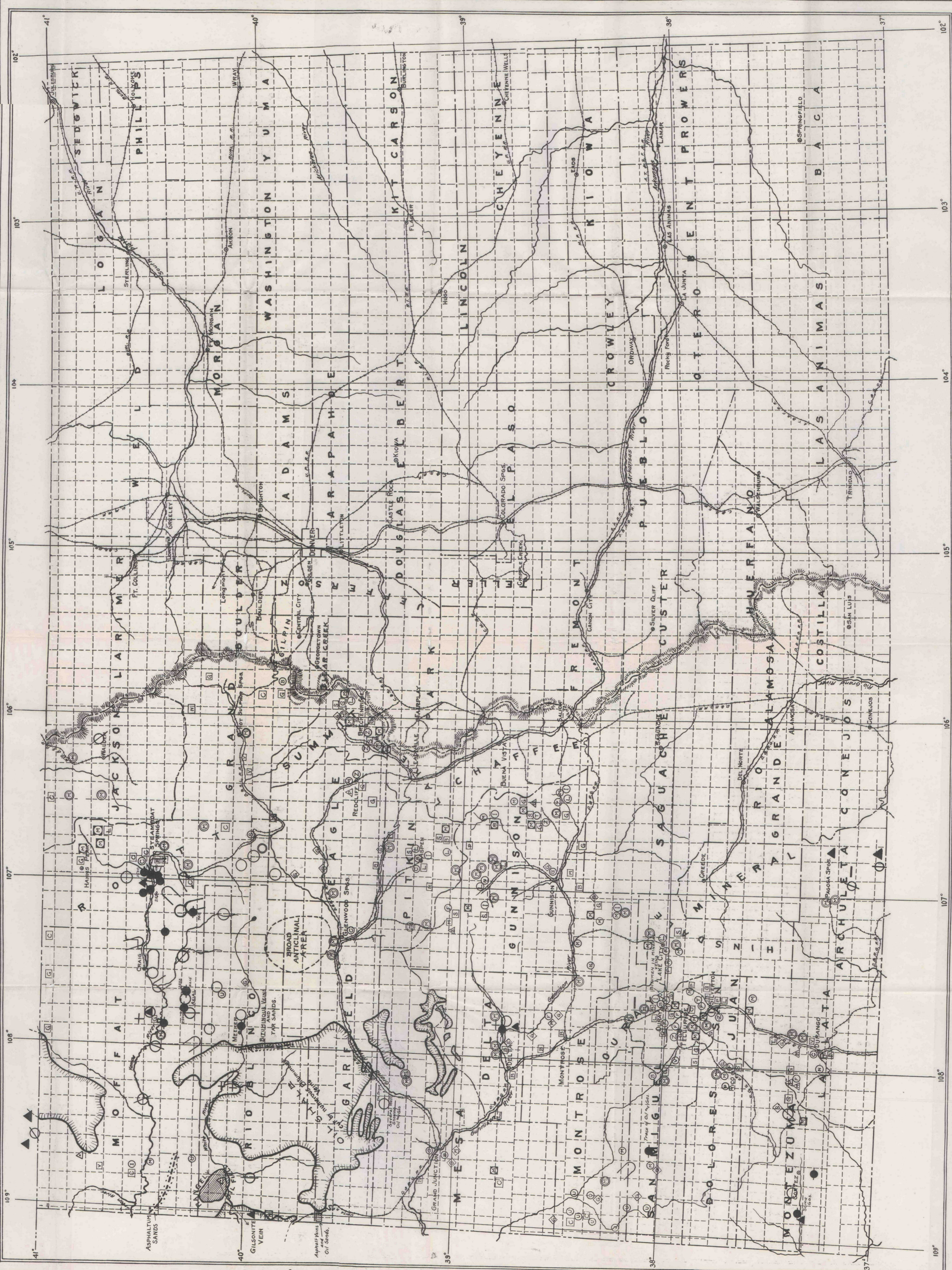
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COAL DEPOSITS OF THE WESTERN SLOPE



COLORADO STATE GEOLOGICAL SURVEY
R. B. BOULDER, COLORADO



Map labels for counties: SEDGWICK, PHILLIPS, LOGAN, MORGAN, WASHINGTON, YUMA, KIT CARSON, LINCOLN, CHEYENNE, KIOWA, PUEBLO, BENT, PROWERS, ADAMS, ARAPAHOE, DOUGLAS, ELBERT, WELD, LAS ANIMAS, BACA, JACKSON, LARIMER, BOULDER, JEFFERSON, ADAMS, PARK, FREMONT, CUSTER, ALAMOSA, COSTILLA, CONEJOS, ARCHULETA, MONTEZUMA, DOLORES, SAN JUAN.

Major cities: DENVER, COLORADO SPRINGS, PUEBLO, MONTROSE, GRAND JUNCTION, GREELEY, FORT COLLINS, BOULDER, COLORED.

Geological features: BROAD ANTICLINAL AREA, ASPHALTUM SANDS, GILSONITE VEIN, ASPHALTUM OIL SANDS, BROAD ANTICLINAL AREA.

Latitude: 37°N, 38°N, 39°N, 40°N, 41°N
Longitude: 102°W, 103°W, 104°W, 105°W, 106°W, 107°W, 108°W, 109°W