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The Cretaceous Formations of Northeastern Colorado

AND

The Foothills Formations of North-Central Colorado

BY

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LETTER OF TRANSMITTAL

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

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

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

Very respectfully,

R. D. GEORGE,
State Geologist.

CONTENTS

CONTENTS

ILLUSTRATIONS.

The Cretaceous Formations

OF THE

Northeastern Colorado Plains

BY JUNIUS HENDERSON

AGE OF COLORADO COAL-BEARING ROCKS

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

LARAMIE FORMATION

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

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

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

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

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

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

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

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

MONTANA GROUP

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

MONTANA GROUP

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

PIERRE

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

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

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

ZONE TRANSITIONAL TO FOX HILLS

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

FOX HILLS

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

LARAMIE FORMATION

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

PALEONTOLOGY

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

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

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

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

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

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

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

MAPS

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

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

THE MARSHALL DISTRICT

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

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

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

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

THE BOULDER DISTRICT

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

THE HAYSTACK BUTTE DISTRICT

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

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

THE LEFT HAND DISTRICT

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

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

THE WHITE ROCK DISTRICT

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

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

THE LONGMONT DISTRICT

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

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

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

THE BERTHOUD DISTRICT

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

Inoceramus labiatus (Schl.)
Inoceramus cf. fragilis H. & M.?
Ostrea undescribed
Acanthoceras coloradoensis Henderson
Metoicoceras swallowi (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.
Avicula sp.
Inoceramus barabini Morton
Inoceramus sagensis Owen
Inoceramus sp.
Ostrea pellucida M. & H.
Lucina occidentalis (Morton)
Pelecypoda undetermined
Margarita nebrascensis (M. & H.)
Gastropoda undetermined
Ptychoceras crassum Whitf.
Baculites ovatus Say
Baculites compressus Say
Scaphites nicolleti (Morton)
Heteroceras cochleatum (M. & H.) ?

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

THE LOVELAND DISTRICT

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

Inoceramus cf. labiatus
Ostrea sp.
Fish vertebrae
Plesiosaur teeth

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

FOSSIL RIDGE

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

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

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

THE FT. COLLINS DISTRICT

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

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

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

THE WELLINGTON DISTRICT

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

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

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

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

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

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

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

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

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

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

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

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

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

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

INDIAN SPRINGS MINE DISTRICT

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

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

ROUND BUTTE DISTRICT

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

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

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

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

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

WILDCAT MOUND

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

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

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

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

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

THE PLATTEVILLE DISTRICT

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

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

THE MILLIKEN DISTRICT

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

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

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

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

THE WINDSOR DISTRICT

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

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

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

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

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

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

CROW CREEK VALLEY

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

THE OSGOOD DISTRICT

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

COTTONWOOD SPRING DISTRICT

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

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

At Cottonwood Spring the section is as follows:

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

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

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

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

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

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

THE WILDCAT CREEK DISTRICT

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

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

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

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

BIJOU CREEK VALLEY

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

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

THE CANTON DISTRICT

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

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

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

THE WELDON DISTRICT

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

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

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

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

THE MESSEX DISTRICT

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

THE STERLING DISTRICT

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

THE CROOK DISTRICT

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

THE JULESBURG DISTRICT

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

HISTORY OF SOUTH PLATTE VALLEY[38]

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

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

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

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THE FOOTHILLS FORMATIONS OF NORTH CENTRAL COLORADO[1]

BY JUNIUS HENDERSON

The ages, or stratigraphic positions, of the formations which compose the foothills of North Central Colorado, have long been in doubt. Early explorers, finding few fossils or none in these beds, and hence unable to make exact correlations, gave them tentative names, based upon lithological resemblance to formations found elsewhere whose positions in the geological column were supposed to be known. Later workers in the field continued the use of those names, often without cautioning the reader as to existing doubts, but gradually those doubts became more prominent in the growing and scattered literature of the subject.[2] Fossils found both north and south of this area in formations supposed to be synchonous made caution in nomenclature desirable until correlation of our formations with those of adjacent areas could be established. Some fossils reported from the northern portion of the field seemed of sufficient importance to suggest the advisability of further work in that region and the tracing of the formations thence southward. Consequently two parties working under the Colorado Geological Survey spent ten days or more in the field in June, 1907, between the Cache la Poudre and the northern boundary of Colorado, and in October of the same year work was resumed at that stream and pushed southward to Boulder.

The results of this work, coupled with that done by others farther south, somewhat change the geologic map of Eastern Colorado and definitely determine the age of at least the lowest of the sedimentary formations of the region. The topographic sheets of the United States Geological Survey for Boulder, Niwot, Mt. Olympus, Loveland, Ft. Collins, and Livermore Quadrangles were used as a base map. The last three were not then published, but photographic copies were kindly furnished by the Survey. A considerable portion of the work in Livermore Quadrangle was done by

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

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

Professor R. D. Crawford, Dr. James Underhill, Mr. G. S. Dodds, and Mr. B. H. Jackson. Mr. H. W. Clatworthy assisted for several days in Loveland Quadrangle, Mr. S. A. Rohwer in Livermore Quadrangle, and Mr. Albert Dakan accompanied the writer to Perry Park and Manitou Park, where his knowledge of the region and its geologic features greatly expedited the work.

TOPOGRAPHY

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

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

FOLDS AND FAULTS

The Normal Monocline.—The sedimentary rocks are upturned at varying angles upon the basal slopes of the Rocky Mountains, flattening out as they pass under the plains (Figs. 3, 4 and 5). At Boulder the dips are very strong, and in places the strata are vertical or even overturned, but northward the dip in some places is less than twelve degrees. This monocline is persistent throughout the region, except where it becomes a limb of a syncline, and everywhere any change in the direction of the dip finds instant expression in a change in the direction of the strike of the ridges. Usually the strike is approximately north-south and the dip easterly, but in the Livermore Quadrangle two east-west synclines produce northerly and southerly dips, with approximately east-west strike for many miles in the limbs of the folds which correspond to the normal monocline.

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

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

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

North of the Cache la Poudre the Livermore and Red Mountain synclines extend far back into the mountains. The anticlines which connected the two, and also connected them with the normal monocline to the north and south, have been eroded away, leaving

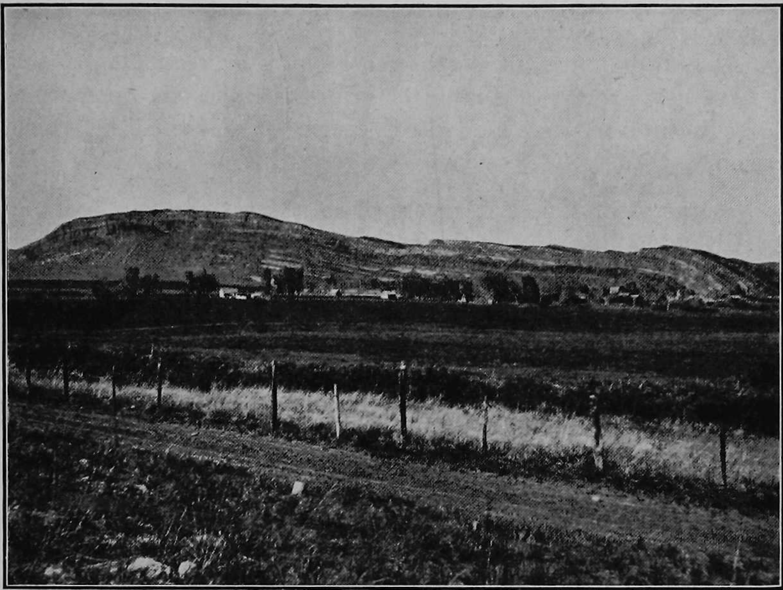

Fig. 1. Bellvue fold, looking north of east, with the village at south end of fold. Lyons formation at the top of cliff, Fountain at the base.

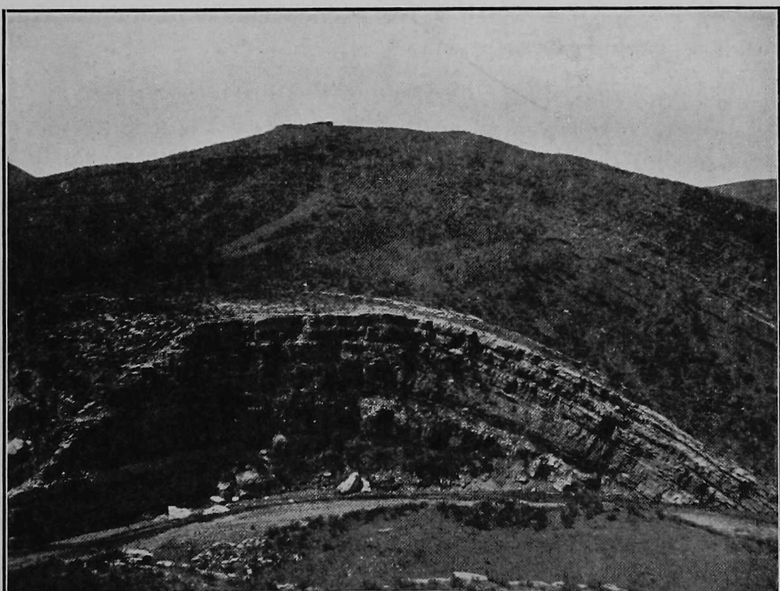

Fig. 2. Sand Creek fold, looking south. The cliff is the Lyons formation, with a little Fountain at the base, and the Lykins sloping upward from the top of the cliff to the top of the hill.

the granite cores exposed. In the western part of the Red Mountain syncline denudation has been carried to such an extent that even the lower Fountain is represented only by remnants, so that we have now exposed virtually the original sea-bottom upon which the sedimentaries were deposited, somewhat dissected by recent erosion.

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

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

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

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

STRATIGRAPHY

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

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

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

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

PRE-CARBONIFEROUS

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

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

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

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

CARBONIFEROUS

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

Eldridge (12, p. 53) has noted that in the Denver Basin the conglomerates are usually loosely agglomerated, but in some places are hard and compact and difficult to distinguish from the granite, from the debris of which they are formed. The same is true of those beds in the region north of the Denver Basin. At Boulder the conglomerates are quite resistant, forming the second ridge or series of "hog-backs," including the well-known "Flat Irons" back of the Chautauqua grounds. There the Lyons, instead of crowning the ridge, as it does farther north, rests some distance down its east slope, and the valley, instead of cutting into the Fountain, as it does farther north, cuts into the granite or the granite-Fountain contact. (Compare Figs. 3, 4 and 5.)

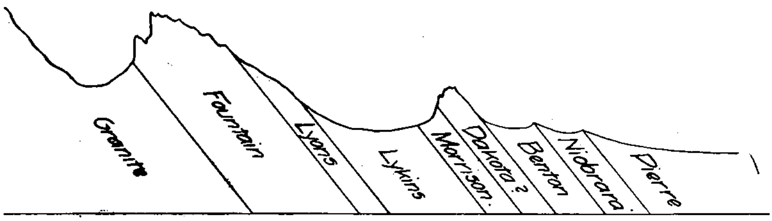

Fig. 3. Generalized section at Boulder.

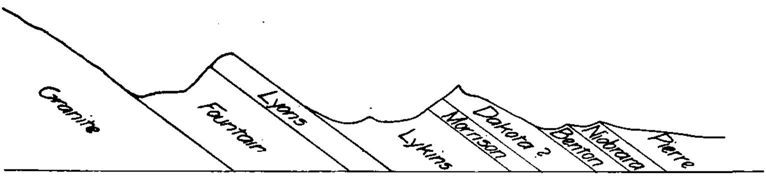

Fig. 4. Generalized section in Northern Larimer County.

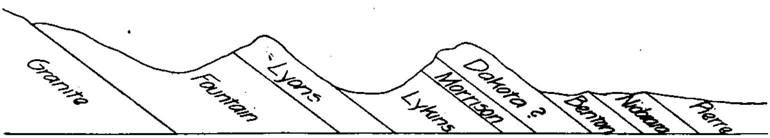

Fig. 5. Generalized section at Left-Hand Creek.

The Fountain conglomerates being quite friable north of the Denver Basin, their erosion uniformly forms a valley back of the Lyons escarpment, and, in fact, is chiefly responsible for the existence of the escarpment. In the Fort Collins and Loveland Quadrangles and northern part of Boulder Quadrangle the Fountain forms the base and usually the Lyons the top of the escarpment, the cliff being produced by the undermining of the more resistant

Lyons formation, while the more gentle east slope follows approximately the dip. In Livermore Quadrangle the Pennsylvanian limestones, which are assigned partly to the upper Fountain and partly to the Lyons formation, and do not extend south of the Cache la Poudre, often form the crest of the escarpment, with the upper Lyons well down on its east slope. On Lefthand Creek and at some other places we find a compromise, the upper Fountain being non-resistant, with a resultant valley, while the lower Fountain is resistant and extends well up the granite slope of the mountains, as shown in Fig. 5. Possibly the lower beds in such places represent an earlier period of deposition, or at least the earlier filling in of the troughs of the eroded granite surface when subsidence of the sea-bed began and before it had progressed sufficiently for general deposition to commence, the strata overlapping and advancing shoreward with continued subsidence. Emmons (12, pp. 18-19) suggested that the basal deposits where these conglomerates and sandstones are thickest might be Carboniferous, equivalent to the Fountain; but the upper portions and the overlying Lyons are now considered Upper Carboniferous and equivalent to the Fountain, which leads to a suspicion that the lower deposits in such places may be Lower Carboniferous. The conglomerate was deposited upon an eroded granite surface, and, therefore, as the shore began to subside, deposition would first commence in the troughs of the uneven surface, which would be first invaded by the encroaching sea. Consequently, the formation varies from a few hundred to many hundred feet in thickness. The planing of the original relief by shoreline erosion as the sea advanced in the Boulder District and Denver Basin has been discussed by Fenneman (14, pp. 205-214; see, also, Crosby 2, p. 144), the discussion applying with equal force, however, to the entire region from Denver to the Wyoming line. The actual contact of the basal conglomerate and granite is usually concealed by debris from the west slope of the contact valley, but when it can be seen it often shows the uneven surface. At Red Mountain, north of Livermore, the sedimentaries, including most of the Fountain, have been stripped from the granite by erosion for a width of three miles, leaving thin remnants scattered over a plain slightly dissected by recent erosion, but clearly exhibiting a portion of the original sea-bottom upon which the conglomerates were laid. The condition of the feldspar in the arkose portions of the conglomerate indicates deposition at a rate approximating the disintegration of the granite of the adjacent shore, and doubtless the upward building of the formation and the subsidence were about equal. In Livermore and Fort Collins Quadrangles, much of the conglomerate is calcareous, effervescing freely in dilute hydrochloric acid, but farther south it is much less so, or not at all.

In the Boulder District and Denver Basin no fossils have been found in the Fountain and Lyons formations and none northward in Colorado except in northern Larimer County, where brachiopods of Paleozoic types are uniformly found. Emmons and Eldridge, in the Denver Basin Monograph, placed the Fountain, Lyons, and Lykins formations together in the Triassic system, under the name Wyoming[3], subdividing it into Upper Wyoming (=Lykins) and Lower Wyoming (= Lyons+Fountain). Fenneman, in his Boulder Bulletin, gave to the Upper Wyoming the local name Lykins and subdivided Lower Wyoming into two members, correlating the basal conglomerates with the Fountain formation of Whitman Cross (4) and calling the overlying "Creamy Sandstone" the Lyons. He still retained all three in the Triassic system, but with a query and footnote (p. 20), quoting Darton (per Eldridge) to the effect that Lower Wyoming is of Pennsylvanian age. Girty (17, pp. 101, 107, 109, 110) fails to distinguish between Upper and Lower Wyoming, and supposes that the Fountain is entirely below the Wyoming, for which supposition the reason does not appear. The Denver Monograph and Boulder Bulletin touch only the southern portion of the area now under discussion, where no fossils have been found to aid in ascertaining the age of these formations. There seems no doubt about the Fountain as recognized by Fenneman at Boulder being the same as the conglomerates underlying the Lyons and resting upon granite and quartz-schist from Boulder to the north line of the state, as I have followed the formation the entire distance and found it everywhere fairly exposed. Consequently, if Dr. Fenneman's correlation of the Boulder District conglomerates with the Fountain is correct, as it appears to be, then all of the conglomerates below the Lyons in the area now under discussion are Fountain. Darton, who was familiar with the Fountain in the region from which it was first described, also considers our conglomerates Fountain.

White (39, p. 176) found no fossils in these formations at Spring Canyon, southwest of Fort Collins, or at Box Elder, near

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

the Wyoming line (though we now know two fossil horizons at the latter place) but in a later paper (40, p. 134) he reports the following species from northwest of Bellvue: *Retzia woosteri, Spirifer rockymontanus, Spiriferina octoplicata, Spirigera subtilita, Hemipronites crenistria, Axophyllum rudis* and an undetermined gasteropod, all discovered by Mr. L. C. Wooster. He quotes Mr. Wooster thus:

"They were obtained from some pebbles in a conglomerate resting upon the eroded face of the granite, 32 miles west and 18 miles north of Greeley, Colorado. A portion of the pebbles of this conglomerate was evidently derived from the granite upon which it rests." Dr. White then adds:

"He found no Carboniferous strata *in situ* in that region, but it is evident that the 'pebbles' which contain the fossils here noticed have not been transported to any considerable distance from the ledges from which they were derived."

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

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

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

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

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

"The Fountain, or Lower Wyoming, extends for many miles along the Front Range, lying directly on the irregular surface of the crystalline rocks for the greater part of its course. * * * The Upper Carboniferous limestone, which is found in the northern portion of the Front range near the Wyoming state line and in the Culebra Range, appears to merge into the Fountain red beds, which I believe are precisely equivalent to the Lower Wyoming of Eldridge and the Badito formation of Hills, and represent the Amsden formation and overlying Tensleep sandstone of the Bighorn Range and the Minnelusa of the Black Hills. The gray sandstone which generally marks the summit of the lower red beds appears to be the same as the Tensleep sandstone of the Bighorns and the sandstone which usually occurs at the same horizon (Upper Minnelusa) in the Black Hills. Upon this sandstone there lies the principal upper series of red beds, the Upper Wyoming of Eldridge, a formation clearly separable in the Front Range zone in Central and Northern Colorado. This series has been found to contain, near its base, a persistent and characteristic layer of limestone, usually very thin in Colorado, which separates a thin series of fine-grained red beds below from a thick overlying mass of fine-grained gypsiferous beds above, presenting precisely the succession of Opeche and Spearfish red beds with intervening Minnekahta limestone found in the Black Hills and Eastern Wyoming. This sequence is clear at La Porte, Lyons, Boulder, Morrison, Perry Park, and the Garden of the Gods, in Colorado; but, approaching the Arkansas River, the region of the typical Fountain formation, this upper gypsiferous series appears to thin and end. * * * In Box Elder Valley, in the foothills of the Rocky Mountains, at the Wyoming state line, there are exposures of limestones containing Pennsylvanian fossils, overlain by fine-grained gypsiferous red beds of the Chugwater formation, which in turn are capped uniformly by the Sundance formation, or marine Jurassic. These upper red beds continue far to the south, but the Pennsylvanian limestone rapidly gives place to coarse sandstones, mainly of red color, which extend for many miles south as the basal member of the sedimentary series. These coarse beds are always separated from the Chugwater formation by a sandstone which overlies the Pennsylvanian limestone in Wyoming, where I have designated it the Tensleep sandstone. This sandstone is mostly a fine-grained, regularly bedded rock from 50 to 200 feet thick, varying in color from gray to red. I believe it to be an important horizon marker. The most northern exposures that I examined in Colorado were in Owl Canyon, which is a small branch of the Cache la Poudre drainage that is followed by the old main road from Denver to Laramie."

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

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

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

The same is likely true of the more southerly locality from which the Wooster fossils came. At Perry Park we found a fauna in part the same in a cherty limestone about 50 or 60 feet above the granite, and overlaid apparently conformably, by coarse sandstones and conglomerates which appear to be equivalent to the Fountain, the relations being about the same as at Box Elder. The apparent conformity of these formations was noted also by Lee (34, p. 97; see, also, Girty 17, pp. 169, 170, 187, 209, 217), but other known facts raise a doubt as to its reality.

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

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

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

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

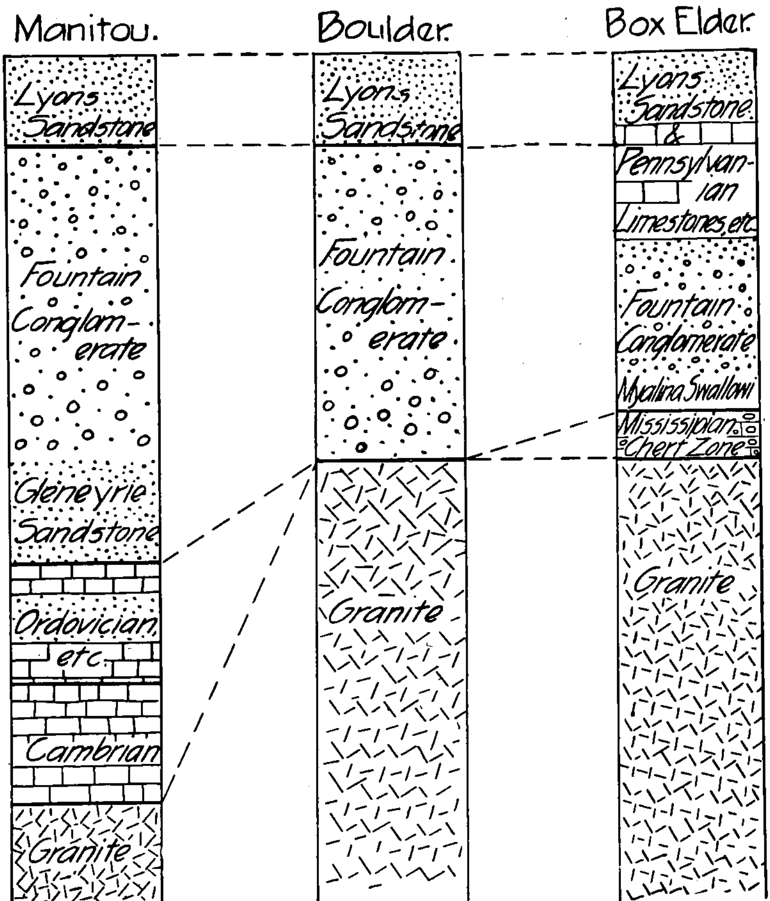

Fig. 6. Generalized geologic columns from granite to Lyons sandstone at Box Elder, Boulder and Manitou.

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

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

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

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

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

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

As noted under the Fountain formation, Darton excludes the Pennsylvanian limestones from the Lyons formation at Owl Canyon, and says they pass into the Fountain. Of this I am not so certain. From Boulder to the Cache la Poudre these two formations are sharply differentiated, and neither contains any impor-

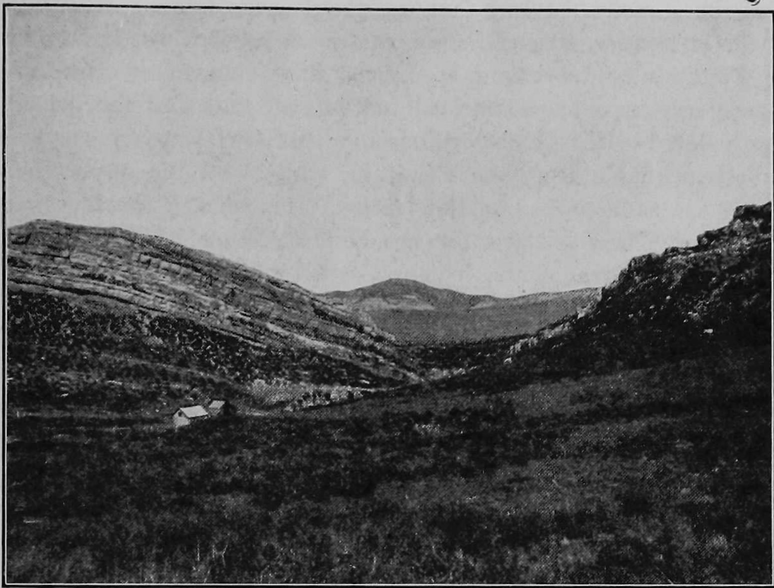

Fig. 7. Looking east through Owl Canyon. The ridge in the foreground is crowned by Pennsylvania limestones, with Fountain conglomerates at the base.

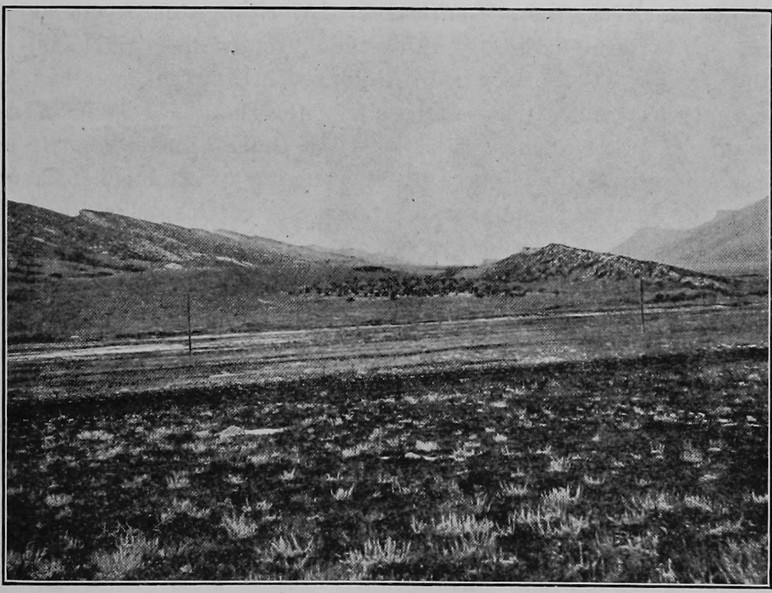

Fig. 8. Ridge making, cross-bedded sandstone in the lower part of the Lykins formation, south of Owl Canyon, looking north, with Carboniferous limestone ridge on the left, and Dakota-Morrison escarpment showing dimly on the extreme right.

tant limestones. At Owl Canyon, about seven miles north of the Cache la Poudre, strong limestones are found which are underlaid by Fountain and overlaid by Lyons, these limestones continuing thence sixteen miles northward to the state line and far beyond. Intercalated with the lower limestones at Owl Canyon are beds indistinguishable from the Fountain, while with the upper limestones are sandstones like the Lyons. The next to the top limestone is the best horizon for brachiopods, other beds containing many crinoid fragments, which also extend well down into the Fountain. The species of brachiopods are mentioned under the Fountain formation, and as there noted are Pennsylvanian and tentatively considered rather early Pennsylvanian. Tracing the escarpment southward for six miles the limestones practically disappear, bringing the Lyons-like sandstones together in the upper part and the Fountain-like beds together in the lower part, the Fountain and Lyons becoming sharply differentiated and continuing thus in their extension southward.[4] The upper limestones appear to pass very definitely into the Lyons. Hence the Lyons as well as all or nearly all of the Fountain must be considered Upper Carboniferous of the Pennsylvanian stage.

PERMO-TRIASSIC ?

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

From Owl Canyon to Little Thompson I have mapped as part of the Lykins a more resistant sandstone, strongly cross-bedded,

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

which forms a ridge in the valley and which sometimes extends nearly to the top of the east slope of the Lyons escarpment. It is difficult to distinguish from the Lyons sandstone and should perhaps be assigned to that formation, but is uniformly separated from the latter everywhere north of the Little Thompson by strata lith-

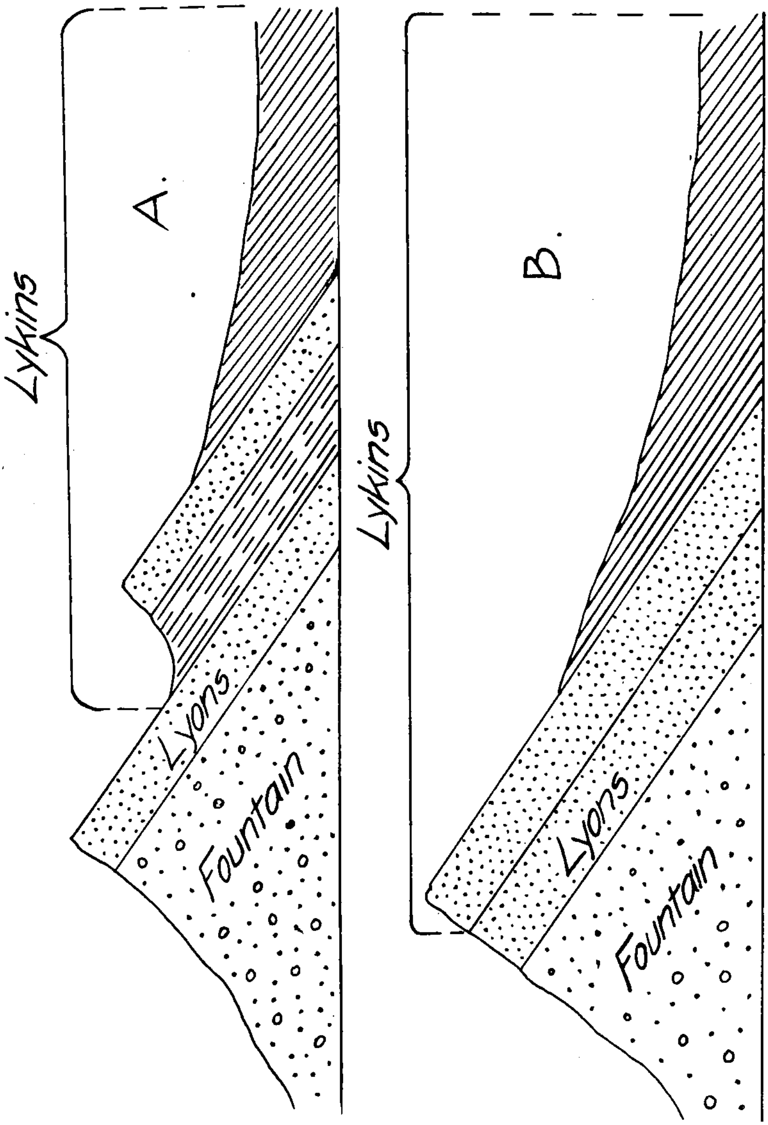

Fig. 9. A. East-West section, showing ridge of cross-bedded sandstone in the Lykins formation west of Fort Collins. B, showing apparently the same sandstone crowning the Lyons escarpment north of the Little Thompson.

ologically resembling the Lykins. In approaching Little Thompson Canyon these intervening beds rapidly play out, bringing the sandstone which is mapped as Lykins into contact with the Lykins and making the former the crest of the escarpment, almost covering the latter. (See Fig. 9.) Thence southward it is doubtful if the two sandstones can be recognized as distinct formations, and nowhere have I found a noticeable unconformity. As the two sandstones after coalescing form an almost vertical escarpment, if they are distinct it is practically impossible to represent the Lyons on the map, yet northward they are quite distinct. The one which is mapped as Lykins in the northern region passes beneath the "Crinkled" sandstone of Fenneman's report, which is but a few feet above the Lyons just north of Boulder. This problem is worthy of further investigation.[5]

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

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

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

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

JURASSIC

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

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

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

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

JURASSIC OR CRETACEOUS

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

Stanton (36, p. 657) says the Morrison in the foothills of the Front Range and similar beds in Wyoming, Montana and Western

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

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

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

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

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

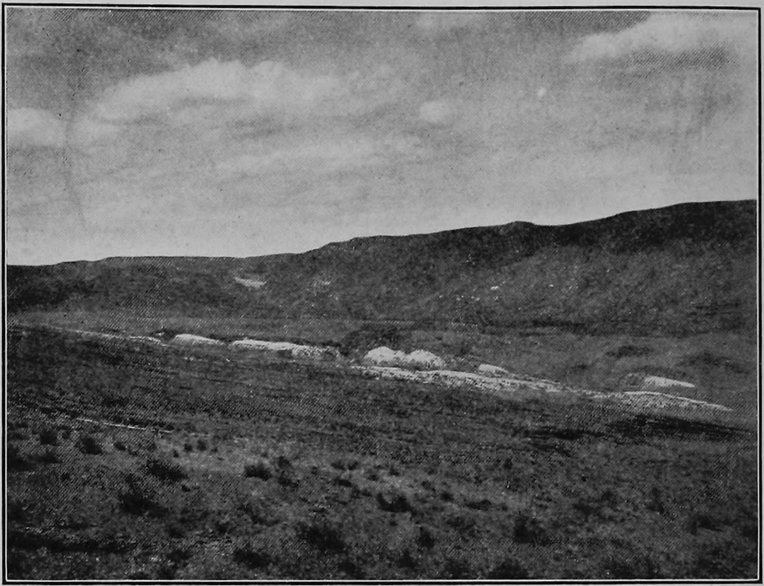

Fig. 10. Gypsum beds in the Lykins formation, southeast of Box Elder post-office, looking northeast.

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

CRETACEOUS

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

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

Taken together, these three members, which are remarkably uniform throughout Eastern Colorado, have, until within a few years, been considered together as fresh-water strata under the name "Dakota," the supposition being that the time equivalent of the Comanche had not been discovered or was missing. Recently the discovery of marine fossils of Comanche age in the medial shale member near Two Buttes in Prowers County, and on Purgatory River, twenty miles south of La Junta, by Darton (9, p. 120) and Lee (33, p. 343) has modified the former views on that subject. They thought that these fossils occurred in the Morrison, but Stanton (36, p. 662) has shown that view to be incorrect. He reports that the Morrison dinosaurs are 200 feet below the Comanche fossils, and that the upper sandstone of the so-called

"Dakota," where it passes under the Benton at the latter locality, contains a true Dakota flora and is separated from the underlying Comanche by an unconformity. The Comanche formation is also reported at Canon City by Stanton. Eldridge (12, p. 64) says that no marine fossils have been found in the Dakota of the Denver Basin. In the sense in which he used the term Dakota, that was also true for the region north of the Denver Basin until recently, but Dr. Stanton and this writer have now found *Inoceramus*, *Ostrea*, etc., at almost every good exposure of the medial shales from five miles north of Boulder to Owl Canyon in Northern Larimer County, though they are not determinative.

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

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

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

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

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

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

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

Montana Group. { *Pierre Formation*
Fox Hills Formation

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

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

Laramie Formation.[6]—This formation, consisting of sandstones and shales and containing the coal beds of Northern Colorado, east of the mountains, marks the close of Cretaceous deposition and the final retreat of the sea from the region. The faunas of the Colorado and Montana Groups are strictly marine. The Laramie faunas, on the other hand, are of brackish-water and fresh-water types, and indicate a period of low-lying shores and marshes. Some of the lower sandstones are locally difficult to distinguish from the upper Fox Hills, but when seen in large masses at a little distance, they generally have a somewhat lighter color than the Fox Hills, and usually the Fox Hills yields marine fossils such as *Cardium, Mactra, Dentalium, Nucula*, etc., which will not be found in the Laramie. Although two Laramie species, *Ostrea glabra* and *Melania wyomingensis,* are frequently found in Fox Hills strata, they need mislead no one, as in such cases they are associated with marine species.

TERTIARY

The Tertiary formations which once probably covered the region up to the foothill line, have been cut away throughout most

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

of the area under discussion by the streams which have aided the South Platte in carving its broad valley (25, pp. 251, 252), leaving portions, however, abutting on the foothills near the Wyoming line, and from Golden southward.

QUARTERNARY

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

ERUPTIVE ROCKS

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

The Valmont dike has been the subject of study by Hayden, Cross, Diller and Fenneman, and the latter has also mapped and reported upon most of the intrusive bodies of the foothills.[7] The important body indicated southeast of Lyons on the map accompanying the present report does not appear to have been reported before, and limited time and adverse conditions of weather have prevented detailed examination. Superficially it appeared to be of the same general nature as the others along the foothills which have been studied by Dr. Fenneman. No intrusives were noted in the sedimentaries north of the St. Vrain Valley.

ECONOMIC GEOLOGY

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

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

Limestone.—The limestones of the Lykins, Morrison and Niobrara formations have been burned for lime for local use all along

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

the foothills. The basal limestone of the Niobrara has been most used. The Pennsylvanian limestones are now being extensively quarried at Engleside, just south of Owl Canyon, for use in the sugar factories of Northern Colorado, to which the material is transported by a short branch railroad connecting with the Colorado and Southern at Fort Collins.

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

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

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

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

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

HISTORICAL GEOLOGY

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

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

At the beginning of Lyons time, the character of the materials depositing changed to fine sand. Subsidence and deposition perhaps continued through Lykins time, though probably parts of these formations are subaerial (Vail, 36-A). During Morrison and perhaps part of Lyons, Lykins and "Dakota" time the sea was apparently shut out from the region by some barrier, as indicated by fresh-water beds; but subsidence must have continued, as the medial "Dakota" shales contain marine fossils and overlie the Morrison in such a way as to show that the sea then reached a much higher level with reference to the nearest land. During Benton, Niobrara, and Pierre time, the indications are that the sea in the region now represented by the edge of the plains reached a greater depth than theretofore. How far the shoreline had then retreated westward we have now no way of knowing, as the formations have been planed off the mountains, but it is inconceivable that it could be less than several miles.

There was probably a distinct shallowing of the sea toward middle Pierre time, and again in early Fox Hills time as the retreat of the sea began. Though we have direct evidence of the overlap of strata caused by the encroachment of the sea during Carboniferous time, we have no such evidence of the reverse process toward the close of Cretaceous time, because these formations have been planed back a long ways from their original edge. During Laramie time brackish-water and fresh-water conditions prevailed, with low-lying shores and marshes.

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

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

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

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

SUMMARY

This report is the result of a review of the literature bearing directly or indirectly upon the subject, and a study of the formations in the field from the southern line of Boulder County to the northern boundary of the state.

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

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

The overlying fine-grained sandstone, called the Lyons by Fenneman, has been traced almost continuously from Perry Park to Wyoming, and it is now known to be Pennsylvanian.

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

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

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

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

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

The pre-Cretaceous history of the region is obscure and little known. From early Carboniferous to the end of Cretaceous time there was an almost continual subsidence of the sea bottom, its rate approximately coinciding with the rate of deposition, so that the sea never attained great depth in this region, although the total subsidence must have reached over 10,000 feet, as shown by the thickness of the deposits. The shore line, at first perhaps approximately coincident with the present axis of the foothills, slowly encroached upon the land or present mountain area, the extent of which encroachment is unknown, but must have been at least ten or fifteen miles. Temporary interruptions in the subsidence are marked by slight unconformities and fresh-water deposits. Vail (36-A) has discussed the evidence of climatic pulsations and subaerial origin of portions of the Lyons and Lykins formations. At the end of Cretaceous time the sea retreated, and during Tertiary time the entire region was lifted over a mile above sea level, the great foothill monocline was steepened, the mountains reared far above the plains, and thick fresh-water deposits were laid over the more or less upturned edges of the Cretaceous strata. More recently these Tertiary beds have been eroded from most of the region under discussion except along the northern boundary of the state.

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INDEX